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RESEARCH ARTICLE

Assessing the Validity of the N-Shaped LCC Hypothesis in Türkiye: Exploring the Impact of Renewable Energy

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Abstract

An investigation of the intricate interplay between environmental factors and economic growth constitutes a crucial area of study. This study examines how renewable energy consumption affects environmental conditions while employing the framework of the Load Capacity Curve hypothesis. The analysis examines whether Türkiye demonstrates an N-shaped pattern, suggesting a complex relationship between economic growth and environmental degradation, from 1965 to 2022. The research findings are supported by econometric analyses, including the ARDL and bounds tests for cointegration. This indicates the presence of the N-shaped LCC hypothesis. Furthermore, this study identifies the short-term impact of renewable energy consumption on environmental degradation levels. This research contributes to our understanding of the complex interrelationships among economic growth, the utilisation of renewable energy, and environmental preservation. The insights gained are of value to countries engaged in efforts to promote balanced economic development in harmony with ecological sustainability.

Keywords: *Load Capacity Curve, Economic Growth, Renewable Energy, ARDL, Bound Test*
Jel Codes: *Q50,O40,Q20,C32*

Türkiye'de N Şeklindeki LCC Hipotezinin Geçerliliğinin Değerlendirilmesi: Yenilenebilir Enerjinin Etkisinin Araştırılması

Özet

Çevresel faktörler ile ekonomik büyüme arasındaki karmaşık etkileşimin incelenmesi önemli bir çalışma alanını temsil etmektedir. Bu çalışma, Yük Kapasitesi Eğrisi hipotezi çerçevesinde yenilenebilir enerji tüketiminin çevresel koşulları nasıl etkilediğini incelemektedir. Analiz, Türkiye'nin 1965'ten 2022'ye kadar ekonomik büyüme ve çevresel bozulma arasında karmaşık bir ilişkiye işaret eden N şeklinde bir model gösterip göstermediğini incelemektedir. Araştırma bulguları, eşbütünleşme için ARDL ve sınır testlerinin kullanımı da dahil olmak üzere ekonometrik analizlerle desteklenmektedir. Bu da N-şekilli LCC hipotezinin varlığına işaret etmektedir. Ayrıca, bu çalışma yenilenebilir enerji tüketiminin çevresel bozulma seviyeleri üzerindeki kısa vadeli etkisini tanımlamaktadır. Bu araştırma, ekonomik büyüme, yenilenebilir enerji kullanımı ve çevrenin korunması arasındaki karmaşık karşılıklı ilişkileri anlamamıza katkıda bulunmaktadır. Elde edilen içgörüler, ekolojik sürdürülebilirlikle uyum içinde dengeli ekonomik kalkınmayı teşvik etme çabası içinde olan ülkeler için değer taşımaktadır..

Anahtar kelimeler: *Yük kapasite eğrisi, ekonomik büyüme, yenilenebilir enerji, ardl, sınır testi*
Jel Kodu: *Q50,O40,Q20,C32*

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1. INTRODUCTION

In recent times, there has been a notable increase in the level of attention paid to environmental degradation compared to previous periods. Historically, economic growth has been pursued without adequate consideration of the resulting environmental stress, which has led to substantial degradation. The rapid growth of economies, coupled with industrialization and urbanization, has significantly increased energy consumption and environmental pressures (Shahbaz et al., 2019). This context has sparked growing interest among scholars and policymakers in both theoretical and empirical approaches within environmental economics. The increasing recognition of the interrelationship between the economy and the environment has prompted a significant increase in the quantity and quality of research examining the intricate relationship between economic advancement and environmental sustainability. One of the most frequently employed and extensively researched frameworks in this field is the Environmental Kuznets Curve (EKC).

The Environmental Kuznets Curve (EKC), originally identified by Simon Kuznets, was developed to describe the relationship between economic development and income inequality. In his original proposal, Kuznets posited that during the initial phases of economic growth, there tends to be an increase in income inequality. Conversely, as economic growth continues, income disparity diminishes, ultimately creating an inverted U-shaped relationship. Grossman & Krueger (1994) expanded upon Kuznets' framework by applying this concept to environmental economics and developing the hypothesis of the Environmental Kuznets Curve. This hypothesis proposes that environmental degradation intensifies during the initial stages of economic growth but subsequently declines after a certain threshold of economic development is attained. The EKC has consequently emerged as a pivotal focus of research, in particular in the context of the mounting global concern about the environment, due to the detrimental impact of climate change and the adverse effects of environmental degradation on human well-being and ecosystems. The drive for continued economic expansion has led to the examination of additional factors contributing to environmental strain.

The pressing need for strategies to address environmental degradation has become more evident in light of the growing urgency to mitigate the adverse effects of climate change. Since the 1970s, there has been a significant challenge to the global economy arising from the environmental consequences of the unprecedented emissions of greenhouse gases (GHGs) (Erdogan, 2024). Consequently, there has been an appreciable increase in the quantity of academic research addressing environmental degradation. Despite the acknowledged importance of various factors, including financial development ((Khan et al., 2022; Numan et al., 2023; Zhang et al., 2022), geopolitical risks (Pata & Ertugrul, 2023), economic policy uncertainty (Wu et al., 2023), and research and development (Dogan & Pata, 2022), it is energy consumption that is of particular concern in its impact on environmental quality.

The overreliance on non-renewable energy sources has been identified as a primary contributor to environmental degradation. The consumption of fossil fuels, such as coal and oil, has the adverse effect of exacerbating pollution, as well as accelerating climate change. In stark contrast, the use of renewable energy sources, including wind, solar, and hydroelectric power, offers a significant improvement in environmental quality, as evidenced by their role in reducing carbon dioxide emissions and other pollutants (Khan et al., 2021). The transition to renewable energy is thus of paramount importance if we are to achieve sustainable environmental outcomes. This transition requires significant input from all sectors, particularly from governments, which bear significant responsibility in this regard. In order to achieve the aforementioned sustainable environmental outcomes, it is necessary to implement effective policy measures which include discouraging the use of fossils fuels, enforcing stringent environmental regulations, and promoting the adoption of renewable energy sources (Ibrahim & Ajide, 2021).

A multitude of metrics has been utilized by researchers to measure the extent of environmental degradation. At the outset, the metric of primary relevance for the purpose of assessing the extent of air pollution was that of carbon dioxide emissions. However, this measure has inherent limitations, particularly in the context of contamination of water and soil pollution. In consequence, the ecological footprint emerged as a more comprehensive indicator than CO2 emissions. The initial prioritization of the ecological footprint was based on its comprehensive assessment of resource demand and regeneration capacity, has increasingly been supplanted by the load capacity factor (LCF), which integrates multiple dimensions of environmental stress and resource consumption, rendering it a superior measure for environmental impact assessment. (Pata & Ertugrul, 2023). The LCF hypothesis, proposed by Siche et al. (2010), has become a pivotal framework for assessing environmental degradation due to its comprehensive and integrative approach.

This study offers a number of new insights and contributions. The study takes an in-depth look at the long-term effects of economic growth and renewable energy sources on load capacity factor (LCF) for the case of Türkiye . The aim of this prolonged temporal analysis is to gain a better understanding of how economic development and renewable energy consumption affect each other and the LCF as a whole. Secondly, this study deviates from the prevailing focus on the widely acknowledged N-shaped Environmental Kuznets Curve (EKC) hypothesis in existing literature. Instead, it aims to examine the potential applicability of the N-shaped load capacity curve (LCC) hypothesis. This departure from the conventional framework signals a deliberate shift towards exploring an aspect of the environmental-economic relationship that has been less extensively studied. This study seeks to gain further insight into the complex relationship between environmental capacity dynamics, energy sources, and economic growth by examining the fluctuations of the LCF, economic growth and renewable energy consumption. Such methodological refinement is an important indication of the study's dedication to comprehensively understanding the complex nature of sustainability challenges, which is a commendable objective. Consequently, this study endeavors to ascertain if the impact of economic growth on environmental degradation varies across different stages of economic development in Türkiye by examining the N-shaped Environmental Kuznets Curve.

The following structure will be employed throughout this paper: The introductory chapter will provide a comprehensive overview of the topic under consideration, emphasizing its importance. The second chapter will review pertinent literature, synthesizing key findings and theoretical perspectives within this domain. The third chapter will delineate the methodology employed and the data utilized in the analysis, detailing the sources and analytical techniques employed. The fourth chapter will present the results of the econometric estimations, interpreting the findings within the context of the EKC hypothesis. The final chapter will discuss the conclusions reached, offering insights and implications for policy and future research.

2. LITERATURE REVIEW

The Environmental Kuznets Curve (EKC) is a subject that has attracted significant interest and extensive research from scholars exploring its various hypotheses, including those related to the N-shaped trajectory. This curve illustrates the relationship between environmental degradation and economic growth. It proposes that initially, as economies develop and mature, environmental quality may deteriorate. However, it suggests that at a certain turning point, environmental quality may begin to improve. However, there is a risk that further economic growth may lead to renewed environmental degradation. This nuanced hypothesis has been subjected to scrutiny by numerous scholars from diverse regions and economic contexts. Churchill et al. (2018) conducted a comprehensive study to examine the existence of the Environmental Kuznets Curve across 20 OECD countries. The results indicated a spectrum of findings. In some countries, there was evidence that the relationship between environmental degradation and economic growth follows the inverted U-shaped pattern that was previously thought to be the norm. Nevertheless, it was intriguing to note that several countries exhibited an N-shaped relationship, which seemed to challenge the conventional understanding of the curve's pattern.

Building on this foundation, Shehzad et al. (2022) explored the specific case of Algeria to examine whether the N-shaped EKC hypothesis might apply there. Their study indicated that the country's environmental-economic dynamics are significantly shaped by natural resources and economic globalization. Their findings indicated that economic growth and ecological footprints appear to have an N-shaped relationship, suggesting the possibility of multiple turning points in the relationship between economic development and environmental degradation in Algeria.

In an attempt to expand the geographical scope, Fakher et al. (2023) conducted a study that examined the N-shaped Environmental Kuznets Curve (EKC) using environmental indicators in selected OPEC countries. Their comprehensive analysis yielded a nuanced understanding of the complex relationship between per capita income and environmental quality indicators. The results indicated an N-shaped relationship, suggesting that environmental quality may initially worsen with income growth, improve following a certain income threshold, and deteriorate again at higher income levels. Furthermore, they observed an inverted N-shaped EKC concerning environmental quality indicators, which suggests that this relationship may have a multifaceted nature within the context of resource-rich economies. Additionally, Awan & Azam (2022) conducted a parallel investigation evaluating the potential applicability of the EKC hypothesis to veto-power countries within the G-20. Incorporating a wide range of variables that can influence environmental degradation, their analysis found evidence to support the existence of a N-shaped relationship.

It is important to note that there is not universal alignment among studies with the N-shaped EKC hypothesis. For instance, Gyamfi et al. (2021) examined the environmental implications of economic growth in the E7 countries. Their empirical findings, however, did not align with expectations in this case, and the presence of an N-shaped EKC in the emerging economies under consideration did not emerge as a confirmed result. Instead, they found that there is an inverted-U shaped relationship between the two variables. This suggests that the positive environmental effects of economic growth may diminish beyond a certain development threshold.

Özokcu & Özdemir (2017) provided further insights by challenging the conventional understanding of the EKC hypothesis. Their study, encompassing both high-income OECD countries and emerging economies, revealed N-shaped and inverted N-shaped relationships in environmental-economic dynamics, challenging the linear trajectory posited by the EKC hypothesis.

Huang et al. (2023) took an LCC focus and explored the load capacity curve hypothesis in India. This study shed light on how economic growth affects environmental capacity. It also revealed the complex interplay between the two, which is an area for continued study and discussion. It was found that the LCC had an N-shaped curve, which suggests that there are fluctuations in India's environmental capacity with economic development. Moreover, their analysis indicated the potential impact of energy consumption on environmental degradation. This suggests that sustainable energy policies might be a useful way to help mitigate some of the adverse environmental effects associated with economic growth.

It would be beneficial to consider a shift in perspective from the EKC hypothesis to the implications of energy sources. In an effort to gain a better understanding of the role that clean energy and energy security can play in leading emitter economies, where Deng et al. (2024) undertook a thorough investigation. Their analysis revealed that there is a significant positive impact when export diversification, green energy adoption, and energy security are present in an economy. This underscores the importance for top emitter economies to transition away from fossil fuels to cleaner and more secure energy sources in order to achieve sustainable environmental outcomes, even as the economy continues to grow. A country-specific analysis was conducted by Mahmood et al. (2021), whose investigated the N-shaped energy-environmental Kuznets Curve hypothesis in Saudi Arabia.

At long last, Hakkak et al. (2023) set out to investigate the potential relationship between nuclear and renewable energy use, ecological footprint and load capacity factor in the Russian Federation. They tested both the EKC and LCC hypotheses. Their findings indicated that renewable energy can offer significant environmental benefits in both the short term and the long term. They also suggest that nuclear energy could play a role in sustainable environmental management. This further reinforces the value in diversifying energy portfolios in order to mitigate the potential environmental impact associated with economic growth.

There is a certain degree of uncertainty surrounding the precise form that the N-shaped trajectory might take. Some studies do appear to confirm the presence of an N-shaped curve, but others challenge the conventional understanding of the curve, which highlights the need for more nuanced and diverse analyses that consider a number of different economic contexts and regional peculiarities. In addition, the broader trend revealed by studies on renewable energy consumption appears to indicate a notable reduction in environmental degradation. It can be reasonably inferred that the increased adoption and utilisation of renewable energy sources, such as solar, wind, and hydroelectric power, contribute to mitigating harmful environmental impacts typically associated with fossil fuel consumption. Apart from studies that focus on the N-shaped load capacity curve, numerous other studies have examined various aspects of the determinants of environmental degradation. One such study has been conducted by Akhter et al. (2024) examined the relationship between artificial intelligence (AI), financial globalization, and the load capacity factor (LCF) in the United States over the period from 1990 to 2019. Their findings revealed a significant positive correlation between private investments in AI and LCF, thereby enhancing environmental sustainability through optimized energy utilization and waste reduction. However, both technological innovation and financial globalization demonstrate a negative correlation with LCF in both the short and long term, likely due to increased industrial activities and heightened resource consumption. This suggests that while AI-driven advancements contribute positively to environmental sustainability, broader economic and technological globalization may counteract these benefits. Expanding on this line of thought, Bekun et al. (2024) explore the Environmental Kuznets Curve (EKC) hypothesis within the MINT economies, utilizing LCF as the analytical framework, thereby highlighting the inadequate current level of renewable energy consumption in these economies to effectively mitigate climate change challenges. While renewable energy adoption is on the rise, it has not yet reached a level sufficient to significantly counteract carbon emissions and environmental degradation. This finding is consistent with the conclusions of Akhter et al. (2024), which underscores the necessity for the refinement of renewable energy policies to mitigate the deleterious effects of industrial expansion and globalization on environmental sustainability.

In a similar vein, Özkan et al. (2023) examined the dynamic effects of financial development, energy efficiency, economic growth, and technological innovation on environmental degradation in India from 1980 to 2020 through the lens of LCF. Their findings indicate that financial development, economic growth, and technological innovation have a negative impact on LCF by fostering energy-intensive industries and increasing emissions, thereby exacerbating environmental degradation. In contrast, energy efficiency emerges as a pivotal factor in enhancing environmental quality by reducing overall energy consumption per unit of economic output. These conclusions are consistent with those of Bekun et al. (2024), which underscores the necessity for economic and technological advancements to be accompanied by stringent energy efficiency measures to ensure sustainable environmental outcomes. A significant aspect of the discourse on LCF pertains to the relationship between unemployment and environmental conditions, particularly within the framework of the Environmental Phillips Curve. Ayad and Djedaiet (2024) have examined this relationship across G7 nations from 1980 to 2021, employing LCF as a key metric. Their empirical findings validate the existence of both the Ecological Phillips Curve and the LCF hypothesis, revealing a negative correlation between unemployment rates and environmental degradation. This suggests that economic downturns, marked by reduced industrial activity, may temporarily alleviate environmental pressures. This interplay underscores the necessity for a balanced approach to economic policy and environmental stewardship.

In their study, Uche and Ngepah (2024) examined the impact of green technology, energy transition, and resource rents on LCF in South Africa. Their findings indicate that LCF significantly improves at certain quantiles following the transition to clean energy, thereby highlighting the effectiveness of sustainable energy policies in enhancing environmental quality. Furthermore, while resource rents exhibit a positive influence on LCF at the upper and middle quantiles, they prove ineffective at the lower quantile. This finding underscores the importance of equitable distribution of natural resource revenues for achieving widespread environmental benefits. A similar pattern is exhibited by economic growth, which enhances LCF at the upper and middle quantiles but diminishes at the highest quantiles. This finding implies diminishing returns to environmental sustainability at higher stages of economic development. These findings are consistent with those reported by Özkan et al. (2023) and Ayad and Djedaiet (2024), underscoring the intricate nature of economic-environmental interactions. Sun et al. (2024) expand on this global perspective by investigating the impact of environmental-related technologies, natural resources, and renewable energy on LCF across 17 APEC economies from 1990 to 2019. Their study reveals that economic growth has a negative effect on environmental quality due to increased emissions and resource exploitation. Conversely, advancements in environmental technologies and urbanization play a crucial role in mitigating these adverse effects, thereby supporting the argument that technological innovation must be strategically aligned with environmental sustainability initiatives.

A more exhaustive review was conducted by Pata et al., (2025), who undertook a worldwide analysis of the load capacity curve (LCC), emphasizing the role of FinTech and government effectiveness in addition to renewable energy across a total of 69 countries. Their findings indicate that the LCC hypothesis is applicable to middle-income countries, where the combination of FinTech, foreign direct investment (FDI), and renewable energy collectively fosters ecological progress. Furthermore, the findings underscore the pivotal role of government effectiveness in mitigating the load capacity factor, thereby underscoring the imperative for the formulation of robust policy frameworks to bolster environmental sustainability. The extant body of literature signifies an augmentation in research endeavors concentrating on the determinants of LCF, with a preponderance of studies anchored on the EKC hypothesis. Nevertheless, a conspicuous lacuna persists with respect to the potentiality of an N-shaped LCF hypothesis, particularly within the context of Türkiye. Addressing this gap, the present study aims to explore the validity of the N-shaped LCF hypothesis, thereby contributing to the broader discourse on environmental sustainability and economic development. This investigation offers a more nuanced understanding of LCF dynamics in emerging economies, providing valuable insights for policymakers and researchers alike.

3. METHOD

The aim of this study is to explore whether there is a presence of N-shaped or inverted N-shaped LCC hypotheses, as well as to examine the impact of renewable energy consumption on the load capacity factor in Türkiye from 1965 to 2022. The model utilized in this research is delineated as follows:

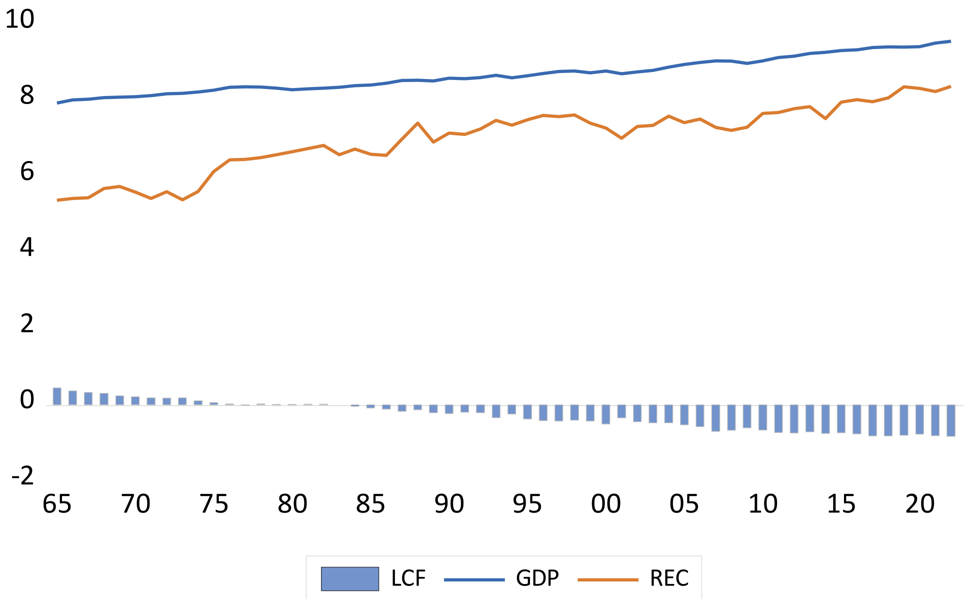
$$LCF = f(\ln GDPC, \ln GDPC^2, \ln GDPC^3, \ln REC) \quad (1)$$

In Eq. 1, GDPC represents the gross domestic product per capita, $GDPC^2$ symbolizes the quadratic term of GDPC, $GDPC^3$ denotes the cubic term of GDPC, and REC denotes renewable energy consumption. The load capacity factor (LCF) serves as the focal variable of interest in this context. By integrating GDPC in its primary, squared, and cubic manifestations, the model accounts for potential nonlinear associations between economic prosperity and LCF. Furthermore, the inclusion of REC enables the examination of the potential influence of renewable energy consumption on LCF. Thus, this model provides a structured framework for investigating and interpreting the intricate relationships among these variables in elucidating LCF dynamics.

The study makes use of three primary sources of data for its analysis. GDP per capita, obtained from the World Bank database, is presented in constant 2015 US$. Renewable energy consumption per capita (kWh equivalent) comes from Our World in Data, while ecological footprint and biocapacity data, provided by the Global Footprint Network, are used to calculate the load capacity factor. In order to ensure the greatest analytical rigor, all variables have been natural log transformed.

Figure 1 offers an historical overview of the variables analyzed in this study for the case of Türkiye from 1965 up to and including 2022. The data appears to suggest that both GDP per capita and renewable energy consumption have demonstrated a consistent upward trend over the observed period, which could be reflective of economic growth and an increasing shift towards renewable energy sources. It is also worth noting that while there has been economic growth and greater use of renewable energy, there has also been a downward trend in load capacity factor.

Figure 1: The Trends of Variables



Furthermore, Table 1 presents the descriptive statistics of the variables that have been subjected to analysis. The table presents a series of descriptive statistics for three variables: Load Capacity Factor (LCF), GDP per capita (GDP), and Renewable Energy Consumption per capita (REC), based on 58 observations. The findings of the analysis demonstrate that, on average, LCF is negative, indicative of a decline over time. In contrast, GDP and REC exhibit growth trends. The data ranges demonstrate a notable degree of variation in all three variables. With regard to GDP and REC, it can be observed that they exhibit a general upward trend, which suggests a process of economic development and a shift towards renewable energy in Türkiye. Furthermore, the dispersion observed in the data, as indicated by the standard deviations, indicates a moderate spread around the mean values. Additionally, Jarque-Bera test statistics for variables indicate that these series fail to reject the null hypothesis, indicating that data are normally distributed.

Table 1: Descriptive Statistics of Variables

	LCF	**GDP**	**REC**
Mean	-0.285	8.675	7.003
Median	-0.290	8.623	7.257
Maximum	0.444	9.550	8.366
Minimum	-0.831	7.928	5.373
Std. Dev.	0.370	0.442	0.851
Skewness	0.107	0.312	-0.518
Kurtosis	1.809	2.040	2.334
Jarque-Bera	3.538	3.165	3.673
Probability	0.170	0.205	0.159
Observations	58	58	58

Moreover, this study employs the Autoregressive Distributed Lag (ARDL) methodology, which is renowned for its adaptability in accommodating both stationary and non-stationary variables during estimation, a significant advantage over traditional approaches. By integrating such variables into the analysis, ARDL enables a more sophisticated comprehension of the relationships under investigation. In contrast to numerous conventional methods, ARDL permits the analysis of both short-term dynamics and long-term trends, thereby providing a comprehensive understanding of variable behaviour over time. Furthermore, in order to investigate potential long-term interrelations between the variables in question, the study employs the cointegration test, as developed by Pesaran et al. (2001). This is a widely accepted approach in econometric analysis.

Within Eq 2, the θ parameter represents the coefficients delineating long-term effects, while ϕ embodies the coefficients reflecting short-term impacts. Furthermore, the presence of β_0 denotes the intercept, representing the constant term intrinsic to the equation.

$$\triangle \ln\text{LCF}= \beta_0 + \sum_{i=1}^{m} \theta_1 \Delta\ln\text{LCF}_{t-i} + \sum_{i=0}^{m} \theta_2 \triangle \ln\text{GDPC}_{t-i} + \sum_{t=0}^{m} \theta_3 \triangle \ln\text{GDPC}^2_{t-t} + \sum_{t=0}^{m} \theta_4 \triangle \ln\text{GDPC}^3_{t-t} + \sum_{t=0}^{m} \theta_5 \triangle \ln REC + \phi_1 \text{EA}_{t-1} + \phi_2 \ln\text{GDPC}_{t-1} + \phi_{3\ln}\ln\text{GDPC}^2_{t-1} + \phi_4 \ln\text{GDPC}^3_{t-1} + \phi_5 \ln REC + \varepsilon_t \quad (2)$$

$$\triangle \ln LCF = \omega_0 + \sum_{i=1}^{m} \omega_1 \triangle \ln LCF_{t-i} + \sum_{i=0}^{m} \omega_2 \triangle \ln\text{GDPC}_{t-1} + \sum_{i=0}^{m} \omega_3 \triangle \ln\text{GDPC}^2_{t-i} + \sum_{i=0}^{m} \omega_4 \triangle \ln\text{GDPC}^3_{t-i} + \sum_{i=0}^{m} \omega_5 \triangle \ln REC + \varphi ECM_{t-1} + \varepsilon_t \quad (3)$$

Moreover, the error correction model, as presented by Eq 3, includes the constant term denoted by ω_0 and the error correction term ECM.

In addition, the study employs a variety of diagnostic tests to guarantee the model's reliability and the soundness of its results, thus enhancing the validity and credibility of its findings. Collectively, these diagnostic evaluations serve to examine various aspects of the model's performance, including its specifications, serial correlation, heteroscedasticity, and normality of residuals. This approach serves to fortify the methodological integrity of the study.

4. RESULTS

This section presents the practical implementation of the econometric estimations outlined in the previous part. The paper commences with an examination of a pivotal preliminary stage, namely, the determination of the stationarity levels of the variables. This is a crucial step in selecting the appropriate econometric method. In order to achieve this, the augmented Dickey-Fuller (ADF) , Phillips-Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests were employed, with the resulting insights providing information about the stationarity status of each variable. The findings, shown in Table 2, illustrate the behavior of the variables. Moreover, the investigation has revealed that while the Load Capacity Factor (LCF) variable exhibits stationarity at its original level, the remaining variables appear to be non-stationary in their present form. Nevertheless, after the application of the first-differencing technique, all the variables exhibited the desired properties of stationarity. This process ensures the integrity and reliability of subsequent econometric analysis, thus providing a robust foundation for estimation procedures conducted in this study.

Table 2: Unit Root Tests

Variables	**ADF Test**		**PP Test**		**KPSS**	
	Level	***First Difference***	***Level***	***First Difference***	***Level***	***First Difference***
LCF	-4.7775***	-7.800***	-4.724***	-12.073***	0.0835	0.0746
GDP	-1.650	-7.453***	-1.650	-7.559***	0.2135**	0.0729
REC	-2.784	-8.450***	-2.784	-9.195***	0.1789**	0.0838

In order to examine the unit root properties in the presence of structural breaks, in addition to the unit root tests discussed above, the Zivot-Andrews structural break unit root test was also carried out. The results of this test are consistent with the results presented in Table 1, indicating that the series exhibit both I(0) and I(1) integration.

Table 3: Zivot-Andrews Structural Break Unit Root Test

Variables	***Level***	***Break Date***	***First Difference***	***Break Date***	***I(d)***
LCF	-5.957***	2007	-8.282***	1984	I(0)
GDP	-4.501	1999	-7.689***	1977	I(1)
REC	-4.743*	1975	-8.737***	1977	I(1)

The cointegration relationship is established using the bound test method proposed by (Pesaran et al., 2001) and presented in table 3. With a test statistic value of 7.520, surpassing the critical values at both the I(0) and I(1) levels of significance at the 1% threshold, the presence of cointegration is confirmed based on the bound test results. This outcome underscores the long-term equilibrium relationship among the variables under examination, signifying their interdependence and the presence of stable, systematic patterns in their dynamics. Thus, the bound test offers robust evidence supporting the existence of cointegration, bolstering the reliability and validity of the study's findings.

Table 3: Bound Test

F-Bounds Test

Test Statistic	Value	Signif.	I(0)	I(1)
		Asymptotic: n=1000		
F-statistic	7.520	10%	2.2	3.09
k	4	5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37

Additionally, the long-run and short-run results are presented in Table 4, revealing insightful dynamics between economic growth and the Load Capacity Factor (LCF). The analysis suggests a non-linear relationship, characterized by an N-shaped pattern, between these variables, thereby supporting the N-shaped LCC hypothesis based on ARDL results. Specifically, a 1 percent increase in GDP per capita (GDPC) is found to enhance LCF by 62.88 percent, while the square of GDPC contributes to a 7.6 percent decrease in LCF. Furthermore, the cubic form of GDPC shows a slight increase of 0.3 percent. Despite variations in coefficients between short-run and long-run results, the consistent sign of these coefficients indicates a stable relationship. The findings suggest that while economic growth initially leads to increased environmental pollution, subsequent stages of growth may mitigate this impact. However, caution is warranted in interpreting these results, as the cubic form of GDPC implies a subsequent phase of increased environmental degradation. Therefore, it would be premature to conclude that economic growth inherently leads to reduced environmental degradation in the long run, given its potential adverse effects in subsequent phases.

Table 4: ARDL Long and Short run Results

Long-Run Results

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
GDPC	62.886	21.405	2.937	0.005
$GDPC^2$	-7.600	2.426	-3.132	0.003
$GDPC^3$	0.301	0.091	3.287	0.001
REC	0.001	0.024	0.063	0.949
C	-170.600	62.844	-2.714	0.009

Short Run Results

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
GDPC	0.321	0.085	3.761	0.000
$GDPC^2$	-6.027	2.070	-2.911	0.005
$GDPC^3$	0.238	0.078	3.028	0.004

REC	0.047	0.020	2.367	0.022
ECM	-0.793	0.112	-7.065	0.000

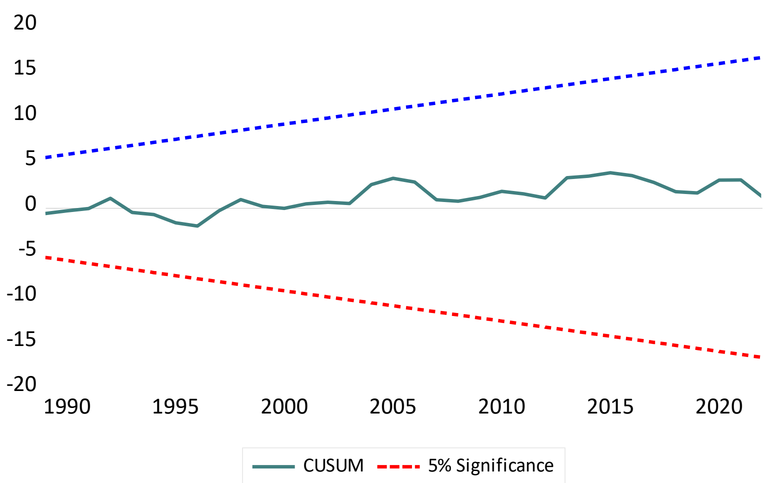
Another crucial finding from the results is that renewable energy consumption demonstrates significance only in the short run, lacking significance in the long run within the context of Türkiye . This observation highlights an important distinction in the temporal impact of renewable energy consumption on environmental degradation. Specifically, the increase in renewable energy consumption is found to have a significant and beneficial effect on reducing environmental degradation in the short run, aligning with expectations and contributing to environmental well-being in Türkiye . However, the absence of significance in the long run suggests that while renewable energy may offer immediate environmental benefits, its sustained impact on mitigating environmental degradation over extended periods remains uncertain. This underscores the need for continuous evaluation and strategic planning in promoting renewable energy adoption to ensure long-term environmental sustainability and resilience in Türkiye .

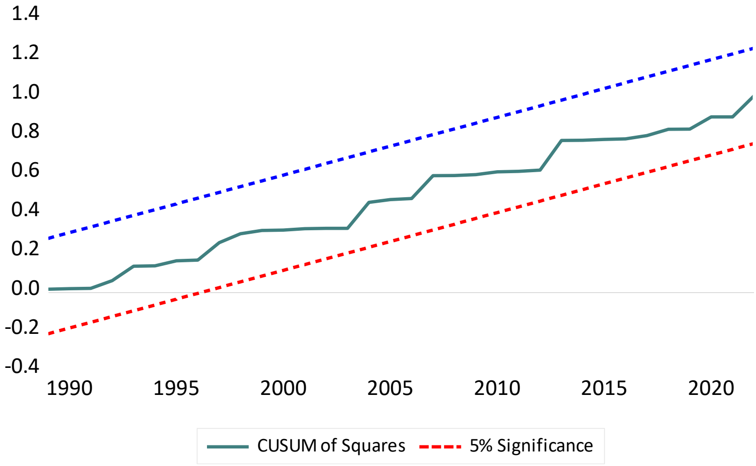
Table 5: Diagnostic Test Results

Diagnostic Test	**Statistics**	**Prob.**
Ramsey RESET Test	0.943	0.336
Breusch-Godfrey Serial Correlation LM Test	1.865	0.166
Breusch-Pagan-Godfrey Heteroskedasticity Test	0.543	0.817
White Heteroskedasticity Test	0.453	0.979
Jarque-Bera	1.122	0.570

Moreover, Table 5 presents the diagnostic test outcomes aimed at scrutinizing the robustness and reliability of both the model and the dataset. The results of these diagnostic tests confirm the adequacy of the model and the integrity of the data

Figure 2: CUSUM and CUSUMSQ





The subsequent phase of the estimation process involves verifying the robustness and reliability of the estimation results. To this end, diagnostic tests are conducted, all of which consistently affirm the reliability and robustness of the estimation outcomes. Furthermore, visual representations of Cusum and Cusumsq test results are provided in Figure 2. The interpretation of these figures indicates that the Cusum and Cusumsq tests illustrate the stability of the model established in this paper over time. This visualization serves as compelling evidence supporting the model's consistency and reliability, affirming its suitability for analyzing the relationship between variables in the context of the study. Overall, these diagnostic tests and visual presentations reinforce the credibility and validity of the estimation results, enhancing confidence in the findings and conclusions drawn in this research.

5. CONCLUSION

Historically, the Earth has been viewed as a fundamental resource for economic production and development, with the recognition that human existence is inherently tied to the planet's sustenance, this perspective has prompted a profound interrogation into the nexus between environmental considerations and economic advancement. Consequently, there has been a concerted effort to scrutinize the implications of economic growth on the environment, reflecting a recognition of the indispensable interdependence between human prosperity and ecological integrity.

This inquiry, commonly explored through the lens of the Environmental Kuznets Curve (EKC) hypothesis, has evolved over time, transitioning from proxies like CO2 emissions to more comprehensive measures such as ecological footprint and, most recently, Load Capacity Factor (LCF). While the N-shaped EKC hypothesis remains a fundamental focus in the literature, this research introduces a novel approach by using LCF to measure environmental degradation and investigate the N-shaped LCC in Türkiye , spanning a significant period from 1965 to 2022.

The findings reveal an N-shaped relationship between LCF and economic growth, indicating a pattern where economic growth initially rises, declines after reaching a certain threshold, and then increases environmental degradation in its later phases. This highlights the complexity of the relationship, as economic growth may appear to decrease environmental degradation during a middle phase, potentially misleading policymakers. Consequently, the study suggests that Türkiye 's economic growth trajectory is not environmentally friendly and advocates for a shift towards more sustainable approaches.

The results align with the findings of Shehzad et al. (2022), Fakher et al. (2023), Awan and Azam (2022), Özokcu and Özdemir (2017), and Huang et al. (2023), confirming the existence of an N-shaped load capacity curve. This study further validates this relationship in the context of Türkiye .

The study highlights the significance of renewable energy consumption, particularly in the short term, in mitigating environmental degradation. As anticipated, the adoption of renewable energy, replacing non-renewable sources, contributes to reducing environmental pressures. As highlighted in previous studies, increasing the share of renewable energy is essential for achieving more environmentally sustainable energy consumption. This study supports this notion, consistent with the findings of Bekun et al. (2024), Uche and Ngepah (2024), Özkan et al. (2023), Ayad and Djedaiet (2024), Pata et al. (2025), and Deng et al. (2024). However, in the case of Türkiye, renewable energy has a significant impact on load capacity only in the short term. In contrast, other studies, such as Hakkak et al. (2023) on Russia, suggest that renewable energy can influence load capacity in both the short and long term.

Ultimately, the study underscores the challenges faced by many developing and emerging economies, where non-renewable energy usage and environmentally unfriendly production processes often prevail due to their accessibility and cost-effectiveness. Addressing these challenges requires a concerted effort towards embracing sustainable practices and policies that prioritize environmental conservation alongside economic growth. By highlighting the complex and dynamic relationship between economic growth and environmental degradation, this paper has important implications for policymakers. This relationship evolves through different stages of economic development, rather than following a simple linear pattern. Incomplete or misleading conclusions, and potentially ineffective policy decisions, can result from focusing solely on one or two stages of this progression. In order to ensure sustainable development, policy makers should adopt strategies that are in balance between economic expansion and environmental protection. This requires a comprehensive approach that integrates environmental considerations into economic planning. In addition, to mitigate environmental degradation while maintaining economic growth, the effective use of renewable energy sources is critical. Priority should be given to investing in clean energy infrastructure, improving energy efficiency, and promoting policy measures.

DECLARATIONS

FUNDING / SUPPORT INFORMATION

No financial support was received.

CONTRIBUTIONS OF AUTHORS

The entire study was conducted by a single author. The author was responsible for conceptualization, data collection, analysis, writing, and editing of the manuscript.

CONFLICT OF INTEREST

The author declare that there is no conflict of interest.

DATA AVAILABILITY

The data are publicly available.

ETHICAL STATEMENT

This study does not involve research with human or animal participants; therefore, ethical approval was not required.

ARTIFICIAL INTELLIGENCE (AI) USAGE STATEMENT

No AI-based tools were used in this study.

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