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RENEWABLE ENERGY AND CO_2 EMISSIONS: A CASE STUDY OF TURKIYE (1985-2022)

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Abstract

The intricate interconnection between economic expansion and environmental protection continues to be a significant area of academic enquiry and policy debate. By analyzing the impact of economic expansion and renewable energy consumption on environmental degradation, this article aims to contribute to the ongoing discourse on this topic from a Turkish perspective. The study employs theoretical frameworks such as the N-shaped variant of the Kuznets curve hypothesis, in conjunction with considerations of renewable energy integration and population dynamics, to provide nuanced perspectives on Turkey's environmental-economic landscape. The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were used to examine unit roots, followed by the application of the Autoregressive Distributed Lag (ARDL) methodology for econometric estimation. The bounds test confirmed a long-run cointegrating relationship among the variables. Diagnostic tests validated the robustness of the estimation, while the CUSUM and CUSUMSQ tests indicated stable coefficients over time, with no signs of instability.Empirical results suggest that the N-shaped Kuznets curve hypothesis is relevant in Turkey. An initial exacerbation of environmental degradation occurred, followed by amelioration as economic maturity ensued. Furthermore, the study suggests that sustainable energy sources warrant greater consideration in national energy strategies, given the potential of renewable energy to reduce carbon dioxide emissions.

Keywords: CO_2 Emission, Renewable Energy, Economic Growth, Sustainability, ARDL

Jel Kodları: S43, S51, O44

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1. Introduction

In the contemporary era, environmental concerns have emerged as a significant topic of discussion, particularly the acknowledgment of the non-sustainability of environmental degradation, which adversely impacts human life quality and renders living conditions untenable. Wildfires, melting glaciers, species extinction and displacement, soil infertility, and changes in precipitation all affect the entirety of living organisms. (Erat et al., 2023)

The relationship between economic progress and ecological degradation has been extensively studied by scholars, often using the theoretical construct of the Environmental Kuznets Curve (EKC). The EKC hypothesizes a curvilinear relationship between economic progress and ecological decline, depicting a trajectory that resembles an inverted U-shape. This theoretical framework implies that environmental conditions can deteriorate in the early stages of economic expansion, only to improve after a critical threshold of development is reached.

This hypothesis, originally proposed by Kuznets (1955) in the context of income inequality, has been extended to the study of environmental impacts with the aim of uncovering U-shaped or inverted U-shaped relationships. A multitude of empirical studies have been conducted with the objective of elucidating the dynamics of this relationship. Those who espouse the EKC hypothesis posit that as economies advance, they become better positioned to invest in environmental protection measures, resulting in a reduction in environmental degradation once a certain income threshold is reached. In the context of academic investigations, specific studies have provided empirical evidence to substantiate the EKC hypothesis hypothesis such as Shahbaz et al. (2015), Kazemi & Mousavi (2015), Wang et al. (2016), Sarkodie & Strezov (2019) whereas its validity has been challenged in others such as Loi & Duy (2010),Lee et al. (2010), Özokcu & Özdemir (2017). The observed discrepancies in outcomes can be attributed to variations in the economic and environmental performance of distinct countries or groups of countries. To illustrate, countries classified as either high-income or low-income can yield disparate findings with regard to the applicability of the EKC hypothesis.(Leal & Marques, 2020).

While the U-shaped or inverted U-shaped correlation between economic expansion and environmental decline has been the focus of considerable attention within academic circles, the investigation of an N-shaped relationship represents an emerging and pivotal area of inquiry. In contrast to the conventional U-shaped trajectory, which posits that environmental degradation initially intensifies with economic advancement but subsequently abates, the N-shaped curve delineates a scenario wherein the quality of the environment deteriorates at the inception of economic growth, experiences an upswing during an intermediate period, but subsequently deteriorates once again at elevated levels of economic development or vice versa.

In developing countries, the dynamics between economic growth and development represent a complex interplay of factors due to unique socio-economic conditions and challenges. Developing countries face the dual challenge of environmental degradation and economic stagnation as their pursuit of growth leads to increased energy consumption and consequent environmental degradation, compounded by inadequate policy responses to mitigate these impacts (Hanif, 2017).

While energy is a fundamental necessity for human progress and the advancement of economic activity, the shift towards renewable energy sources represents a promising avenue for the future to mitigate climate change, its sustainability is essential to ensure that intergenerational energy needs are effectively met (Owusu & Asumadu-Sarkodie, 2016).

The impact of energy sources on environmental degradation has been established as a significant determinant in several studies such as Alola et al. (2019), Xue et al. (2021),Usman et al. (2020), Ali et al. (2020), Nathaniel & Bekun (2021), Destek & Sarkodie (2019). Nonetheless, the results of these studies fail to converge on similar outcomes, indicating significant disparities in their findings.

A fundamental distinction exists between renewable and non-renewable energy sources. This is primarily due to the fact that renewable energy has the potential to produce energy with significantly less environmental impact. A notable characteristic of renewable energy is its ability to reduce dependence on foreign energy sources by utilizing domestic resource (Alper & Oguz (2016), Pata (2021)). While the initial construction of renewable energy infrastructure requires the use of foreign resources, once in operation it becomes self-sustaining and independent of further external inputs. As a result, countries without abundant fossil fuel reserves can benefit from the adoption of renewable energy, thereby reducing their dependence on resource-rich countries.

The recent expansion of renewable energy production is attributed to government initiatives and a significant decline in the cost of renewable energy technologies, which are evolving in response to increasing energy demand; despite the production of renewable energy necessitating the utilization of resources such as land, steel and other materials, the environmental impact of this process is comparatively less pronounced in comparison to that of fossil fuel sources (Ansari et al., 2021).

This study examines the impact of renewable energy consumption on environmental degradation in Turkey from 1985 to 2022, with a focus on the presence of an N-shaped Environmental Kuznets Curve (EKC). The research is organized into several key sections: the introduction contextualizes the research problem, followed by a literature review establishing the theoretical foundation. The methodology outlines data collection and analysis. The results section presents findings from econometric analyses, and the conclusion summarizes key contributions, implications, and future research directions.

2. Literature Review

The investigation of the quadratic relationship, which seeks to understand the impact of economic expansion on environmental degradation, has been a focal point in scholarly research. Scholars have primarily aimed to uncover whether this relationship follows a concave (U-shaped) trajectory, indicating that initial environmental degradation can be followed by environmental improvement as economies expansion, or a convex (inverted U-shaped) trajectory, indicating that The degradation of the environment worsens at first, but then improves as the economy reaches a certain level of development.

In addition to examining the quadratic relationship, researchers have also turned their attention to examining the cubic form of this relationship, which reveals an "N-shaped" correlation pattern. This distinctive pattern suggests the potential for multiple phases economic expansion and environmental quality. Initially, environmental quality can deteriorate, followed by an improvement, and potentially a deterioration at higher levels of economic progress. The seminal studies of Grossman & Krueger (1991) provide valuable insights into these relationships. In their study, the researchers conducted a comprehensive cross-sectional analysis to reveal the impact of economic progress on air quality in 42 countries belonging to the North American Free Trade Agreement (NAFTA). Using sophisticated analytical techniques, such as horizontal cross-sectional analysis, they were able to discern the intricate dynamics between these variables. The findings indicated that there is inverted U-shaped relationship between air quality and income. This indicates that initially, as income increases, the impact of environmental degradation worsens, but then improves after the income threshold reached. Building on their initial investigation, Grossman & Krueger (1994) expanded their investigation to examine of the relation between per capita income and water quality. This broadened perspective permitted the examination of additional dimensions of the environmental-economic relationship. The study yielded a nuanced picture, with some variables exhibiting an inverted U-shaped relationship, in alignment with their previous findings, while others demonstrated an N-shaped relation, which is indicative of a more complex dynamic.

Moreover, building on the investigation of the EKC hypothesis, the research by Allard et al. (2018) delves more deeply into the intricate dynamics of environmental-economic relationships, with a particular focus on the N-shaped form of the curve. A panel quantile regression analysis was employed by Allard et al. (2018) to investigate the N-shaped EKC in order to examine the relationship between CO_2 emissions and GDP per capita in 74 countries from 1994 to 2012. This study has identified evidence of an N-shaped EKC in all income groups, with the exception of those in the upper-middle-income category. It has also demonstrated the existence of heterogeneity within this N-shaped EKC.

Khan et al. (2023) undertook an examination focusing on the ten nations with the highest carbon emissions levels. Their findings indicated a strong correlation between economic growth and the consumption of energy. Specifically, the research showed that CO_2 emissions are positively linked with per capita gross domestic product and cubic of GDP while negatively correlated with square of GDP. Additionally, energy consumption was also positively correlated with CO_2 emissions level. Eventually, this study corroborating N shaped EKC hypothesis.

In the case of Turkey, several studies have been conducted to determine the presence of an N-shaped or inverted N-shaped curve that describes the correlation between environmental degradation and economic progress.

In their study, Akbostanci et al. (2009) analysed data from 1968 to 2003 and found a consistently increasing relationship between CO_2 emissions and income, as well as an N-shaped relationship for other emissions. Furthermore, Başar & Temurlenk (2010) discovered that there was no discernible correlation between income and CO_2 emissions. Instead, they identified an inverse "N"-shaped relationship with specific CO_2 metrics.

In a subsequent study Kocak (2014) analyzed the same topic which is over a period spanning from 1960 to 2010. There is an emphasis on the fact that energy consumption has a significantly greater impact on carbon emissions, therefore, advocated for the implementation of renewable energy policies with the objective of reducing environmental pollution. In a further study, Erdoğan et al. (2015) confirmed these conclusions by analyzing data from 1975 to 2010. Their findings indicated the existence of an inverse "U"-shaped relationship between the two variables. Furthermore, Kılıç & Akalın (2016) conducted an analysis spanning the period from 1960 to 2011, utilising the ARDL model. While their initial findings were consistent with the EKC hypothesis, indicating an inverted U-shaped relationship between per capita income and pollution, further analysis employing a cubic model revealed an additional N-shaped relationship, suggesting a more intricate dynamic between income and pollution.

Additionally, Ceylan & Karaağaç (2020) conducted a comprehensive analysis of data from 1960 to 2014. The EKC hypothesis was not supported by their findings. Their analysis revealed a co-integration relationship with a structural break among the variables, confirming the existence of an N-shaped EKC in Turkey. In particular, Güzel (2021) conducted an exhaustive investigation utilising annual data spanning the period 1960 to 2015. This entailed applying ARDL cointegration test, which revealed an N-shaped relation between income and pollution.

A substantial corpus of research has investigated the intricate relationship between energy consumption and environmental pollution, elucidating the intricate dynamics within this domain. By drawing upon seminal studies conducted in a variety of countries over different time periods, the objective is to synthesize key findings in order to provide a comprehensive understanding of the subject matter.

In their analysis of the relationship between CO_2 emissions, renewable electricity generation, and gross domestic product in Turkey from 1961 to 2010, Bölük & Mert (2015) employed an ARDL approach. The findings demonstrate a statistically significant and negative relationship between renewable electricity generation (exclusive of hydropower) and CO_2 emissions in the long run, thereby substantiating the capacity of renewable energy to diminish environmental impacts.

Expanding on this discourse, the objective of the study by Çağlar & Mert (2017) was twofold: firstly, to test the EKC hypothesis and, secondly, to elucidate the relationship between renewable energy consumption and greenhouse gas emissions in Turkey. The study analyzed data from 1960 to 2013 and found that renewable energy consumption contributes to the reduction of GHG emissions. This provides further evidence of the environmental benefits associated with the adoption of renewable energy.

In a broader examination of developing countries, Zafar et al. (2019) investigated 18 countries over the period from 1990 to 2015. The results of the study support the assumption that the consumption of renewable energy has a reverse correlation with carbon emissions, while the consumption of nonrenewable energy has the opposite correlation and exacerbates ecological damage.

Koc & Bulus (2020) conducted an extensive study in South Korea from 1971 to 2017. The research revealed that an increase in real GDP and energy consumption has a detrimental impact on pollution levels. Nevertheless, the study also identified renewable energy consumption and openness to trade as mitigating factors, which have the effect of reducing carbon emissions.

Moreover, Özpolat & Nakıpoğlu Özsoy (2021) examined renewable energy's impact on environmental degradation in Turkey between 1990 and 2015. A negative correlation was found between the consumption of renewable energy and the emission of carbon dioxide, while a positive correlation was found between the consumption of non-renewable energy and the emission of carbon dioxide.

Existing literature presents mixed evidence on the validity of the Kuznets curve, with studies identifying N-shaped and inverse N-shaped patterns, while others report a U-shaped relationship between economic growth and environmental quality. Additionally, the relationship between energy consumption—both renewable and non-renewable—and economic growth has been a focal point of empirical research. Against this backdrop, this study aims to provide a comprehensive analysis of the N-shaped Kuznets curve hypothesis and examine the impact of renewable energy consumption on economic growth in Turkey, utilizing a broader temporal framework to capture long-term dynamicsç

3. Methods And Materials

The primary aim of this investigation is twofold: First, to discern the presence of an N-shaped or inverted N-shaped curve; and second, to evaluate the influence of renewable energy on CO_2 emissions. In order to achieve these goals, the study will consider a number of key variables, including CO_2 emissions, gross domestic product per capita, renewable energy consumption, and population growth. The temporal scope of the study spans from 1985 to 2022, encompassing a substantial period facilitated by the availability of comprehensive data.

Figure 1 provides an illustrative representation of how these variables have evolved over time. By examining the data presented, it is possible to identify some trends and patterns in the data over a period of years. It is worth noting that both CO_2 emissions and GDP per capita appear to have risen over the course of the study period. This suggests that economic activity and environmental impact have both grown. Similarly, it seems that renewable energy consumption also demonstrate a general upward trend, although there are some years where there are fluctuations. In contrast, annual population growth displays a declining trend over time, with a stabilization after 2010. However, there is considerable variability throughout the observation period. By examining these temporal dynamics, the study aims to gain a deeper understanding of the complex interactions between economic development, renewable energy utilization, population dynamics, and their collective impact on environmental sustainability.

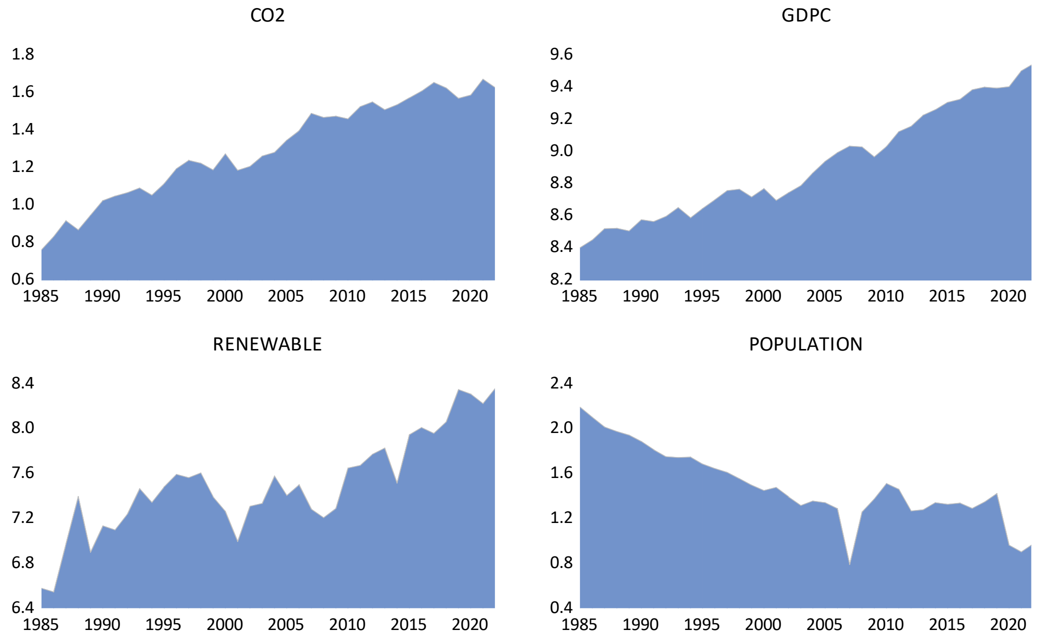

Figure 1.
Evolution of series over time

In this research study, a set of variables essential for understanding the determinants of environmental degradation is identified. These variables are presented in Table 1, along with detailed descriptions of the respective data sources. Notably, per capita CO_2 emissions represent a particularly significant metric in environmental studies, as they provide a means to assess the impact of carbon dioxide emissions, which have been widely utilized in numerous studies as an indicator of environmental degradation

Table 1.
Definition of variables

Abbreviation	Definition	Source
CO_2	CO_2 Emissions per capita, from fossil fuels and industry.	Our World in Data
GDP	GDP per capita (constant 2015 US$)	World Bank
Renewable	Energy consumption from Renewables per capita (kWh - equivalent)	Our World in Data
Population	Population growth (annual %)	World Bank

In addition to considerations of the environment, Gross Domestic Product per capita serves as a valuable indicator of economic growth. The incorporation of this variable into the study enables an investigation of the intricate interrelationship between economic prosperity and environmental sustainability. In addition, the incorporation of quadratic and cubic economic transformations allows for a more comprehensive analysis of the potential impact of economic growth on environmental degradation.

Moreover, the study examines the potential of renewable energy as a means of reducing CO_2 emissions. It is therefore of interest to consider the potential role of renewable energy consumption as a means of reducing CO_2 emissions and influencing environmental outcomes. This can be quantified in terms of per capita energy consumption from renewables. Through the investigation of these variables and their interactions, the research aims to contribute to a more nuanced understanding of the complex relationships between economic growth, environmental quality, and the utilisation of renewable energy.

Table 2.
Descriptive statistics

	CO_2	**GDPC**	**Renewable**	**Population**
Mean	0.987	8.675	7.003	1.760
Median	1.081	8.623	7.257	1.752
Maximum	1.675	9.550	8.366	2.618
Minimum	-0.137	7.928	5.373	0.796
Std. Dev.	0.510	0.442	0.851	0.461
Observations	58	58	58	58

The descriptive statistics indicate that the variables under consideration exhibit relatively narrow ranges. The mean values for CO_2, GDPC, Renewable, and Population are 0.987544, 8.675113, 7.003705, and 1.760338, respectively. It would appear that the medians are quite close to the means, which suggests that the distributions can be symmetrical. It is notable that GDPC exhibits the smallest standard deviation of 0.493191, indicating less variability compared to the other variables. Meanwhile, it is worth noting that GDPC and Renewable demonstrate moderate variability with standard deviations of 0.442402 and 0.851775, respectively. It would appear that the population variable shows a standard deviation of 0.461829, which might suggest moderate variability. With 58 observations for each variable, it seems that the sample size is adequate for drawing meaningful conclusions about the dataset.

In this study, we have employed a methodological framework that encompasses the analysis of time series data, beginning with an examination of their stationarity levels. In order to assess stationarity, two well-established statistical tools were employed, namely the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, which were designed for the purpose of identifying the presence of unit roots in a time series.

Following the stationarity assessment, the study proceeds to employ the Autoregressive Distributed Lag (ARDL) modeling approach, with bound test cointegration methodology, as a means of further analysis. It is of significant importance to note that Cointegration analysis is a fundamental tool for elucidating the long-run relationships between variables that can exhibit non-stationary behaviour individually.. The ARDL model, when used in conjunction with the bound test cointegration methodology, allows for the examination of both short-run and long-run dynamics within data.

While various cointegration techniques exist, including the Engle-Granger and Johansen methods, the decision to utilize the bound test approach is based on its suitability for situations where the series exhibit disparate levels of stationarity. This methodology is particularly well-suited to accommodate series with varying stationarity properties, offering a robust analytical framework for the study's objectives. Furthermore, it is important to note that the bound test approach necessitates that the series under investigation should not demonstrate integrated of order 2 (I(2)) behavior. This helps to ensure the applicability and reliability of the methodology within the context of the study. The following model delineates the formal representation of the Autoregressive Distributed Lag (ARDL) model utilized within the research framework. Each variable is represented by its corresponding abbreviation as outlined in Table 1. Equation 1 elucidates the concurrent examination of both the enduring and immediate impacts of the variables. Here, α denotes the long-term coefficients and θ represents the short-term coefficients, with α_0 signifying the constant term.

$$\triangle \text{ CO2 } = \alpha_0 + \sum_{i=1}^{n} \alpha_1 \triangle \text{ CO2 }_{t-i} + \sum_{i=0}^{n} \alpha_2 \triangle GDPC_{t-i} + \sum_{t=0}^{n} \alpha_3 \triangle GDPC_{t-t}^2$$
$$+ \sum_{t=0}^{n} \alpha_4 \triangle GDPC_{t-i}^3 + \sum_{i=0}^{n} \alpha_5 \triangle Renewable_{t-i} + \sum_{l=0}^{n} \alpha_6 \triangle \text{Population}_{t-i}$$
$$+\theta_1 \text{ CO2 }_{t-1} + \theta_2 \text{ GDPC }_{t-1} + \theta_3 GDPC_{t-1}^2 + \theta_4 GDPC_{t-1}^3 + \theta_5 \text{ Renewable }_{t-1} + \theta_6 \text{ Population}_{t-1} + \varepsilon_t$$

Equation (1)

Additionally, the error correction of the model is encapsulated in Equation 2.

$$\triangle CO2 = \lambda_0 + \sum_{i=1}^{n} \lambda_1 \triangle CO2t_{t-i} + \sum_{i=0}^{n} \lambda_2 \triangle GDPC_{t-1} + \sum_{i=0}^{n} \lambda_3 \triangle GDPC_{t-i}^2$$
$$+ \sum_{i=0}^{n} \lambda_4 \Delta GDPC_{t-i}^3 + \sum_{i=0}^{n} \lambda_5 \triangle Renewable_{t-i} + \sum_{i=0}^{n} \lambda_6 \triangle \text{Population}_{t-i}$$
$$+ \varphi ECM_{t-1} + \varepsilon_t$$

Equation (2)

The constant term is denoted by λ_0, with the operator Δ representing the first difference. The error correction term is symbolized by ECM.

In addition to the estimation of the ARDL model, a series of diagnostic test statistics are conducted to ensure the reliability and robustness of the model. These tests serve to evaluate various aspects of the model's performance and assumptions. The RESET (Regression Specification Error Test) is employed to detect any omitted variables or misspecifications in the model. The Breusch-Godfrey Serial Correlation LM Test is employed to assess the existence of autocorrelation within the model residuals. Heteroskedasticity is examined using a specific test to determine if it affects the model's efficiency and inference with Breusch-Pagan-Godfrey test. Additionally, A normality test is employed to ascertain whether the residuals exhibit a normal distribution. Furthermore, the stability of the estimation is assessed through the examination of CUSUM and CUSUMSQ tests, which detect structural changes or parameter instability over time. By conducting these diagnostic tests, it is aimed to ensure the reliability and validity of the ARDL model and its estimates for further analysis and interpretation.

4. Empirical Results

This section of the study is dedicated to presenting the findings of the empirical analysis. Before embarking on the econometric estimations, it would be prudent to perform a unit root test to determine the most suitable methodological approach. The rationale behind this approach is that different time series data can exhibit varying degrees of stationarity, which could potentially necessitate the selection of an appropriate model. To address this issue, an Augmented Dickey-Fuller (ADF) and a Phillips-Perron (PP) unit root test was performed.

The results of the unit root tests indicate that the population growth variable is the only one that does not exhibit a unit root at the level, whereas all other variables manifest unit root presence. Upon applying first differencing, all series demonstrate stationarity.

Table 3.
Unit Root Test Results

	ADF		PP	
	I(0)	I(1)	I(0)	I(1)
CO_2	-2.3995	-7.2173***	-2.3445	-7.587 ***
	(0.3759)	(0.000)	(0.403)	(0.000)
GDPC	-1.6502	-7.4534***	-1.6502	-7.559 ***
	(0.7601)	(0.000)	(0.760)	(0.000)
Renewable	-2.7846	-8.4509***	-2.7846	-9.195***
	(0.2088)	(0.000)	(0.208)	(0.000)
Population	-3.5105**	-8.0834***	-3.4948**	-16.974
	(0.0477)	(0.000)	(0.049)	(0.000)

*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Probabilities are provided in parentheses.

In light of these findings, it may be worth considering the potential benefits of employing the Autoregressive Distributed Lag (ARDL) methodology for conducting econometric tests. The ARDL methodology has the potential to be particularly advantageous in that it allows for testing even when the series exhibit different levels of stationarity.

Table 4.
Bounds Test

Value	**Signif.**	**I(0)**	**I(1)**
12.30245	10%	2.08	3
5	5%	2.39	3.38
	2.5%	2.7	3.73
	1%	3.06	4.15

After establishing the optimal lag length using the Hannan-Quinn criteria, which is a method commonly used for selecting the lag order in time series models, it seems that a lag length of (1,0,0,0,0,1) is the most suitable for the analysis. This lag length specification is of significant value as it facilitates the capture of the dynamic relationship between variables over time. To assess cointegration, the analysis employs the Bound test, which was proposed by Pesaran et al. (2001). Once the bound test statistic has been generated, it must be subjected to a comparison against the critical values in order to ascertain its significance.

In this particular instance, the F-statistic calculated from the Bound test is estimated to be 12.302. This value is above both the lower and upper critical values established for the Bound test. Such a result suggests that the observed relationship among the variables can be statistically significant and robust, which could indicate the presence of cointegration. In view of the findings of the Bound test, it can be reasonably inferred that there is a cointegration among the variables included in the analysis.

Table 5.
ARDL Long Run Form

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GDPC	247.964**	104.937	2.362	0.0248
GDPC2	-26.789**	11.628	-2.303	0.0283
GDPC3	0.967**	0.429	2.251	0.0319
Renewable	-0.131**	0.051	-2.537	0.0166
Population	0.097	0.079	1.219	0.2322
C	-764.395**	315.507	-2.422	0.0217

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

In examining the long-term relationships between variables, Table 5 could be a valuable tool, offering insights into the long-term relationships between the variables under consideration. It is worth noting that, with the exception of population growth, it appears that all other variables have a discernible and statistically significant impact on the levels of CO_2 within the Turkish context. The ARDL long-run results indicate significant relationships with environmental degradation. The p-values for GDPC (0.0248), $GDPC^2$ (0.0283), and $GDPC^3$ (0.0319) show significance at the 5% level, supporting the N-shaped Kuznets curve hypothesis. This suggests that as GDP per capita increases, environmental degradation initially worsens before improving at higher levels of GDP. The RENEWABLES variable also demonstrates significance ($p = 0.0166$), indicating that increased renewable energy consumption is associated with reduced environmental degradation. In contrast, the population variable is not significant ($p = 0.2322$).

The findings of the long-term analysis suggest that there can be a relationship between economic growth and environmental deterioration that could be described as an inverted U-shaped curve. In particular, the coefficient associated with gross domestic product per capita appears to indicate a potential positive correlation between economic growth and carbon emissions. It is worth noting that the coefficients associated with the square root and cubic forms of GDPC exhibit negative and positive values, respectively.

Moreover, the examination yielded an important discovery regarding the prospective influence of renewable energy consumption on carbon dioxide emissions. The analysis indicates that an increase in the utilisation of renewable energy sources may result in a discernible reduction in CO_2 emissions over time. A 1% increase in renewable energy consumption is associated with a 0.13% decrease in CO_2 emissions. This empirical observation suggests that renewable energy policies can have the potential to be effective in mitigating carbon emissions and advancing environmental sustainability objectives.

Table 6.
Error Correction Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ECM	-0.719***	0.070	-10.165	0.0000
GDPC	178.478**	74.659	2.390	0.0233
GDPC2	-19.282**	8.265	-2.332	0.0266
GDPC3	0.696**	0.305	2.281	0.0298
Renewables	-0.094***	0.034	-2.782	0.0092
Population	-0.028	0.030	-0.931	0.3590
R Squared	0.737908	Mean Dependent		0.025021
Adjusted R Squared	0.730628	S.D. Dependent		0.048685
S.E	0.025268	Akaike İnfo Criterion		-4.467353
SSR	0.022985	Schwarz Criterion		-4.381164
Log Likelihood	86.87971	Hannan Quinn Criter		-4.436688
Durbin Watson Stat	1.615321			

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

The outcomes of the Error Correction Model (ECM), as detailed in Table 6, appear to indicate the establishment of a cointegration equation, which could suggest a robust relationship among the variables under examination. It is pertinent to highlight that the negative coefficient associated with the ECM, with a value below unity (0.719), suggests a rapid adjustment towards the long-term equilibrium. This observation suggests that the system is effective in correcting short-term deviations from the equilibrium path. The Error Correction Model (ECM) results indicate significant relationships with environmental degradation. The ECM coefficient is highly significant ($p = 0.0000$), demonstrating a strong adjustment towards long-run equilibrium. The p-values for GDPC (0.0233), $GDPC^2$ (0.0266), and $GDPC^3$ (0.0298) support the N-shaped Kuznets curve hypothesis, suggesting that increases in GDP per capita initially worsen environmental degradation before improving at higher levels. The Renewables variable is also significant ($p = 0.0092$), indicating that greater renewable energy consumption reduces environmental degradation. In contrast, the population variable is not significant ($p = 0.3590$).

Moreover, the findings of the long-term analysis appear to be supported by the significance and directional consistency of the coefficients. Notably, there does not appear to be any significant association between population growth and CO_2 emissions in the short term, which is in accordance with the long-term findings on this topic. It appears that GDPC maintains a positive sign, while its square term manifests as negative, which could be indicative of an inverted U-shaped relationship in the short run. It is noteworthy that the cubic form of GDPC appears to exhibit a positive coefficient, which could indicate the potential existence of an "N-shaped" EKC hypothesis in the short-term context. The results are consistent with existing literature regarding the N-shaped Kuznets curve, as indicated by Başar and Temurlenk (2010), Bölük and Mert (2015), Allard et al. (2018), Güzel (2021), Ceylan and Karaağaç (2020), and Khan et al. (2023). Additionally, the findings align with studies on renewable energy, including those by Zafar et al. (2019), Koc and Bulus (2020), and Özpolat and Nakıpoğlu Özsoy (2021).

Moreover, preliminary findings suggest that the impact of renewable energy consumption on CO_2 emissions in the short run is negative. It appears that a 1% increase in the utilisation of renewable energy is associated with a 0.094% reduction in CO_2 emissions. The empirical evidence indicates that short-term policies designed to facilitate the adoption of renewable energy can be an effective means of reducing carbon emissions and advancing environmental sustainability objectives.

Table 7.
Diagnostic Test Results

Diagnostic Tests	**Value**	**Probability**
Ramsey Reset Test	0,052	0,820
Breusch Pagan Godfrey Heteroskedasticity Test	0,446	0,864
Jarque Bera Normality Test	1,643	0,439
Breusch Godfrey Serial Correlation LM Test	0,912	0,413

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

Table 7 presents the outcomes of diagnostic tests conducted to assess the reliability and validity of the statistical analysis. These diagnostic tests included in this study are an important part of evaluating the robustness of the model and ensuring the integrity of the results. The results of these diagnostic tests indicate that the model meets the necessary criteria for reliability.

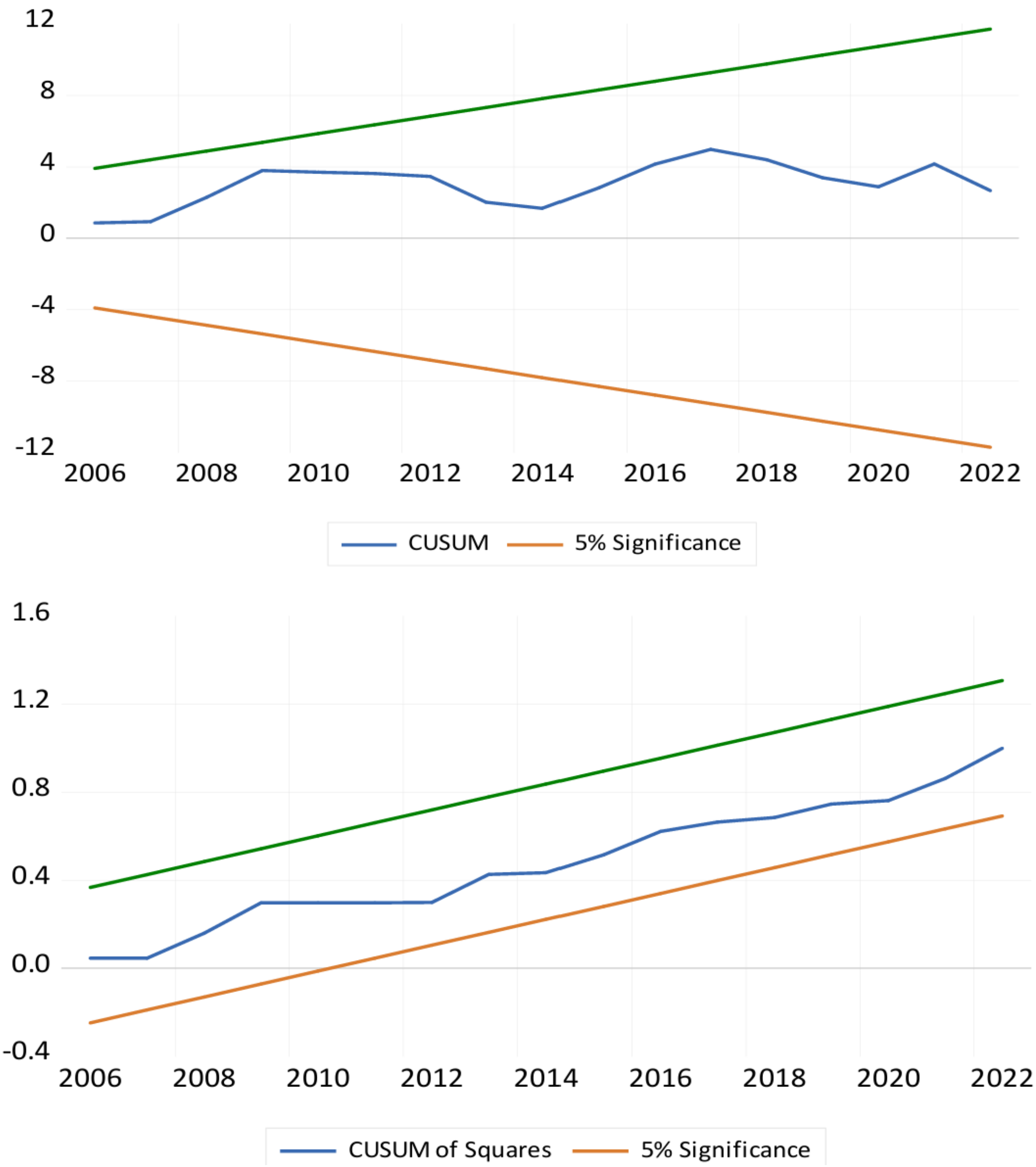

Figure 2.

CUSUM and CUSUMsq

Furthermore, the stability of the model is assessed through the Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUMsq) tests, the findings of which are depicted in Figure 2. These tests are instrumental in evaluating whether the coefficients in the model remain stable over time or exhibit significant fluctuations, indicating instability. The results of both the CUSUM and CUSUMsq tests provide reassuring evidence that the model maintains stability throughout the observed time period

5. Conclusion

In this intellectual context, this study aims to offer a nuanced understanding of the environmental-economic dynamics in Turkey. By exploring the applicability of the N-shaped EKC hypothesis and the role of renewable energy, the research hopes to uncover the complex nuances that shape environmental outcomes in Turkey. Additionally, the analysis incorporates the variable of population growth, recognizing its potential implications for environmental sustainability over time.

The findings of this study offer valuable insights into the environmental-economic landscape of Turkey. The bounds test results indicated the existence of cointegration among the variables, demonstrating a significant long-term equilibrium relationship between them. Specifically, the long-term analysis of ARDL model supported the validity of the N-shaped Environmental Kuznets Curve (EKC), confirming that the relationship between economic growth and environmental degradation follows this pattern. It was also revealed that the contribution of renewable energy to reducing CO2 emissions. Interestingly, the analysis showed that population growth did not have a statistically significant impact on CO2 emissions, suggesting that other factors may play a more critical role in influencing environmental outcomes.

Additionally, the error correction model (ECM) provided further insights, aligning closely with the long-term results and reinforcing the robustness of the findings. To ensure the accuracy and reliability of the model, several diagnostic tests were conducted, including the RESET test, the heteroskedasticity test, the normality test, and the serial correlation test. The outcomes of these tests confirmed that the model's estimations are robust and reliable.

Moreover, the stability of the model over time was verified using the CUSUM and CUSUMSQ tests, which assess cumulative sum control charts for model stability. Both tests indicated that the model is stable, further validating its appropriateness for the analysis of the long-term relationship between economic variables, renewable energy, and CO2 emissions.

The confirmation of the N-shaped EKC hypothesis provides further evidence to support the view that economic growth and environmental quality are not necessarily mutually exclusive. This suggests that context-sensitive policy interventions may be necessary to achieve a more balanced approach to economic growth and environmental protection. Moreover, the discovery of an inverted U-shaped relationship suggests that the impact of economic development on environmental outcomes may not be straightforward. This highlights the need for policy responses that are carefully considered and tailored to the specific circumstances.

Furthermore, the study highlights the potential of renewable energy in reducing carbon dioxide emissions, suggesting that sustainable energy sources can warrant greater consideration in national energy agendas. Despite these valuable insights, the study acknowledges certain methodological limitations, including data constraints and the necessity for longitudinal analyses to discern temporal patterns.

In light of these findings, we can conclude that this study offers a valuable contribution to academic understanding by offering insights into the complex interrelationships between economic progress and environmental imperatives in Turkey. The research aims to contribute to evidence-based policymaking aimed at fostering sustainable development and environmental stewardship in Turkey and beyond by delineating the temporal dynamics of this relationship and identifying pertinent policy implications.

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