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An Empirical Study on the Environmental Effects of Agricultural Value-Added, Industrialization, and Economic Growth in Turkey

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ABSTRACT

In this study, the effects of economic growth, industrialization and agricultural value added on carbon emissions in Turkey were examined within the framework of the Environmental Kuznets Curve (EKC) hypothesis. In the analysis, the validity of the EKC hypothesis was tested with the ARDL (autoregressive distributed lag) model using annual data for the period 1968-2020. The findings show that there is a cointegration relationship between the variables and that in the long term, economic growth initially increases carbon emissions while decreasing them after a certain threshold level. This result reveals that the EKC hypothesis is valid for Turkey. In addition, it was determined that industrialization increases carbon emissions in the long term, while agricultural value added reduces emissions. The results show that agricultural value added reduces carbon emissions in Turkey. This situation can be interpreted as the limited mechanization in agricultural activities and the relatively high prevalence of sustainable agricultural practices. It was determined that industrialization has an increasing effect on carbon emissions. This finding indicates that the industrialization process in Turkey can have a largely energy-intensive and fossil fuel-based structure. Therefore, substituting fossil fuel-based industrial activities with environmentally friendly, renewable energy sources can both increase environmental sustainability and support the economic growth of Turkey, which is largely dependent on foreign energy.

Keywords: Environmental Sustainability, Economic Growth, Industrialization, Agricultural Value-Added
JEL Classifications: Q56, Q13, Q1

1. INTRODUCTION

The approach of sustainable development, which has emerged in the context of global environmental problems, constitutes an important area in the political and economic agendas of many governments and numerous organizations in the international arena. Despite the various definitions and goals related to sustainable development, it can be said that this concept forms a common ground of consensus in the development efforts of nations as a whole. This situation has been a significant factor in the recent intensive inclusion of the environmental factor in economic models. Sustainable development aims to ensure the sustainable use of natural resources and to establish a stable harmony between the economy and the environment.

With industrialization, the resulting industrial transformation and production advancements have made economic development, economic growth, and social welfare the highest values. Therefore, the realization of economic development and growth has emerged as a compulsory requirement for the unlimited use of natural resources. As a result of these processes, nature has begun to be perceived as an economic value exploited for the achievement of economic welfare, with its intrinsic value being disregarded. In countries that have completed or are involved in the industrialization

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process, rapid and uncontrolled economic growth and unplanned industrialization movements have led to rapid changes in the natural structure by ignoring the environmental factor and the emergence of a new social environment. In many countries, the environmental pollution caused by intense industrialization and the increasing negative effects of this phenomenon on human life have also mobilized public opinion in developed countries, and with the increasing attention of society, the environmental problem has become one of the current economic issues (Tuncel et al., 1995). The increasing industrial production, the use of fossil fuels, and the pollutant gases emitted by motor vehicles exceed the environment's capacity for self-renewal, negatively affecting environmental quality and leading to the disruption of the ecological balance. In this study, the impact of industrialization on the environment is evaluated empirically.

Another dimension of the study is the evaluation of the environmental impacts of the agricultural sector. In addition to meeting the need for animal and plant-based food products necessary for nutrition, the agricultural sector adds value to the national economy through the supply of raw materials required for industrial production (Erdinç and Aydınbaş, 2021). The improvement in the value of agricultural raw materials or products also adds uniqueness to the relevant product (Annes and Wright, 2016). Value-added represents the difference between the monetary value of the goods and services produced and the inputs used in production. From a macro perspective, agricultural value-added refers to the net output obtained by subtracting inputs from the total outputs in the agricultural sector. In other words, agricultural value-added is the improvement in the physical condition and monetary value of the agricultural product produced (Lu and Dudensing, 2015). Due to the high value-added created, the produced goods can be consumed domestically, and the expenditures on the product remain within the country. In recent years, modern inputs and technology have been used more intensively in agricultural production compared to the past. Accordingly, the agricultural products obtained are delivered to domestic and international consumers through various processing stages (Erdinç and Aydınbaş, 2021).

In developed countries, high technology integration can make it possible to obtain high agricultural value-added with lower environmental costs. In developing countries, however, the increase in agricultural value-added is generally achieved through production methods based on traditional and intensive resource use rather than modern technologies or sustainable practices. In these countries, access to clean technologies is limited due to high costs and financial constraints. Since economic growth is a priority, environmental regulations and sanctions are also not strict enough. Therefore, in developing countries, the increase in agricultural value-added may lead to short-term economic gains but long-term environmental costs.

The relationship between environmental pollution and economic activities has also been the subject of research by economists. In his article titled "Economic Growth and Income Inequality" published in 1955, Simon Kuznets stated that in the early stages of economic development, income inequality would increase, but as growth continued, the disparity would no longer increase further and would eventually decrease. With industrialization, the wealth and capital accumulation of those who initially experienced income growth increased, which also led to income inequality. It was suggested that this increasing income inequality would begin to decline after a certain turning point depending on the continuation of economic development, and that the trend of change would follow an inverted-U shape (Kuznets, 1955). The relationship between income distribution and income level resembling an inverted-U laid the groundwork for the emergence of the Environmental Kuznets Curve (EKC). This topic was adapted to the environment in the 1990s and was re-examined in some studies based on the relationship between per capita income and environmental quality (Grossman and Krueger, 1991; 1995; Shafik, 1994; Panayotou, 1993; Selden and Song, 1994). These studies found that the level of environmental pollution increases during the initial stages of economic growth, and later decreases, indicating an inverted-U shaped relationship between per capita income and the level of environmental pollution.

Another factor used to explain the relationship in the EKC hypothesis is the income elasticity of demand for a quality environment, in other words, the income elasticity approach (Başar and Temurlenk, 2007). The general findings of the early studies on the EKC hypothesis reveal that some environmental indicators, such as access to clean water, urban sanitation services, and air quality, improve with income growth. However, other indicators show that environmental quality deteriorates as income increases (for example, carbon dioxide emissions and municipal waste). Most of the environmental conditions that evolve with economic growth are relatively expensive situations in terms of local effects and the costs of mitigation with respect to changes in income and lifestyle (Rothman, 1998). As Grossman and Krueger (1995) stated, the effect will vary depending on which side of the EKC a country is on based on its level of development. If it is a developed country, it is expected to be on the downward-sloping side because developed countries tend to abandon pollution-generating production and turn to importing these goods from other countries.

The EKC hypothesis consists of three phases: Scale effect, structural effect, and technological effect. According to the scale effect, in developing countries, economic growth activities are carried out while environmental pollution is ignored. During this process, industrialization and energy demand increase. In the structural effect phase, fundamental changes occur. In this phase, environmental pollution continues to increase, but this pollution rises only up to a certain turning point. After this point, while economic growth activities continue, environmental pollution begins to decrease. In the final phase, the technological effect phase, emphasis is placed on research and development activities, income levels gradually increase, and environmentally friendly clean technologies are utilized. In this phase, a noticeable decrease in environmental pollution occurs (Grossman and Krueger, 1995).

In this study, the effects of economic growth, industrialization, and agricultural value-added on carbon emissions in Turkey are examined within the framework of the Environmental Kuznets

Curve (EKC) hypothesis. The study uses data covering the years 1968-2020 and applies the ARDL, FMOLS, and CCR methods.

2. BACKGROUND AND RELATED WORKS

Since the 19th century, economic activities and their impact on environmental quality have been the subject of research. One of the earliest studies on this subject belongs to Thomas Malthus. According to Malthus, poverty prevention programs are related to environmental degradation and may threaten the quality of life of future generations. Malthus explained the relationship between economic growth, development, and environmental quality. According to Malthus, environmental pollution and CO_2 emissions are largely affected by economic growth and development.

When the empirical literature is evaluated, it is observed that the explanatory variables included in the analyses have gradually diversified. As stated in the theoretical framework, in order to determine the validity of the EKC hypothesis, it is sufficient to include the variable representing per capita environmental degradation and the per capita income variable. However, over time, additional variables have been incorporated into the analysis beyond these two. Examples of such variables include energy consumption, urban population growth, industrialization, trade openness ratio, agricultural value-added, foreign direct investment, public expenditures, the Human Development Index, and the level of financial development.

In recent years, interest in the relationship between environmental degradation and economic development has increased. Identifying such a relationship is of great importance in determining macroeconomic policies. Various studies on this subject have suggested that the level of environmental degradation and economic growth follow an inverted U-shaped relationship. Among these studies are Dijkgraaf and Vollebergh (1998), Schmalensee et al. (1998), Kristrom and Lundgren (2005), Martinez-Zarzoso and Bengochea-Morancho (2004), Galeotti et al. (2005), Rezek and Rogers (2008), Lamla (2009), Pao and Tsai (2011), and Han et al. (2011). After Grossman and Krueger (1995) and Selden and Song (1995) provided empirical evidence showing that economic growth would gradually lead to environmental degradation in its initial stages and then to an improvement in environmental conditions after reaching a certain level of growth, this hypothesis has been tested by many researchers. In recent years, numerous studies have sought to reveal the connection between pollution and income (Pearson, 1994; Stern et al., 1996; Dinda, 2009). These studies suggest that there is an inverted U-shaped relationship between income and environmental quality. For example, Jalil and Mahmud (2009), using data from 1971 to 2005 for China, tested the Environmental Kuznets Curve (EKC) and found that the EKC hypothesis is valid for CO_2 emissions. Similarly, a more recent study by Zanin and Marra (2012) for France and Switzerland also confirmed the validity of the inverted U-shaped EKC hypothesis.

Ahmed and Long (2012) examined the relationship between economic growth and CO_2 emissions using annual data for Pakistan from 1971 to 2008 through the ARDL (autoregressive distributed lag) model and found that the EKC hypothesis is valid both in the short term and in the long term. Shahbaz et al. (2013) also applied a similar method for Romania using data from 1980 to 2010 and reached the same conclusions.

On the other hand, some studies have not confirmed the EKC hypothesis. Cialani (2007) examined the relationship between per capita GDP and CO_2 emissions in Italy for the period 1861-2002 and found that the inverted U-shaped EKC form was not consistent with the data. Similarly, Akbostancı et al. (2009), using a time series model covering the period 1968-2003 for Turkey, revealed a monotonically increasing relationship between CO_2 emissions and per capita income, and stated that the EKC hypothesis was not valid. This result indicates that economic growth may not automatically reduce environmental degradation, and thus, the pollution problem may persist alongside growth.

Moutinho et al. (2020) examined the EKC based on sectoral GDP for seven sectors in 12 OPEC countries. The study formed a U-shaped EKC for the agriculture, forestry, and fishing industries, the construction sector, and other economic activities. Agricultural value-added can be considered equivalent to production growth and productivity in the agricultural sector. Increased production raises resource use, which directly or indirectly increases environmental damage. Eştürk, Mert. (2022), in their analysis based on the share of agricultural value-added in GDP for OECD countries, found that agricultural value-added increases CO_2 emissions.

Some studies indicate that the increase in agricultural value-added initially raises environmental impacts, but after a certain income or technology threshold is passed, the environmental cost decreases. Similar to the EKC hypothesis, the rise in agricultural income levels enables investment in cleaner technologies and a shift toward sustainable practices. Ahmed et al. (2021), in their study, show that in developing countries, agricultural growth increases emissions in the short term but its effect diminishes in the long term. Although studies focusing on the Turkish economy are limited, Çetin et al. (2020) stated that the increase in agricultural value-added in Turkey reduces emissions in the long term. This finding suggests that higher value-added and lower emissions may be possible through advanced agricultural technologies, renewable energy, and sustainable agricultural practices.

3. DATA AND MODEL

In this study, the relationships between industry, agriculture, and the environment in Turkey are evaluated. To reflect the absolute economic contribution of the agricultural sector, the agricultural value-added variable in constant 2015 US dollars is used. Since the share of agricultural activities in GDP reflects not only the amount of production but also the relative change depending on the size of other sectors, it may not fully correspond with absolute measurements of environmental impacts. Therefore, by using the real value-added indicator, it is aimed to more clearly reflect the environmental impacts directly related to the level of production.

The research is based on the Environmental Kuznets Curve (EKC) hypothesis. In the analysis, a 55-year data set covering the period from 1968 to 2022 was used. The study includes key variables reflecting the relationship between economic growth, industrialization, and the value-added provided by the agricultural sector to the economy and environmental quality. On the other hand, since the earliest data for the industrial and agricultural value-added variables dates back to 1968, the analysis starts from this year. The ARDL method was used to test the relationship between the variables in the study. The specific measurements and data sources of these variables are detailed in Table 1. In order to balance the variance in the dataset, all variables in the series were subjected to logarithmic transformation.

The empirical framework of this study evaluates the EKC hypothesis within the context of the Turkish sample. In the model, CO_2 is included as the dependent variable, serving as the main indicator of environmental impact. The independent variables selected for the analysis are economic growth, industrialization, and agricultural value-added. The model is structured as follows:

$$lnCO_2 = \theta_0 + \theta_1\, lnGDP_t + \theta_2\, lnGDP^2_t + \theta_3\, nIND_t + \theta_4\, lnAGRI_t + e_t \quad (1)$$

Here, θ_1, θ_2, θ_3, and θ_4 represent the coefficients associated with each independent variable and reflect the effects of these variables on CO_2 emissions. While θ_0 represents the constant term, e_t denotes the error term. To ensure linearity in the relationships between variables and to facilitate interpretation, a logarithmic form is used. To examine the nonlinear effects predicted by the EKC hypothesis, the square of the economic growth variable is included in the model. This variable is important for testing whether economic growth reduces emissions after surpassing a certain threshold. It is expected that the coefficient θ_1 will be positive and θ_2 will be negative. This indicates that economic growth increases carbon emissions up to a certain point, then decreases them, providing empirical evidence for the validity of the EKC hypothesis for Turkey. The coefficients of the other variables included in the model (θ_3 and θ_4) are expected to take positive or negative values depending on the country's industrial and agricultural activities and policies.

4. METHODOLOGY

In this study, the impact of economic growth, industrialization, and agricultural development on the environment was analyzed within the framework of the ARDL bounds testing approach. This approach offers the opportunity to examine possible cointegration relationships among non-stationary variables. In the ARDL bounds test, both long-term and short-term relationships among the variables are estimated simultaneously, which helps to prevent problems arising from omitted variables and autocorrelation (Narayan, 2004: 197). This approach is particularly advantageous for obtaining effective and reliable results in data sets with a low number of observations (Gençoğlu and Kuşkaya, 2017, p.2). In the ARDL bounds testing method, only series that become stationary at level or at the first difference can be included in the model (Pesaran and Shin, 1995). Accordingly, the first stage of the analysis consists of stationarity tests of the variables.

Stationarity, defined as the condition where the variables in a time series have constant variance and mean over time (Granger and Newbold, 1984, p.4), is detected using unit root tests. In this study, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests, which are widely applied in the literature, were utilized. In these approaches, the null hypothesis is stated as "a unit root exists" (Pata et al., 2016, p.264).

After determining through stationarity tests that the variables are stationary at level and first difference, cointegration relationships in the study were examined using the ARDL F-bounds testing method developed by Pesaran et al. The equation below presents the econometric expression of the unrestricted error correction model (UECM), which was constructed for the estimation of long- and short-term parameters (Narayan, 2005, p.1981; Narayan and Smyth, 2005, p.103).

$$\begin{aligned}\Delta lnCO_{2t} &= \alpha_0 + \sum_{i=1}^{n} \alpha_{i1}\Delta lnCO_{2t-i} + \sum_{k=0}^{n} \alpha_{1k}\Delta lnGDP_{t-k} \\ &+ \sum_{k=0}^{n} \alpha_{2k}\Delta lnGDP^2{}_{t-k} + \sum_{k=0}^{n} \alpha_{3k}\Delta lnIND_{t-k} \\ &+ \sum_{k=0}^{n} \alpha_{4k}\Delta lnAGRI_{t-k} + \lambda_1 lnCO_{2t-1} + \lambda_2 lnGDP_{t-1} \\ &+ \lambda_3 lnGDP^2{}_{t-1} + \lambda_4 lnIND_{t-1} + \lambda_5 lnAGRI_{t-1} + e_{1t}\end{aligned} \quad (2)$$

In the equation, the symbol Δ represents the difference operator; $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ and $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5$ denote the model coefficients; and e_{1t} represents the error term. Additionally, n indicates the appropriate lag length. In the previously mentioned F-bounds test, the null hypothesis is expressed as ($\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = 0$).

Table 1: Data definitions

Variables	Measurements	Source of data	Code
Carbon emissions	Per capita (ton)	Our World in Data	$lnCO_2$
Economic growth	Per capita gross domestic product (constant 2015 US dollars)	World Bank (WDI)	lnGDP
Industrialization	Industry (including construction) value-added (constant 2015 US dollars)	World Bank (WDI)	lnIND
Agricultural value-added	Industry (including construction) value-added (constant 2015 US dollars)	World Bank (WDI)	lnAGRI

Table 2: Descriptive statistics

Statistic	$lnCO_2$	lnGDP	lnIND	lnAGRI
Mean	1.022327	8.712519	25.09235	2.657173
Median	1.089182	8.655083	25.07721	2.724388
Maximum	1.652940	9.550741	26.46502	3.727795
Minimum	0.037759	8.069710	23.61207	1.710866
Standard deviation	0.469389	0.423007	0.838225	0.632076
Skewness	−0.383237	0.350538	0.019641	0.173185
Kurtosis	1.972948	2.005981	1.860355	1.710175
Jarque-Bera	3.763649	3.390710	2.979934	4.087464
Probability	0.152312	0.183534	0.225380	0.129544
Observations	55	55	55	55

Table 3: ADF and PP unit root results

Models	Variables	ADF	PP	ADF	PP	Decision
		I (0)		I (1)		
Model with Constant	$lnCO_2$	−2.36[0] (0.15)	−2.94[8] (0.04)	−6.43[0] (0.00)*	−6.37[4] (0.00)*	H₀ is rejected at I (1)
	lnGDP	0.89[0] (0.99)	1.15[4] (0.99)	−6,98[0] (0.00)*	−6.98[3] (0.00)*	
	lnIND	−0.70[0] (0.83)	−0.74[5] (0.82)	−6.49[0] (0.00)*	−6.63[6] (0.00)*	
	lnAGRI	−1.20[0] (0.66)	−1.40[7] (0.57)	−7.28[0] (0.00)*	−7.46[6] (0.00)*	
Model with Constant and Trend	$lnCO_2$	−2.22[0] (0.46)	−2,17[4] (0.49)	−6.82[0] (0.00)*	−7.02[8] (0.00)*	
	lnGDP	−1.66[0] (0.75)	−1.74[1] (0.71)	−7.09[0] (0.00)*	−7,14[4] (0.00)*	
	lnIND	−3.12[0] (0.11)	−3.39[2] (0.06)	−6.44[0] (0.00)*	−6.56[6] (0.00)*	
	lnAGRI	−2.37[0] (0.38)	−2.37[0] (0.38)	−7.31[0] (0.00)*	−7.74[7] (0.00)*	

The values in the table represent the test statistics, with [ ] indicating the maximum lag length and bandwidth, and ( ) denoting the *P* value of the test statistic

If the F-statistic obtained from the test is lower than the lower I(0) and upper I(1) bound critical values, the null hypothesis of no cointegration is accepted. If the value lies between these critical bounds, no conclusive inference can be made. However, if the value exceeds the critical bounds, it indicates the presence of a cointegration relationship (Narayan, 2005, p.1981). If a cointegration relationship among the variables in the ARDL model is detected, the appropriate lag lengths are determined by considering the optimum lag length, and the most suitable model is selected. When the variables included in the ARDL bounds test are based on annual observations, it is recommended that the optimum lag length be set to two (Narayan, 2004, p.200; Narayan and Smyth, 2006, p.338). In this study, since all observations consist of annual data, the optimum lag length was taken as two. The appropriate lag lengths in the model are determined using the akaike ınformation criterion (AIC) or the schwarz criterion (SIC). After determining the appropriate lag lengths, the model is estimated using the OLS method (Narayan, 2004, p.200; Narayan and Smyth, 2005, p.104). Following this step, the long-term coefficients of the model are estimated (Narayan, 2004, p.200).

$$lnCO_2 = \alpha_0 + \sum_{i=1}^{n1} \alpha_{1i} \Delta lnCO_{2t-i} + \sum_{k=0}^{n2} \alpha_{2k} \Delta lnGDP_{t-k} + \sum_{k=0}^{n3} \alpha_{3k} \Delta lnGDP^2{}_{t-k} + \sum_{k=0}^{n4} \alpha_{4k} \Delta lnIND_{t-k} + \sum_{k=0}^{n5} \alpha_{5k} \Delta lnAGRI_{t-k} + e_t \quad (3)$$

If the coefficients calculated in the long-term model yield significant results, it becomes possible to draw inferences about the direction of the relationship between the variables (Bıtrak, 2023, p.1055). In the final stage of the ARDL model, an error correction model is constructed to analyze the short-term relationships among the variables (Narayan, 2004, p.200).

$$\Delta lnCO_2 = \alpha_0 + \sum_{i=1}^{n1} \alpha_{1i} \Delta lnCO_{2t-i} + \sum_{k=0}^{n2} \alpha_{2k} \Delta lnGDP_{t-k} + \sum_{k=0}^{n3} \alpha_{3k} \Delta GDP^2{}_{t-k} + \sum_{k=0}^{n4} \alpha_{4k} \Delta lnIND_{t-k} + \sum_{k=0}^{n5} \alpha_{5k} \Delta lnAGRI_{t-k} + \Psi COINTEQ_{t-k} + e_t \quad (4)$$

In the equation above, the term COINTEQ represents the error correction term, and Ψ denotes the error correction coefficient, which indicates the speed at which short-term shocks return to equilibrium. In the error correction model, it is expected that this coefficient will be negative and statistically significant. A coefficient value between 0 and −1 indicates that short-term shocks tend to reach the long-term equilibrium level in a monotonic manner. If the value lies between −1 and −2, it suggests that the shocks may reach the long-term equilibrium level with diminishing oscillations. Conversely, if the value exceeds −2, it indicates a tendency for the shocks to diverge from the long-term equilibrium level (Alam and Quazi, 2003, p.97; Gülmez, 2015, p.147).

Table 4: Bounds testing for long-run relationship

Test statistic	Value	Significance (%)	I (0)	I (1)
F-statistic	24.80216	10	2.345	3.28
K	4	5	2.763	3.813
		1	3.738	4.947

Case II: The restricted intercept and no trend model was used, and the critical table values were obtained from the study by Narayan (2005: 1987)

In this study, FMOLS (fully modified ordinary least squares) and CCR (canonical cointegrating regression) methods were used to evaluate the reliability of the results obtained from the ARDL model. Various studies in the literature have suggested that FMOLS and CCR approaches are suitable for assessing the robustness of long-term ARDL estimates. These methods effectively address issues such as obtaining reliable parameters in small sample sizes, endogeneity, serial correlation, omitted variable bias, and measurement errors (Raihan et al., 2023, p.8).

5. EMPIRICAL RESULTS

When examining the statistical summary of the main variables analyzed in the study, it was found that the highest average value belonged to the industrialization variable, while the lowest average was observed in the carbon emissions variable. It was determined that all variables, except for carbon emissions, exhibited positive skewness. The Jarque-Bera values indicated that all variables were normally distributed (Table 2).

In the stationarity tests conducted for the ARDL model, differencing was applied to series that exhibited non-stationary characteristics at level. As indicated by the results of the ADF and PP tests, most of the variables in the study were not stationary at level; however, after differencing, all variables became stationary at the 1% significance level. Additionally, according to the PP test, the carbon emissions variable was found to be stationary

Table 5: Long-run and short run coefficients based on ARDL model

Variable	Long-run			Short-run		
	Coefficient	t-statistic	Prob.	Coefficient	t-statistic	Prob.
lnGDP	9.117	5.661	0.000*	-	-	-
$lnGDP^2$	−0.489	−6.107	0.000*	-	-	-
lnIND	0.389	3.187	0.002*	-	-	-
lnAGRI	−0.340	−2.149	0.036**	-	-	-
C	−42.587	−6.294	0.000*	-	-	-
CointEq(−1)*	-	-	-	−0.800	−12.818	0.000*
F-statistic (prob)		2455.367 (0.000)*			-	
Log likelihood		-			116.358	
Durbin-Watson		1.639			1.639	
R^2		0.996			0.668	
Adjusted R^2		0.995			0.668	

* and ** denote statistical significance at the 1% and 5% levels, respectively

at the 5% significance level in the model with a constant, and the industrialization variable was found to be stationary at the 10% significance level in the model with both constant and trend (Table 3). These results confirm the appropriateness of using the ARDL model, which is particularly suitable for datasets containing variables that are stationary at level and first difference (I[0] and I[1]).

During the construction of the ARDL model, due to the fact that the series consist of annual observations, the optimum lag length was set as two, and the most appropriate model was determined based on the AIC criterion. Accordingly, it was concluded that the most suitable model is the ARDL (1, 0, 0, 0, 0) model. The F-test result, which evaluates the existence of a long-run relationship among the variables in the model, and the critical bound values are presented in Table 4. According to the findings, the calculated F-statistic value of 24.80216 exceeds the upper bound critical value of 4.947 at the 1% significance level, indicating a strong long-run cointegration relationship among the variables.

The findings obtained from the ARDL long-run and short-run analyses are presented in Table 5. Considering the R^2 values of the estimated ARDL model, it is observed that the explanatory power of the model is high, and the F-statistic indicates that the independent variables have a significant explanatory effect on the dependent variable. Additionally, the Durbin-Watson value being close to two indicates that there is no autocorrelation problem in the model. Among the variables included in the long-run analysis, the coefficients of economic growth, the square of economic growth, and industrialization are statistically significant at the 1% level, while the coefficient of agricultural development is significant at the 5% level. According to the findings, economic growth significantly increases carbon emissions, and the coefficient of the square of economic growth is calculated as negative. This result confirms the validity of the EKC hypothesis for Turkey. In other words, once economic growth surpasses a certain threshold level, environmental degradation is expected to decline. On the other hand, in the long run, a 1% increase in industrialization leads to approximately a 0.38% increase in carbon emissions, while a 1% increase in agricultural development results in approximately a 0.34% decrease in carbon emissions. Regarding the short-run results of the ARDL model, it is observed that all variables are excluded from the model. However, the error correction term lying between −1 and 0 indicates that short-term shocks will converge monotonically to the long-run equilibrium level. Accordingly, 80% of the shocks emerging in the short run are expected to return to equilibrium within 1 year. In other words, the shocks are likely to converge to equilibrium within approximately 1.25 years.

Table 6: Dianostic tests

Dianostic tests	Test statistic	P-values	Decision
BG-LM	1.808	0.175	There is no serial correlation
BPG	0.554	0.733	There is no heteroscedasticity
Ramsey reset	0.176	0.860	The residuals are normally distributed
Jarque-Bera	1.013	0.602	The model is correctly constructed

In order to examine and validate the reliability of the ARDL model, various diagnostic tests were applied. The results indicated that the proposed model is acceptable in terms of autocorrelation, normality, heteroscedasticity, and model specification error (Table 6). In addition, to assess the stability of the long-run model estimated in this study, the Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUMQ) tests of recursive residuals were conducted. These tests allow for the evaluation of structural breaks in the model coefficients and whether the predictive power of the model remains valid over time (Brown et al., 1975, p.153-154). The results of the CUSUM and CUSUMQ tests are shown in Figure 1. The graphs demonstrate that the residuals remain within the critical bounds at the 5% significance level, indicating that the proposed model is stable over the relevant period.

5.1. Robustness Check

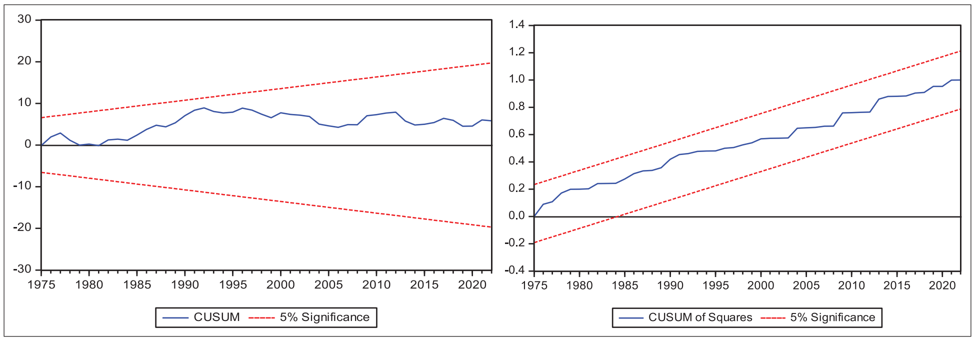
The robustness of the long-run estimation results obtained through the ARDL approach was evaluated using the FMOLS and CCR methods. The estimation results are presented in Table 7. The signs of the coefficients obtained from the FMOLS and CCR models were consistent with the long-run ARDL coefficients and yielded reliable results. The high R^2 and adjusted R^2 values demonstrate the accuracy of the estimations. In both models, the positive coefficient of the economic growth variable

Table 7: FMOLS and CCR results for robustness check

Variables	FMOLS			CCR		
	Coefficient	t-statistic	Prob.	Coefficient	t-statistic	Prob.
lnGDP	9.332	6.346	0.000*	9.266	5.717	0.000*
$lnGDP^2$	−0.500	−6.843	0.000*	−0.494	−6.067	0.000*
lnIND	0.372	3.336	0.001*	0.368	2.996	0.004*
lnAGRI	−0.312	−2.252	0.028**	−0.345	−1.967	0.054***
C	−43.925	−7.247	0.000*	−42.862	−5.830	0.000*
R-squared		0.995			0.995	
Adjusted R-squared		0.995			0.995	

*, **, and *** denote statistical significance at the 1%, 5%, and 10% levels, respectively

Figure 1: CUSUM and CUSUMQ tests results



and the negative coefficient of the squared economic growth variable indicate the validity of the EKC hypothesis. Similarly, it was found that industrialization increases carbon emissions, while agricultural development reduces them. In summary, the FMOLS and CCR results are in full agreement with the ARDL model results.

6. CONCLUSION

In the context of the findings obtained from the study conducted to investigate the impact of economic growth, industrialization, and agricultural development on environmental degradation in the case of Turkey, it has been observed that economic growth and industrialization increase carbon emissions. Increases in economic growth and industrialization lead to a higher demand for energy sources such as fossil fuels, which in turn causes an increase in carbon emissions (Raihan and Tuspekova, 2022, p.802). As a result of the analysis, it has been concluded that the square of economic growth has a reducing effect on carbon emissions, indicating an inverted U-shaped relationship between economic growth and carbon emissions and confirming the validity of the EKC hypothesis in Turkey. In other words, after a certain threshold point, economic growth begins to have a mitigating effect on carbon emissions. This result is consistent with the findings of previous studies conducted on Turkey for different periods by Balıbey (2015), Bölük and Mert (2015), Ozatac et al. (2017), Pata (2018), and Genç et al. (2022), although it differs from those of Alola and Donve (2021) and Kılavuz et al. (2021). These findings reveal the study's position and contribution in the literature. In this study, the environmental effects of agricultural value added are evaluated separately, filling an important gap in the literature. In empirical studies related to environmental sustainability in Turkey, economic growth and industrialization variables are generally emphasized; the agricultural sector is mostly either ignored or treated merely as a control variable. However, in this study, industrialization and agricultural value added are evaluated together, and their different directional effects on carbon emissions are analyzed in detail. In this regard, the study comparatively reveals the environmental impacts of sectoral structures in Turkey and emphasizes the need for environmental policies to be differentiated at the sectoral level. The findings point to the importance of renewable energy and environmentally friendly agricultural practices in achieving Turkey's environmental sustainability goals.

In our study, the effects of agricultural development on environmental degradation, in addition to economic growth and industrialization in Turkey, were also investigated. The findings indicate that agricultural development has a reducing effect on carbon emissions. Previous studies on agricultural development have yielded different results depending on the period examined, the country in question, and the structural differences in agricultural activities in these countries. For instance, Agboola and Bakun (2019) in Nigeria, and Ali et al. (2019) in Pakistan, stated that agricultural value added had no effect on environmental degradation. On the other hand, Khurshid et al. (2022) in Pakistan, Raihan and Tuspekova (2022) in Brazil, and Ahmed et al. (2025) in Somalia reported that agricultural activities increased environmental degradation. In contrast, Raihan et al. (2023) found that agricultural activities had a positive effect on environmental quality. In the case of Turkey, while Çetin et al. (2020) and Bas et al. (2021) found that agricultural value added reduced carbon emissions, Oğul et al. (2023) argued that agricultural value added increased carbon emissions. The fact that the impact of agricultural value added on the environment can produce different results even within the same country sample can largely be attributed to differences in the examined period range, the methods used to calculate the variables, and changes in national policies.

In our study, which analyzed the validity of the EKC hypothesis for the period 1968-2022 in Turkey and examined the effects of industrialization and agricultural development on carbon emissions using the ARDL bounds testing approach, the consistency of the results obtained through the FMOLS and CCR methods was also evaluated. The findings from the analyses confirmed the existence of a cointegration relationship among carbon emissions, per capita income, industrialization, and agricultural development. According to the long-run analysis results of the ARDL model, industrialization was found to have an increasing effect on carbon emissions, while agricultural value added had a decreasing effect. Furthermore, the results obtained from the FMOLS and CCR regressions were found to be consistent with the results obtained from the long-run ARDL model. In the short run, it was determined that all variables included in the analysis were excluded from the model. Additionally, it is predicted that shocks occurring in the short term will uniformly converge to the long-run equilibrium level. According to the analysis results, it was determined that 80% of the shocks in the short term would return to equilibrium within 1 year. In other words, the shocks are expected to reach the long-term equilibrium level in approximately 1.25 years.

On the other hand, in the context of the findings obtained in our study, it can be stated that industrialization, one of the main driving forces of economic growth, causes environmental degradation. This result is consistent with the findings of Güneysu (2023) in the case of Turkey. The study reveals that the delicate balance between economic growth and environmental sustainability can be achieved through sustainable industrialization and agricultural policies. In this regard, the effective implementation of mechanisms such as carbon taxes, carbon capture, and emissions trading aimed at reducing emissions from fossil fuel use is of great importance.

In light of the analyses and evaluations carried out, it can be said that agricultural value added has a positive effect on environmental quality in the case of Turkey. To put it clearly, the limited level of agricultural mechanization in Turkey, the prevalence of small-scale family farms, and the increasing support for sustainable agricultural practices over the years—as well as the implementation of environmentally friendly agricultural support policies in recent times (such as organic farming, good agricultural practices, pasture improvement projects, etc.)—have played a major role in reducing the environmental damage of low-emission production (Atasoy, 2018). Factors such as the opening of agricultural lands to construction and the reduction of forest areas in Turkey threaten the ecological balance beyond the direct impact of agricultural activities on carbon emissions (Bartone, 1995; Ewing et al., 2010).

As a result, it is important to increase the emphasis on good agricultural practices in Turkey, to prioritize strong incentive policies for renewable energy sources instead of fossil fuels in order to reduce the environmental impacts of industrialization, and to focus on the implementation of feasible economic and fiscal policies for a sustainable environment.

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