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RESEARCH ARTICLE

Unraveling the Link Between Environment and Economic Growth in Türkiye

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Abstract

This study examines the short and long-run and causative interconnections between carbon dioxide (CO2) emissions, economic growth, energy use, and industrialization in Türkiye using yearly data from 1971 to 2021. The paper employs the cointegration autoregressive distributed lag (ARDL) model, which indicates the presence of a long-run nexus between the variables and the estimated long-run coefficient of economic growth, energy use, and industrialization exhibit a sensitivity of -0.726, 0.563, and 0.548 changes in CO2 emissions respectively. The error-correction term is -0.563 and significant at a 1% significance level under the cointegration-ARDL model, suggesting that the deviations from the long-run equilibrium between the variables will be addressed through correction by almost 56.3% yearly. In other words, the speed of adjustment coefficients indicates that when disequilibrium occurs, adjustments returning to equilibrium take almost two years. The Toda and Yamamoto (1995) causality test indicates a unidirectional causal link from industrialization to CO2 emissions. This finding implies that industrialization harms environmental quality in Türkiye; therefore, Türkiye must prioritize sustainable industrial development and embrace green technologies.

Keywords: *Energy Use, Industrialization, ARDL Cointegration Model, Toda-Yamamoto Causality, Türkiye*

Jel Codes: *O13, O44, Q4, Q5.*

Türkiye'de Çevre ve Ekonomik Büyüme Arasındaki Bağlantının Çözülmesi

Özet

Bu çalışma, 1971'den 2021'e kadar yıllık verileri kullanarak Türkiye'de karbondioksit (CO2) emisyonları, ekonomik büyüme, enerji kullanımı ve sanayileşme arasındaki kısa ve uzun vadeli ve nedensel bağlantıları incelemektedir. Makalede eş bütünleşme otoregresif dağıtılmış gecikme (ARDL) modeli kullanılmaktadır. Değişkenler arasında uzun vadeli bir bağlantının varlığını gösteren ve ekonomik büyüme, enerji kullanımı ve sanayileşmenin tahmin edilen uzun vadeli katsayısı, CO2 emisyonlarında sırasıyla -0,726, 0,563 ve 0,548 değişim duyarlılığı sergiler. Hata düzeltme terimi -0,563'tür ve eş bütünleşme-ARDL modeli altında %1 anlamlılık düzeyinde anlamlıdır; bu da değişkenler arasındaki uzun vadeli dengeden sapmaların düzeltme yoluyla yıllık neredeyse %56,3 oranında giderilebileceğini göstermektedir. Başka bir deyişle uyum katsayılarının hızı, dengesizlik oluştuğunda ayarlamaların dengeye dönmesinin neredeyse 2 yıl sürdüğünü göstermektedir. Toda ve Yamamoto (1995) nedensellik testi sanayileşmeden karbon emisyonlarına doğru tek yönlü bir nedensellik ilişkisi olduğunu göstermektedir. Bu bulgu, sanayileşmenin Türkiye'de çevre kalitesine zarar verdiğini; bu nedenle Türkiye'nin sürdürülebilir endüstriyel kalkınmaya öncelik vermesi ve yeşil teknolojileri benimsemesi büyük önem taşımaktadır.

Anahtar kelimeler: *Enerji Kullanımı, Sanayileşme, ARDL Eşbütünleşme Modeli, Toda-Yamamoto Nedensellik, Türkiye*

Jel Kodu: *O13, O44, Q4, Q5.*

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1. INTRODUCTION

Environmental pollution and climatic effects have sparked widespread concern in recent decades, principally due to the serious concerns they pose to human health and the overall well-being of our planet. Among the significant contributors to these issues, carbon dioxide (CO2) emissions have been widely recognized as a significant cause. CO2 emissions are mainly associated with the combustion of fuels in the output of energy, transportation, industrial operations, and other human activities. When released into the atmosphere, CO2 acts as a greenhouse gas, trapping heat and contributing to the greenhouse effect. This leads to rising global temperatures, resulting in various adverse effects on the environment and human systems.

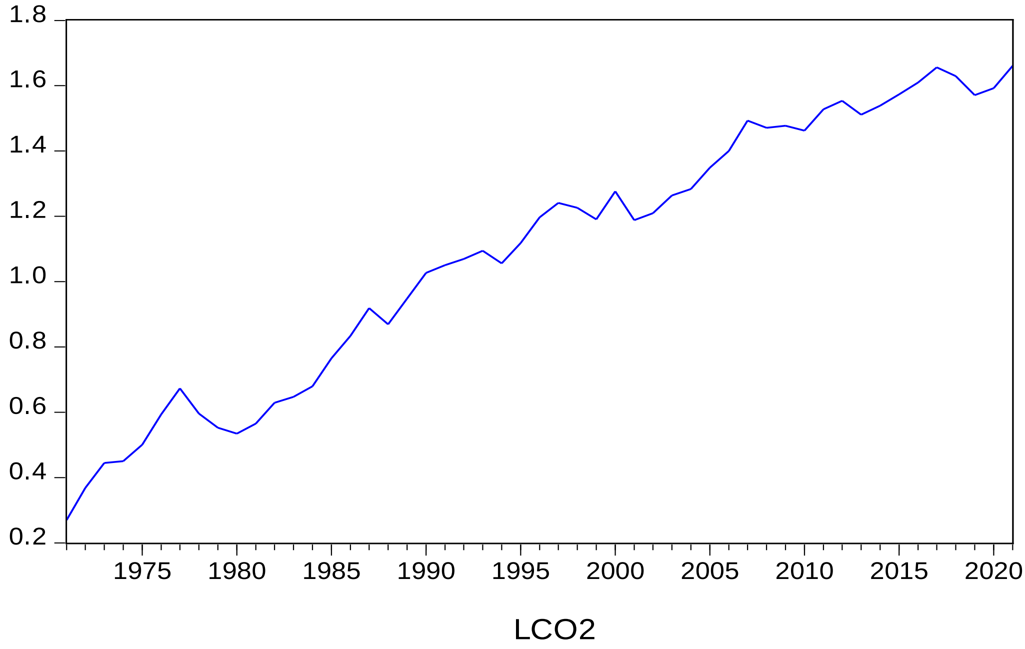
Energy is the principal driver of CO2 emissions and is critical to economic production, growth, and societal progress. However, the environmental effects of energy use and carbon intensity have prompted growing attention to the significance of green energy sources in mitigating these emissions. The substantial quantities of greenhouse gases in the Earth's atmosphere because of human actions, such as the combustion of carbon-based fuels and industrial development, lead to increasingly widespread and intensified climate change. According to the Intergovernmental Panel on Climate Change (IPCC), these issues offer potentially catastrophic environmental risks, prompting the establishment of proactive and decisive climate-related policies, strategies, and plans to deal with the effects of climate conditions. In addition, it has been reported that CO2 emissions alone account for almost 60 percent of worldwide net anthropogenic carbon emissions between 1990 and 2019. (IPCC, UN). Since the early 1990s, the interaction between environmental devastation or deterioration and GDP growth has attracted the interest of numerous researchers. Some researchers have estimated that if the increase in CO2 emissions persists, there will be profound consequences for global environmental quality and economic activities (Begum et al., 2020).

As nations worldwide increase their economic activity to stimulate economic growth, CO2 emissions continue to rise (Bozkurt and Akan, 2014). According to Awan (2013), an adverse relationship exists between economic expansion and environmental quality due to the over-exploitation of natural resources. International organizations, especially the United Nations, have been working on decreasing the catastrophic effects of global climate problems via international agreements and pledges (Ozturk and Acaravci, 2010). The United Nations Framework Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol in 1997 with the commitment to addressing climate crises by reducing climate pollutants, especially by industrialized countries. Including industrialization as a variable in our model can help capture the influence of industrial development on climate pollutants. The Paris Agreement was adopted in 2015 to bolden commitments to driving the global temperature below 2 degrees Celsius within the same framework. Participants of this Agreement must submit reports regarding their persistent dedication towards this objective change through Nationally Determined Contributions (NDCs). They are eligible for financial assistance to blaze a trail for a paradigm shift towards renewable energy adoption and energy efficiency for environmental sustainability to scale down greenhouse gas emissions in their growth activities. As seen in Figure 1, CO2 emissions in Türkiye continue to trend upward from 1970 to 2020.

Türkiye signed the UNFCCC (2004), confirming its commitment to international attempts to combat climate effects . The UNFCCC is an international convention aiming at decreasing levels of CO2 emissions , responding to the impacts of climate conditions , and supporting sustainable development. In 2009, Türkiye also accepted the Kyoto Protocol, an expansion of the UNFCCC. This Protocol provides carbon reduction targets for industrialized nations over specific commitment periods. By ratifying the Protocol, Türkiye demonstrated its intention to take part in international attempts to address the mitigation of climate conditions and decrease carbon emissions. In addition, Türkiye must submit annual inventories of anthropogenic emissions and removal estimates by IPCC recommendations from 2006. Following these requirements , Türkiye submitted to the UNFCCC its

National Inventory Report (NIR) for 1990-2021. This report, however, shows a 50.9%, 113.6%, 162.8%, 179.7%, 196.4%, 196.3%, 191.5%, 205.2%, and 238.0% for the periods 2000, 2010, 2015, 2016, 2017, 2018, 2019, 2020, and 2021 respectively (National Inventory Reports (NIR), Turkish Statistical Institute (TUIK)). In 2021, a significant 85.2% of the aggregate carbon dioxide (CO_2) emissions originate from activities within the energy sector, while 14.5% stem from processes and product usage within the industrial sector. Despite international treaties aimed at lowering the release of greenhouse gases, especially CO_2, global climate crises remain a pressing environmental challenge. Among all the 45 Annex I parties, Türkiye has the highest growth rate of CO_2 emissions. In 2021, Türkiye received a low rating in greenhouse gas emissions and energy consumption, very low in climate policy, and high in renewable energy as per the Climate Change Performance Index (CCPI) (Burck et al., 2020). However, in the same year, Türkiye announced its commitment to net zero by 2053 (UNDP).

Figure 1*:* Carbon dioxide (CO_2) per capita



Previous studies (Erol & Yu, 1987; Stern, 1993; Shafik, 1994; Soytas & Sari, 2009; Lean & Smyth, 2010; Gökmenoğlu & Taspinar, 2016; Rahman & Kashem, 2017; Aftab et al., 2021; Sikder et al., 2022) show that industrialization is an essential metric of economic growth and is highly linked with carbon emissions, but it has been minimally acknowledged in the literature. On the other hand, most studies (Zhu et al., 2019; Moftah and Dilek, 2021; Wang et al., 2022) conclude that there is a bidirectional and unidirectional correlation from CO_2 to GDP level. Conversely, several research investigations (Soytaş and Sarı 2009; Koçak 2014) converge that a discernible causal link between CO_2 emissions, GDP growth, and environmental regulatory variables is lacking. Incorporating industrialization into the equation to better understand the scope and nature of the association between carbon emissions level, GDP growth, energy use, and industrialization is essential for policy formulation to minimize environmental degradation. Hence, this study investigates whether causality exists between carbon emissions, energy use, industrialization, and economic growth in Türkiye. Likewise, this study explores the long-term dynamics and causative connections among economic development, energy use, carbon emissions, and industrialization in Türkiye utilizing the cointegration-ARDL-bound testing and Toda & Yamamoto (1995) causality testing methodologies.

Moreover, this study has three primary objectives. Firstly, it tries to ascertain the possible effects of economic development, energy use, and industrialization on CO2 emissions. Secondly, it seeks to explore whether there are causal links between CO2 emissions, GDP growth, energy consumption, and industrialization. Lastly, this study assesses whether industrialization is happening to the detriment of environmental quality in Türkiye. By examining these aspects, the study aims to provide insights into the complex interactions between economic growth, energy use, industrialization, and sustainability in Türkiye.

The sections hereafter provide a breakdown of this paper's structure: Part 2 outlines a brief literature review; Part 3 details the methodology and data; Part 4 presents the empirical results and analysis; Part 5 concludes the paper with crucial policy implications.

2. LITERATURE REVIEW

The interaction among environmental pollution, economic development, energy use, and energy consumption has been exhaustively studied by many economists and scholars, but the causal relationships between them remain elusive. These studies use three approaches: the interactions between energy use and GDP growth, the association between the level of pollution and GDP growth, and the interrelationships between pollution, energy use, and economic development (Ozturk and Acaravci, 2010).

Drawing on Kraft and Kraft's (1978) empirical investigation on energy and output (GNP) connection and the causal relations between them, using the data for the postwar period 1947-1974 in the United States (US), and finding a one-way causality from GNP to energy, many papers have been written to probe the causal link between energy and output. However, Akarca and Long's (1979) paper, which zeros in on reassessing the energy and GNP nexus in the US, finds Kraft and Kraft's (1978) causal order spurious. Stern (2011) also examines the causal link between US energy use and economic development

from 1947 to 1990 by utilizing a multivariate VAR of energy consumption, GDP, capital stock, and unemployment. Stern concludes that despite the absence of evidence showing energy use causes GDP, a final energy consumption metric accounting for changing fuel combustion causes GDP growth. Soytas and Sari (2003) inspect causal relationships between energy use and economic development in G-7 and developing nations. They find that energy use causes economic development in Germany, Japan, France, and Türkiye; however, the opposite is discovered in Korea and Italy. Moreover, they concluded a bidirectional causality in Argentina. Based on their findings, they infer that energy conservation in countries where energy use causes GDP could be detrimental to GDP.

Acaravci and Ozturk (2012) also investigate the causality between output and electricity use from 1968 to 2006 in Türkiye. They employ a Granger-causality method and find a one-way causality from electricity use to GDP, thus highlighting the importance of electricity use in economic development. These studies among a string of others have been deployed using econometric techniques and methods, but most of the empirical results emerge inconclusive on the energy use and economic development causal link directions (Apergis and Payne, 2010; Jalil and Feridun, 2011; Mehrara, 2007; Shahbaz and Lean, 2012; Ahsan et al., 2020; Murshed et al., 2021; Agan and Balcilar, 2023; Magazzino et al., 2023).

Moreover, a plethora of studies expounds on pollution and GDP growth nexus by using the Environmental Kuznets Curve (EKC) hypothesis, an economic theory that posits that environmental degradation and income growth have a linear relationship in economic development. Still, environmental degradation takes the downturn as incomes rise beyond a turning point (i.e., a higher income level). This is called the inverted-U or Kuznets relationship (Gökmenoğlu and Taspinar, 2016). It implies that economic growth serves as a pathway to the green process. Grossman and

Krueger (1991) propounded the EKC theory, which triggered numerous discussions. In an attempt to investigate the integrity of the inverted-U correlation between pollution and output, Selden and Song (1994) dynamically use the panel data on carbon monoxide, sulfur oxide, oxides of nitrogen, and suspended particulate matter and find that emissions of these pollutants show the inverted-U relationship with output. Conversely, Wagner (2008) finds that the inverted-U interrelation among GDP, CO2, and SO2 emissions acquired through commonly used econometric methods is spurious. That output does not necessarily lead to a fall in emissions.

Furthermore, Tugcu et al. (2012) employ the cointegration-ARDL model to check the long-term and causal links among renewable and nonrenewable energy use and output by utilizing "classical and augmented production functions" and also assessing the energy source that is more effective for output in G-7 nations from 1980 to 2009. They estimate that renewable and nonrenewable energy use matter for output in the long run. They find a two-way causality in all the countries using the classical production function and mixed findings via the augmented production function. Recently, Armeanu et al. (2018) found short-run unidirectional causality from GDP per capita growth to greenhouse gas emissions using a panel vector error correction model and a bidirectional causal link between primary energy consumption and greenhouse gas emissions. Using panel data analysis, Khan et al. (2021) examine the relationship between energy use, population growth, and financial development from 1990 to 2016. Their findings conclude that the impact of energy trilemma and population growth on economic growth is significant only in the long run. In contrast, energy use and financial development influence economic growth in both the short and long run. Several studies, including G. M. Grossman and Krueger (1995), Roca et al. (2001), Kaika and Zervas (2013), Zhu et al. (2019), and Wang et al. (2022), have been conducted on this approach with mixed empirical results primarily due to the nature of economies.

In addition to the abovementioned approaches, a substantial body of study focuses on integrating economic development, energy use, and pollution but yields many disparate results. These ambiguous results pave the way for further research into establishing a balance between development objectives and climate change policies. Since economic development and energy use could determine damaging impacts on the environment by increasing CO2 emissions, which, in turn, harm people, resources ought to be utilized in an environmentally friendly way (Mikayilov et al., 2018). Therefore, it is vital to investigate Türkiye's eco-context to provide better insights that align with energy policy objectives and environmental goals.

Previous studies in the case of Türkiye reveal varying conclusions. This depends on the variations in econometric models taken, data selections, environmental issues, and the country's economic status. For example, Soytas and Sari (2009) examine the causal linkage among output, energy use, and carbon emissions in the long run. They find a unidirectional causality of CO2 emissions on energy use, and that output has no effects on CO2 emissions. Halicioglu (2009) analyzes the dynamic causal connection among income, energy use, CO2, and FDI for the period 1960-2005 using a linear, logarithmic, quadratic model and infers that CO2 emissions are significantly affected by income, and energy use leads to CO2 emission growth. He also finds foreign trade and energy use greatly enhance CO2 emissions. Say and Yucel (2006) investigate the total energy use and total CO2 emissions nexus and find that total energy use significantly influences CO2 emissions. Altinay and Karagol (2004) investigate the causality between output and energy use. They argue that between 1950 and 2000, there was no causal link between energy use and production in Türkiye. Lise (2006) concludes that the primary factor behind CO2 emissions in Türkiye is the expansion of economic activities, along with factors such as the intensity of carbon and shifts in the decomposition of the economy. However, rising energy usage is responsible for a slight drop in CO2 emissions. Ozturk and Acaravci (2010) evaluate the causal association among CO2 emissions, output, energy use, and employment ratio using the cointegration-ARDL-bound testing method. They find a long-term connection for these variables. In addition, they discover that neither CO2 nor energy consumption affects GDP, but rather the employment ratio drives GDP in the near run. According to their findings, the EKC hypothesis is invalid in Türkiye.

3. METHODOLOGY

This section outlines the research methodologies we employ. Our study employs the methodology of the ARDL model; we apply Toda and Yamamoto's (1995) technique to evaluate the directional relationships among the variables.

3.1 Unit root testing

We use unit root tests of Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests to check the stationarity of the variables. The order of integration is a crucial factor in cointegration analysis, as it determines whether the variables need to be differenced before moving forward with the analysis. To proceed to the cointegration-ARDL-bound test, we investigate the time-dependent characteristics of variables in line with Pesaran et al.'s (2001) cointegration-ARDL-bound testing method via ADF and PP unit-root testing approaches.

3.2 Cointegration-ARDL-bound testing

Pesaran et al. (2001) introduced ARDL-bound testing as a novel technique. The ARDL-bound test beats older approaches such as Engle and Granger (1987), Johansen and Juselius (1990), and others since it can be performed as far as the variables are integrated of I(0), I(1), or a mix of both. In addition, with a limited sample size, the ARDL-bound testing method is more consistent and, as a result, it outperforms prior testing methods and can accept various optimal lags. We apply the error-correction model (ECM) to analyze our variables' cointegration using the ARDL-bound test:

$$\Delta lnCO_{2t} = a_0 + \sum_{i=1}^{p} b_i\, \Delta lnCO_{2t-i} + \sum_{i=0}^{q} c_i\, \Delta lnGDP_{t-i} + \sum_{i=0}^{r} d_i\, \Delta lnENG_{t-i} + \sum_{i=o}^{s} e_i\, \Delta lnIND_{t-i} + \beta_1 lnCO_{2t-1} + \beta_2 lnGDP_{t-1} + \beta_3 lnENG_{t-1} + \beta_4 lnIND_{t-1} + \varepsilon_t$$

where Δ and ln are the first difference and the natural log of the variables, respectively. α_0 is the intercept, and ε_t is the error term devoid of serial correlation. Notably, the preceding equation represents the ECM associated with the ARDL framework. The initial component of the equation with sigma signs (i.e., the summation symbols ($\sum$)) denotes the adjustment mechanisms of the errors and the subsequent part (with β) represents the long-run association of the variables.

The bound tests for the null hypothesis (Ho) of no cointegration and the alternative hypothesis (H1) of cointegration, obtained from the joint F-statistic or Wald statistic, are as follows:

H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$

H_1: $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq 0$

Since our observation period is from 1971 to 2021, our F-statistics is set in conjunction with the critical values obtained from the Narayan (2005) reference, which are more appropriate for small observations, unlike the Pesaran et al.'s (2001) critical values that are more suitable for large sample sizes. In line with the assumptions of Narayan's (2005) critical value bounds, which are divided into lower and upper bounds, the null hypothesis of no cointegration will not be rejected if the calculated F-statistics is less than the lower bound I(0); however, if the estimated F-statistics exceeds the upper limit I(1), however, the null hypothesis will be rejected, confirming the presence of cointegration. When the F-statistics lies within the lower and upper boundaries, it is impossible to draw a firm conclusion.

Using the unrestricted error-correction model (UECM), the short-run coefficients are calculated to capture the adjustment process towards equilibrium that follows the establishment of long-term cointegration among the variables. The equation is formulated below:

$$\Delta lnCO_{2t} = a_0 + \sum_{i=1}^{p} b_i \, \Delta lnCO_{2t-1} + \sum_{i=0}^{q} c_i \, \Delta lnGDP_{t-1} + \sum_{i=0}^{r} d_i \, \Delta lnENG_{t-1} + \sum_{i=o}^{s} e_i \, \Delta lnIND_{t-1} + \alpha ECT_{t-1} + \varepsilon_t$$

where α is the parameter of the ECT. The α provides insights into the extent of deviations from the equilibrium point or period; the higher the ECT, the quicker the adjustment. And as such, it is thus expected to show a negative sign and be significant.

To ensure that the model produces reliable, accurate, efficient, and unbiased statistical inferences, we test for and correct serial autocorrelation with "Breusch-Godfrey Serial Correlation LM test," heteroskedasticity with "Breusch-Pagan-Godfrey test," normality with "Jarque-Bera test," and functional misspecification with "Ramsey RESET" test. It is essential to satisfy these assumptions to draw appropriate results from my model. Taking into account Pesaran and Pesaran's (1997) advice derived from Brown et al. (1975) on model stability, I evaluate the stability of my model to improve its resilience via the Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUMSQ).

3.3 Causality test

We apply the causality test Toda and Yamamoto (1995) devised to investigate the causal linkages between our variables. Toda and Yamamoto (1995) developed the Wald test statistic, commonly employed in econometric analysis. This test statistic follows a chi-square distribution. The Toda-Yamamoto Wald test permits the analysis of causal links between variables within a time series framework, even if the variables are non-stationary or have various orders of integration. This is significant since conventional Granger causality tests need variables to be integrated in the same order.

Furthermore, Toda and Yamamoto (1995) test for the causal effects among/between variables by incorporating lags, k, in the standard VAR model, which is then augmented by the maximum, i.e., the highest, order of integration, and the resulting statistic is distributed asymptotically with the optimal lag as the degrees of freedom (df). In this way, problems regarding non-stationarity and endogeneity will be effectively minimized to provide a comprehensive evaluation of causation and, as a result, produce trustworthy judgments. Besides, it's noteworthy that the Toda & Yamamoto (1995) test can be conducted without regard to the cointegration properties of a model, rendering it more robust compared to conventional Granger-causality tests. The VAR(k+dmax) model equation for variables is provided below.

$$lnCO_{2_t} = \beta_0 + \sum_{i=1}^{k} \beta 1_i \, lnCO_{2_{t-i}} + \sum_{j=k+1}^{d_{max}} \beta 2_j lnCO_{2_{t-j}} + \sum_{i=1}^{k} \gamma 1_i \, lnGDP_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma 2_j lnGDP_{t-j} + \sum_{i=1}^{k} \delta 1_i lnENG_{t-i} + \sum_{j=k+1}^{d_{max}} \delta 2_j lnENG_{t-j} + \sum_{i=1}^{k} \theta 1_i lnIND_{t-i} + \sum_{j=k+1}^{d_{max}} \theta 2_j lnIND_{t-j} + \varepsilon 1_t$$

$$= \gamma_0 + \sum_{i=1}^{k} \gamma 1_i lnGDP_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma 2_j \, lnGDP_{t-j} + \sum_{i=1}^{k} \beta 1_i \, lnCO_{2_{t-i}} + \sum_{j=k+1}^{d_{max}} \beta 2_j lnCO_{2_{t-j}} + \sum_{i=1}^{k} \delta 1_i lnENG_{t-i} + \sum_{j=k+1}^{d_{max}} \delta 2_j lnENG_{t-j} + \sum_{i=1}^{k} \theta 1_i lnIND_{t-i} + \sum_{j=k+1}^{d_{max}} \theta 2_j lnIND_{t-j} + \varepsilon 2_t$$

$$lnENG_t = \delta_0 + \sum_{i=1}^{k} \delta 1_i lnENG_{t-i} + \sum_{j=k+1}^{d_{max}} \delta 2_j lnENG_{t-j} + \sum_{i=1}^{k} \gamma 1_i lnGDP_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma 2_j lnGDP_{t-j} + \sum_{i=1}^{k} \beta 1_i \, lnCO_{2_{t-i}} + \sum_{j=k+1}^{d_{max}} \beta 2_j lnCO_{2_{t-j}} + \sum_{i=1}^{k} \theta 1_i lnIND_{t-i} + \sum_{j=k+1}^{d_{max}} \theta 2_j lnIND_{t-j} + \varepsilon 3_t$$

$$lnIND_t = \theta_0 + \sum_{i=1}^{k} \theta 1_i lnIND_{t-i} + \sum_{j=k+1}^{d_{max}} \theta 2_j lnIND_{t-j} + \sum_{i=1}^{k} \delta 1_i lnENG_{t-i} + \sum_{j=k+1}^{d_{max}} \delta 2_j lnENG_{t-j} + \sum_{i=1}^{k} \gamma 1_i lnGDP_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma 2_j lnGDP_{t-j} + \sum_{i=1}^{k} \beta 1_i \, lnCO_{2_{t-i}} + \sum_{j=k+1}^{d_{max}} \beta 2_j lnCO_{2_{t-j}} + \varepsilon 4_t$$

3.4 Data

Annual data for the period 1971-2021 are employed in this research to assess and comprehend the short and long-run dynamics of CO2 emissions, GDP growth, energy use, and industrialization in Türkiye through the cointegration-ARDL bound testing model and their causative linkages via the Toda & Yamamoto (1995) causality test. The variables are described as follows: CO2 represents carbon dioxide (CO2) emissions per capita, measured in tons; GDP denotes GDP per capita in constant 2015 US dollars; ENG signifies energy use per capita, measured in kilowatt-hours; and IND indicates industrial (including construction) value-added per capita, represented in constant 2015.

We transformed the variables into the log form to lessen our regression model's heteroscedasticity problem (i.e., the unequal spread of errors). The variables are thus incorporated into the following estimating equation below:

$$lnCO_{2t} = \beta_0 + \beta_1 lnGDP_t + \beta_2 lnENG_t + \beta_3 lnIND_t + \varepsilon_t$$

where $lnCO_{2t}$ is the response variable and the other variables are the predictor variables, ln is the logarithmic form of the variables, β_0 is the intercept, $\beta_1, \beta_2,$ and β_3 are the coefficients of the predictor variables, and ε_t is the error term. The CO2 emissions and ENG data are taken from Our World in Data (OWID), and the GDP and IND from the World Development Indicator (WDI) online databases.

4. EMPIRICAL RESULTS AND DISCUSSIONS

4.1 Unit-root test results

The Augmented Dickey-Fuller (ADF) test is a widely used unit-root test in econometrics. It establishes whether a time series has a unit root, which indicates non-stationarity. The test is based on the Dickey-Fuller regression model, which includes lagged differences in the series as explanatory variables. The Phillips-Perron (PP) test is another commonly used unit-root test, similar to the ADF test. It is an extension of the ADF test that addresses potential serial correlation in the errors. The PP test employs a similar regression framework as the ADF test but uses robust standard errors to account for serial correlation. *Table 1* demonstrates the times series characteristics of variables using the ADF and PP unit-root testing approaches. Inferences from the ADF and PP showcase that, with an intercept, none of our variables is stationarity at levels; however, with an intercept and trend, energy use at levels is stationary under the ADF and PP tests. Moreover, the findings show that all variables are stationary.

Table 1*:* Unit Root test

	ADF Test		PP Test	
Variables	Intercept	Intercept & Trend	Intercept	Intercept & Trend
		At levels		
$lnCO_2$	-1.6910	-2.6241	-2.1027	-2.7366
lnGDP	0.6787	-1.7788	1.1067	-1.8330
lnENG	-1.8338	-3.3386*	-2.0434	-3.3783*
lnIND	-0.5069	-2.9456	-0.5054	-3.1755
		First difference		
$lnCO_2$	-6.5618***	-6.5718***	-7.0968***	-7.5472***
lnGDP	-6.6908***	-6.7892***	-6.6754***	6.9994***
lnENG	-7.5422***	-7.6843***	-7.6091***	-7.8472***
lnIND	-5.9736***	-5.8910***	-6.2093***	-6.0667***

Note: The null hypothesis has a unit root. *, ** and *** denotes 10%, 5%, and 1% significance level, respectively.

4.2 Cointegration-ARDL-bound test results

Preliminary to carrying out the cointegration-ARDL-bound testing, we use the Schwarz Bayesian Criterion (SBC) to select the optimal lag for our ARDL model. According to this model-selection criterion, as shown in *Table 2*, the ideal lags of CO2 emissions, GDP, energy use, and industrialization are p=1, q=1, r=0 and s=0, respectively, and the ARDL (1,1,0,0) model has been selected. Therefore, we check whether the model has residual problems and omitted variables that could undermine its reliability. Furthermore, the bound F-value, 6.745, is higher than the upper bounds of Narayan (2005) at the 5% significance level, thus backing up the occurrence of a long-run equilibrium relationship in variables.

The long-run estimates of GDP, energy use, and industrialization, which are all significant at the 1% significance level, demonstrate their sensitivity towards CO2 emissions per capita amidst changes, underscoring that a 1% increase in GDP, energy use, and industrialization implies a 72.6% decrease, 56.3% increase and 54.8% increase in CO2 emissions per capita respectively. Meanwhile, predictor variables in the short run have positive impacts on CO2 emissions except GDP at lag 1. They are also all significant save for GDP level. In addition, by comparing the short and long-run impacts of GDP on carbon emissions, the EKC hypothesis, which implies that economic growth serves as a pathway to green improvement, is valid in Türkiye. These findings are consistent with the studies of Gökmenoğlu & Taspinar (2016). Since a negative coefficient linked with the error-correction term (ECT) indicates a trend toward long-run stability, an ECT value of -0.563 suggests that long-run deviations from equilibrium will be corrected at a rate of 56.3% per year. In other words, the speed of adjustment coefficients indicates that when the disequilibrium occurs, adjustments returning to equilibrium take almost two years (computed as the inverse of the absolute value of the error correction parameter).

Table 2: Long-run and Short-run Analysis

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
Short Run				
LCO2(-1)	0.437934	0.121566	3.602427	0.0008
LEN	0.316448	0.137561	2.300427	0.0262
LGDP	0.039925	0.202903	0.196771	0.8449
LGDP(-1)	-0.447797	0.135774	-3.298115	0.0019
LIN	0.307832	0.118944	2.588030	0.0130
C	-6.527759	1.552912	-4.203560	0.0001
R^2	0.994			
Adj. R^2	0.994			
SE. of Reg	0.032			
Prob(F-stat)	0.000			
Long Run				
LEN	0.563009	0.185362	3.037344	0.0040
LGDP	-0.725665	0.247226	-2.935230	0.0053
LIN	0.547679	0.210147	2.606168	0.0124
C	-11.61386	1.774803	-6.543749	0.0000
ECT	-0.563 (0.000)			
F-bound	6.745			

Note: ECT is the error-correction term; F-bound is the bound-F test for cointegration.

Table 3 indicates the diagnostic tests. The findings indicate no evidence of auto-correlation, heteroscedasticity, non-normality, and nonlinearity in the model as the p-values are above the 5% significance level.

In this phase, the CUSUM test is used to determine the existence of a stable, long-term link. The CUSUM test iteratively computes regression coefficients and residuals at specified thresholds. Figures 2 and 3 depict the Cumulative Sum of Recursive Residuals (CUSUM) graphs produced by ARDL stability tests. Each line is confined inside the critical boundaries throughout the range, and none of the lines cross a critical boundary. In addition, the ECM is stable, as evidenced by the fact that the CUSUM and CUSUMSQ statistics reside inside the critical limits. These numbers indicate the consistency of the previously provided ARDL estimation results.

Table 3: Diagnostic Tests

Test	F value	Prob. value
JB Test	3.3097	0.191
LM test	0.2377	0.612
BP Test	1.5184	0.195
RESET Test	0.0714	0.7906

Note: JB is the "Jarque-Bera normality test", LM is the "Breusch-Godfrey serial correlation LM test", BP is the "Breusch-Pagan-Godfrey heteroscedasticity test" and RESET is the "Ramsey RESET test" for functional misspecification.

Figure 2: Results of Cusum Test

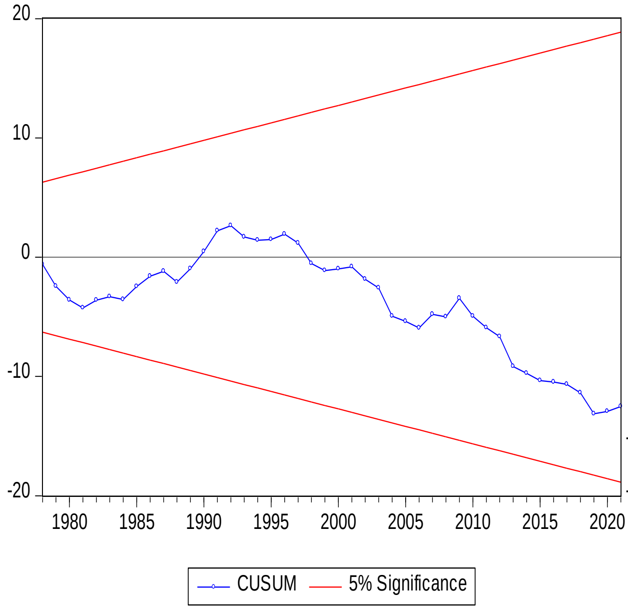
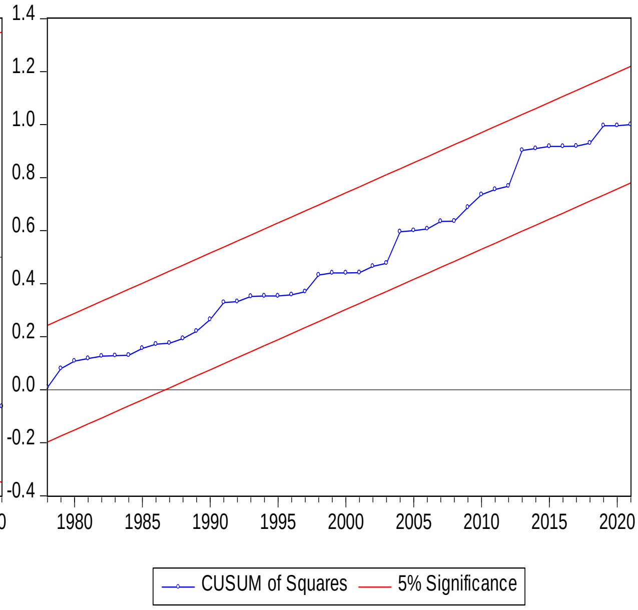


Figure 3: Results of Cusum of Squares Test



4.3 Causality Test

As shown in Table 4, this study employs the Toda & Yamamoto (1995) causality test to check for our variables' presence and causal relationship. All variables are set to levels that prevent any information loss resulting from variances. Subsequently, we conduct residual diagnostic tests, including nonnormality, heteroscedasticity, and autocorrelation tests, and find no indication of lingering issues.

Table 4 suggests no causal links among CO2 emissions, energy use, and GDP growth. However, there is a one-way causality from industrialization to CO2 emissions in Türkiye. As countries undergo industrialization, their energy use increases, increasing emissions. Although one may expect energy use to cause CO2 emissions, considering energy use represents the primary contributor to CO2 emissions, our findings indicate no causal link between them for 1971-2021.

In summary, our results mostly align with the findings of the early study conducted by Ozturk and Acaravci (2010) but uncover a discrepancy with the study by Halicioglu (2009). According to the results of Hossain (2012) and Amri (2017), energy use enhanced carbon emissions in Japan and Algeria. In contrast, Cherni and Jouini (2017) discover a bidirectional association between GDP and CO2 emissions, but there is no correlation between energy use, GDP, and CO2 emissions. Additionally, Bekar (2018) suggests a unidirectional causal relationship between CO2 emissions and GDP in Türkiye. According to Bozkurt and Akan (2014), there is a unidirectional relationship between CO2 emissions and GDP growth in Türkiye, such that an increase in CO2 emissions results in a decline in GDP growth. Similarly, Pata (2018) demonstrates a unidirectional causal relationship between GDP growth and CO2 emissions. The findings demonstrate that an increase in GDP results in a rise in CO2 emissions. Recently, Chen et al. (2020) show a negative and insignificant effect of energy use on carbon emissions in OECD economies. Further research by Raihan and Tuspekova (2022) indicates that a 1% increase in economic development, urbanization, industrialization, and tourism in Türkiye increases C02 emissions by 0.39%, 1.22%, 0.24%, and 0.02%, respectively.

Table 4*:* Toda &Yamamoto (1995) Causality Test Results

Null hypothesis (H_0)	Prob.	Decision
lnGDP is not a cause factor for lnCO2	0.2944	DNR
lnCO2 is not a cause factor for lnGDP	0.5533	DNR
lnENG is not a cause factor for lnCO2	0.9907	DNR
lnCO2 is not a cause factor for lnENG	0.2271	DNR
lnIND is not a cause factor for lnCO2	0.0483	REJECT
lnCO2 is not a cause factor for lnIND	0.5050	DNR
lnGDP is not a cause factor for lnENG	0.9420	DNR
lnENG is not a cause factor for lnGDP	0.7807	DNR
lnIND is not a cause factor for lnGDP	0.2562	DNR
lnGDP is not a cause factor for lnIND	0.6635	DNR
lnENG is not a cause factor for lnIND	0.9692	DNR
lnIND is not a cause factor for lnENG	0.4128	DNR

Note: Bootstrapped critical values are found by running 5000 simulations. HJC criteria choose the best lag length; DNR denotes "Do Not Reject H_0".

5. CONCLUSION AND POLICY IMPLICATIONS

This study explores the CO2 emissions, economic growth, energy use, and industrialization nexus using the cointegration-ARDL-bound testing technique and the Toda & Yamamoto (1995) causality test for 1971-2021 in Türkiye. Empirical findings indicate a significant long-run association among the variables, and the estimated long-run coefficients of GDP, energy use, and industrialization exhibit a sensitivity of -0.726, 0.563, and 0.548 changes in CO2 emissions, respectively. Moreover, the ECT suggests that deviations from the long-term equilibrium state caused by short-term instability will be corrected at 56.3 percent yearly. In other words, the speed of adjustment coefficients indicates that when disequilibrium occurs, adjustments returning to equilibrium take almost two years. The Toda & Yamamoto (1995) causality results reveal a single causal link from industrialization to CO2 emissions. Despite the widespread assumption that energy use causes CO2 emissions since it significantly contributes to CO2 emissions, the findings indicate no evidence of a causal link between them.

Although Türkiye's economic growth has slowed down recently due to the depreciation of the Turkish lira and the novel COVID-19 pandemic, signs of economic growth from the supply-side perspective, such as industrial output, have strengthened. This implies the importance of industrialization in stimulating economic development and shows industrialization must be promoted to facilitate economic development for reduced environmental degradation. Sectorial contributions to economic growth and environmental degradation can vary. Some sectors might show implications of the EKC hypothesis while others do not. On the other hand, Türkiye's economic and environmental performance can also be influenced by global economic trends, trade patterns, and regional environmental dynamics. Furthermore, the EKC framework's applicability to global environmental challenges such as climate change underscores the complexity of Türkiye's sustainable development pathway. For up-to-date insights, referring to recent peer-reviewed studies and reports in environmental economics is crucial.

However, our empirical results suggest that industrialization is happening to the detriment of environmental quality. Therefore, Türkiye must bolden its commitment to fostering environmentally friendly and sustainable industrial production by embracing cleaner technologies. Promoting environmentally friendly industrial practices, such as waste reduction, recycling, and sustainable resource management, is also vital. Embracing circular economy principles can help minimize waste generation and maximize resource efficiency. Encouraging sustainable supply chains and responsible production practices can contribute to a greener and more sustainable industrial sector. Furthermore, supporting research and development in clean technologies, incentivizing companies to adopt sustainable practices, and implementing stringent environmental regulations can all contribute to fostering a more environmentally friendly industrial landscape in Türkiye.

The environment and economic growth nexus in Türkiye is a multifaceted dynamic shaped by the country's unique geographical and economic characteristics. The remarkable natural resources in Türkiye, from fertile agricultural land to diverse ecosystems, have been instrumental in driving economic development. However, rapid industrialization, urbanization, and energy consumption have posed significant environmental challenges, including air and water pollution, deforestation, and habitat loss. Striking a sustainable balance between economic growth and environmental conservation is critical. This necessitates the implementation of stringent environmental regulations, investments in clean technologies, and sustainable land use practices. Additionally, as Türkiye aims to maintain its status as a global tourist destination, responsible tourism management and preserving its cultural and natural heritage become imperative. In this complex interplay, the country faces the task of fostering economic prosperity while safeguarding its environmental assets for current and future generations, requiring well-crafted policies and international cooperation.

Balancing environmental sustainability with economic growth in Türkiye entails a comprehensive policy approach. The country should prioritize sustainable development by investing in green technologies, clean energy sources, and sustainable agricultural practices while rigorously enforcing environmental regulations to prevent pollution and resource depletion. Promoting resource efficiency and a circular economy is vital to minimize waste generation. Conservation efforts should be expanded to protect biodiversity and natural habitats, and investments in sustainable transportation and urban planning are necessary to mitigate air pollution and congestion in urban centers. Türkiye must also develop a holistic climate action plan, encouraging green finance and international cooperation in addressing transboundary environmental issues. Public awareness and education campaigns should promote responsible consumption, and inclusive growth policies can ensure economic prosperity while preserving the environment for future generations. Establishing monitoring systems and regularly reporting progress is critical to transparency and accountability in this multifaceted endeavor.

Moreover, Türkiye has experienced significant economic development in recent decades. Economic expansion often leads to increased energy consumption and, in turn, higher CO2 emissions. While economic growth has contributed to increased emissions in Türkiye, there has been a growing awareness of the need for sustainability. Therefore, Türkiye should give industries some preferential treatment, such as reduced interest rates and taxes, but reinforce its pollutant taxes to promote the transition to green industrialization to stimulate economic progress while upholding environmental sustainability. Therefore, balancing these incentives with appropriate environmental regulations and policies is essential. Reinforcing pollutant taxes can effectively discourage harmful practices, encourage emission reductions, and motivate industries to transition to cleaner alternatives. Pollutant taxes create a financial disincentive for companies to pollute, making it economically favorable for them to adopt cleaner technologies and practices. Implementing a well-designed policy framework that combines preferential treatment for green industries with reinforced pollutant taxes can create a robust incentive structure that aligns economic progress with environmental sustainability. This approach can stimulate economic growth, attract investments in green technologies, and help Türkiye transition towards a more sustainable and environmentally responsible industrial sector.

Energy consumption, economic growth, and industrialization should prioritize a comprehensive approach to achieve sustainability and economic development in Türkiye. This entails a substantial shift towards renewable energy sources like solar and wind power, combined with incentivizing energy-efficient practices in both industrial and residential sectors. Developing a robust research and development ecosystem, especially in clean energy technologies and sustainable manufacturing processes, is critical for long-term growth. Additionally, investments in modern infrastructure, including smart grids, can enhance energy distribution efficiency. Türkiye should also focus on creating a skilled workforce for the green economy through education and vocational training programs. Furthermore, encouraging small and medium-sized enterprises to adopt sustainable practices can foster inclusive economic growth while promoting eco-friendly industrial zones and technology parks. International collaborations and transparent monitoring mechanisms should complement these efforts to ensure Türkiye's energy, economic, and industrial strategies align with global sustainability goals.

Future studies on the policy implications of reconciling environmental sustainability with economic growth in Türkiye should delve into the sectors and strategies that offer the most significant potential for sustainable development. These studies should critically assess the efficacy of environmental regulations, enforcement mechanisms, and incentives for eco-friendly practices, scrutinizing their impact on environmental goals and economic progress. Investigating the integration of resource efficiency and circular economy principles into Türkiye's economic framework and the outcomes of biodiversity conservation efforts, sustainable transportation, and urban planning initiatives can provide valuable insights. Moreover, research should analyze the effectiveness of climate change mitigation and adaptation measures, green financing policies, public awareness campaigns, and international collaborations in achieving the dual objectives of environmental protection and economic prosperity. Monitoring and reporting systems' roles in promoting transparency and inclusive growth policies' impact on income inequality should also be explored to inform evidence-based policymaking for a sustainable future.

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