Van Yüzüncü Yıl Üniversitesi Sosyal Bilimler Enstitüsü Dergisi
Van Yüzüncü Yıl University The Journal of Social Sciences Institute
e-ISSN: 2822 - 3136
Yıl / Year: 2024 - Sayı / Issue: 65

The Role of Renewable Energy, Technological Innovation, and Human Capital on Environmental Quality in Türkiye: Testing the LCC Hypothesis with Smooth Structural Shifts

Yenilenebilir Enerji, Teknolojik Yenilik ve Beşeri Sermayenin Türkiye'nin Çevre Kalitesi Üzerindeki Rolü: LCC Hipotezinin Yumuşak Yapısal Kırılmalarla Test Edilmesi

Muhammet DAŞTAN
Asst. Prof., Ondokuz Mayıs University, Department of Economics, Samsun, Türkiye
Dr. Öğretim Üyesi, Ondokuz Mayıs Üniversitesi, İİBF, İktisat Bölümü, Samsun, Türkiye
Orcid: 0000-0001-6067-8946 , e-posta: muhammet.dastan@omu.edu.tr

Article Information/Makale Bilgisi

Cite as/Atıf: Daştan, M. (2024). The Role of Renewable Energy, Technological Innovation, and Human Capital on Environmental Quality in Türkiye: Testing the LCC Hypothesis with Smooth Structural Shifts. *Van Yüzüncü Yıl University the Journal of Social Sciences Institute,* 65, 76-91.
Daştan, M. (2024).Yenilenebilir Enerji, Teknolojik Yenilik ve Beşeri Sermayenin Türkiye'nin Çevre Kalitesi Üzerindeki Rolü: LCC Hipotezinin Yumuşak Yapısal Kırılmalarla Test Edilmesi. Van Yüzüncü Yıl Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 65, 76-91.

Article Types / Makale Türü: Research Article/Araştırma Makalesi
Received/Geliş Tarihi: 07 May /Mayıs 2024
Accepted/Kabul Tarihi: 19 July /Temmuz 2024
Published/Yayın Tarihi: 30 September/Eylül 2024
Pub Date Season/Yayın Sezonu: September/Eylül
Issue/Sayı: 65 **Pages/Sayfa:** 76-91.

Plagiarism/İntihal: This article has been reviewed by at least two referees and scanned via a plagiarism software./ Bu makale, en az iki hakem tarafından incelendi ve intihal içermediği teyit edildi.
Published by/Yayıncı: Van Yüzüncü Yıl University of Social Sciences Institute/Van Yüzüncü Yıl Üniversitesi Sosyal Bilimler Enstitüsü
Ethical Statement/Etik Beyan: It is declared that scientific and ethical principles have been followed while carrying out and writing this study and that all the sources used have been properly cited/ Bu çalışmanın hazırlanma sürecinde bilimsel ve etik ilkelere uyulduğu ve yararlanılan tüm çalışmaların kaynakçada belirtildiği beyan olunur (Muhammet DAŞTAN).

Abstract

Newly industrializing economies are ardently striving for rapid development, aspiring to emulate the affluence of Western nations. However, amidst this relentless economic dynamism, the world grapples with an escalating climate change crisis. Therefore, it becomes imperative to identify the factors contributing to improving developing nations' environmental quality while concurrently advancing their sustainable development objectives. In this regard, the present study aims to dissect the environmental implications of renewable energy consumption, technological innovation, and human capital and examine the "Load Capacity Curve" (LCC) hypothesis in Türkiye through an extension of the STIRPAT model. To achieve this objective, the research operates a novel econometric methodology, namely the "augmented autoregressive distributed lag" (A-ARDL) approach with Fourier terms, to analyze yearly data from 1980 to 2019. The empirical findings substantiate the validation of the LCC hypothesis in Türkiye, both in the short and long term. Furthermore, the results unveil that renewable energy consumption and human capital significantly bolster ecological welfare over the long term, whereas technological innovation exhibits no discernible impact on the environment. Additionally, the outcomes display that population growth positively impacts the environment in the short term; nevertheless, over the long term, it becomes detrimental to environmental quality.

Keywords

Renewable energy, Technological innovation, Human capital, STIRPAT model, LCC hypothesis

Öz

Yeni sanayileşen ekonomiler, batılı ulusların refah düzeyini yakalama arzusuyla hızlı bir kalkınma çabası içindedir. Ancak, bu güçlü ekonomik dinamizmin ortasında, dünya giderek derinleşen bir iklim değişikliği kriziyle yüzleşmektedir. Bu bakımdan, gelişmekte olan ülkelerin sürdürülebilir kalkınma hedeflerini desteklerken aynı zamanda çevresel kalitelerini artırmalarına katkıda bulunan faktörlerin belirlenmesi zorunlu hale gelmektedir. Bu noktadan hareketle bu çalışma, STIRPAT modelini genişleterek Türkiye'de yenilenebilir enerji tüketimi, teknolojik yenilik ve beşeri sermayenin çevresel etkilerini incelemeyi ve "Yük Kapasite Eğrisi" (YKE) hipotezinin geçerliliğini test etmeyi amaçlamaktadır. Bu amaçla çalışmada, 1980'den 2019'a uzanan yıllık veriler literatüre henüz yeni kazandırılan Fourier terimli "genişletilmiş gecikmesi dağıtılmış otoregresif" (A-ARDL) yaklaşımı kullanılarak analiz edilmektedir. Ampirik bulgular, LCC hipotezinin Türkiye'de hem kısa hem de uzun dönemde geçerli olduğunu kanıtlamaktadır. Ayrıca sonuçlar, yenilenebilir enerji tüketimi ve beşeri sermayenin uzun vadede çevresel kaliteyi önemli ölçüde artırdığını, teknolojik inovasyonun ise çevre üzerinde istatistiki açıdan anlamlı bir etkisinin olmadığını ortaya koymaktadır. Bununla birlikte, bulgular nüfus artışının kısa vadede çevre üzerinde olumlu bir etkiye sahip olduğunu, ancak uzun vadede çevresel kaliteyi düşürdüğünü göstermektedir.

Anahtar Kelimeler

Yenilenebilir enerji, teknolojik inovasyon, beşeri sermaye, STIRPAT model, LCC hipotezi

Introduction

In the wake of the Industrial Revolution, a pivotal epoch that fundamentally redefined the economic structure of Western nations, global economies have set sail on an unyielding quest for rapid economic growth. However, amidst this fervent economic dynamism, the globe has been confronted with the crisis of anthropogenic climate change. According to NOAA (2023), since the advent of the industrial era in the 18th century, human endeavors have escalated atmospheric carbon dioxide (CO2) levels by 50%, indicating that the quantity of CO_2 in 2023 stands at 150% of its magnitude in 1750. This anthropogenically-induced escalation exceeds the natural augmentation witnessed at the culmination of the previous ice age some 20,000 years ago (NASA, 2024). Moreover, a persistent ascent in global temperatures has been observed since the mid-1800s, marked by an average uptick of 0.06 degrees Celsius per decade (Lindsey and Dahlman, 2024), accompanied by a rise in sea levels ranging between 8 and 9 inches (Lindsey, 2022). The intensifying global warming, primarily propelled by fossil fuel consumption in economic activity, amplifies the incidence of heat-related ailments, exacerbates extreme rainfall and flooding, worsens water scarcity in already stressed regions and heightens the likelihood of agricultural droughts impacting crops. Furthermore, it contributes to ecological droughts, heightening the vulnerability of ecosystems, and poses existential threats to terrestrial and marine species alike (Mishra, 2019; Shahgedanova, 2021; Williamson and Guinder, 2021; EPA, 2023; United Nations, 2024).

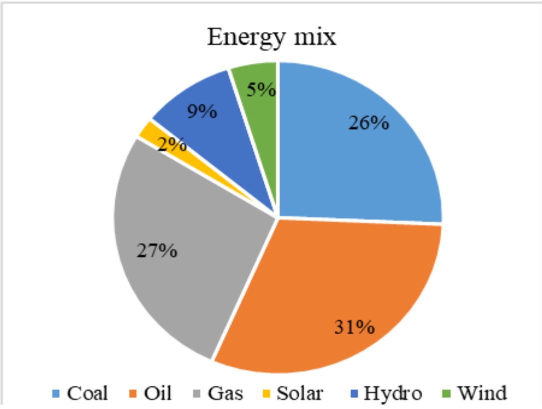
In this milieu, a pressing question emerges: How can newly industrialized countries like Türkiye reconcile the urgency of addressing the climate crisis and its profound ramifications while simultaneously sustaining vigorous growth rates? In the realm of environmental economics studies, the predominant response to this inquiry often revolves around the adoption of cleaner energy sources (Dincer, 2001; Menyah and Wolde-Rufael, 2010). Accordingly, governments across the globe, in alignment with the United Nations, are placing considerable faith in renewable energy (REN) as a pivotal technology for tackling energy-related environmental challenges while fostering sustainable development (Gross et al., 2003). Indeed, United Nation's seventh "Sustainable Development Goal" (SDG-7), titled "Affordable and Clean Energy: Ensure access to affordable, reliable, sustainable and modern energy for all," explicitly targets the promotion of REN development to cope with the multifaceted issues of climate change and advance global sustainable development initiatives (United Nations, 2024). REN presents myriad economic, environmental, and social benefits. Firstly, it derives from inexhaustible, naturally replenishing sources such as the sun, tides, and wind. Secondly, REN sources exhibit cleaner profiles compared to conventional fossil fuels, emitting fewer greenhouse gases over their life cycles (Cheng et al., 2019). Thirdly, by diminishing reliance on imported conventional energy sources (Carfora et al., 2022), REN can enrich energy security and mitigate the price volatility associated with oil imports (Menyah and Wolde-Rufael, (2010). Fourthly, REN technologies engender a stimulative effect on employment by propelling the emergence of new business ventures and bolstering production efficiency (Markandya et al., 2014; Daştan, 2024). Finally, many REN sources are readily accessible to remote, coastal, or isolated communities (U.S. Department of Energy, 2024).

While transitioning from conventional energy to sustainable alternatives offers a promising resolution to environmental issues, the extent to which REN is utilized within the broader energy consumption landscape remains below ideal in many developing countries, including Türkiye. This shortfall can be attributed to a multitude of facets, including entrenched reliance on fossil fuels, prohibitive costs associated with REN infrastructure, insufficient knowledge and technological capabilities, and regulatory hurdles (Shabani, 2024). In this regard, progress in human capital (HCA) and technological innovation (TEI) can exert considerable influence in surmounting the barriers to both the generation and usage of green energy, thereby resulting in a tangible drop in environmental pollution (Tang and Tan, 2013; Zafar et al., 2019; Cheng et al., 2021). As posited by Shabani (2024), proficient or highly educated labor forces are instrumental in driving down costs, fostering technological progress, and spearheading the development of REN solutions. This ultimately improves the availability and affordability of clean energy sources. Furthermore, TEI holds the potential to expedite the adoption of REN to fulfill energy requirements and reshape the energy consumption landscape (Chen and Lei, 2018). Similarly, Alvarado et al. (2021) asserted that employing knowledge and utilizing sophisticated human resources like technology and innovation holds promise in reducing fossil fuel usage. This potential can expedite the transition toward sustainable development, as highlighted by Tang and Tan (2013).

Against this backdrop, the present investigation endeavors to analyze the environmental repercussions of REN consumption (REC), HCA, and TEI in a newly industrialized nation, Türkiye, spanning the years from 1980 to 2019. Since the early 1980s, the country has sustained an average per capita GDP growth rate of 4.8 percent and a population (POP) growth rate of around 1.6 percent (World Bank, 2024). This substantial and rapid expansion in both the economy and POP has not only pushed robust growth in energy demand but has also increased import dependence. According to the Ministry of Foreign Affairs of the Republic of Türkiye (2024), among OECD countries, Türkiye has experienced the most rapid increase in energy demand over the past two decades. During this period, Türkiye ranked second globally, following China, in terms of growth in electricity and natural gas demand. However, the country remains highly dependent on imports, meeting 74% of its energy needs through external sources. Consequently, Türkiye has sought to reshape its energy strategy to manage energy demand growth, lessen energy costs, and mitigate the acceleration of import reliance. These reforms have encompassed initiatives aimed at modernization, liberalization, and the augmentation of domestic production capacity. Significantly, Türkiye has substantially diversified its energy portfolio over the last decade. Renewable electricity generation has tripled during this period, and the establishment of Türkiye's inaugural nuclear power facility is poised to further diversify the nation's energy sources (IEA, 2021). However, fossil fuels remain the backbone of Türkiye's economy, with a pronounced reliance on imports, particularly of oil and gas (see Figure 1, Panel A). Concurrently, Türkiye's per capita carbon emissions from fossil sources and industry have risen from approximately 1.2 tons to 5.1 tons since the 1980s (see Figure 1, Panel B). In addition, Türkiye has made commendable efforts to advance HCA development and foster TEI. As per the "Penn World Table" devised by Feenstra et al. (2015), Türkiye's HCA index, gauged by years of schooling and education returns, has nearly doubled since 1980 (see Figure 1, Panel C). Moreover, the count of patent applications, often indicative of technological advancement in academic literature, has increased by over 1000 percent, rising from 661 to 8,476, based on World Bank statistics (see Figure 1, Panel D). It is also worth noting that Türkiye acceded to the "Kyoto Protocol" in 2009 and signed the "Paris Agreement" in 2016. Subsequently, in 2021, the nation ratified the Paris Agreement with the vision of moving towards net-zero emission target by 2050 and committing to reducing global emissions by a minimum of 50% by 2030 (Daştan and Eygü, 2023). In parallel with these developments, Türkiye initiated a comprehensive array of green economy initiatives within the same timeframe. These initiatives were strategically designed to bolster the adoption of REN sources, enhance energy efficiency practices, and optimize resource allocation, all within the framework of aligning with the objectives outlined in the "European Green Deal" (Küçük and Yüce-Dural, 2024).

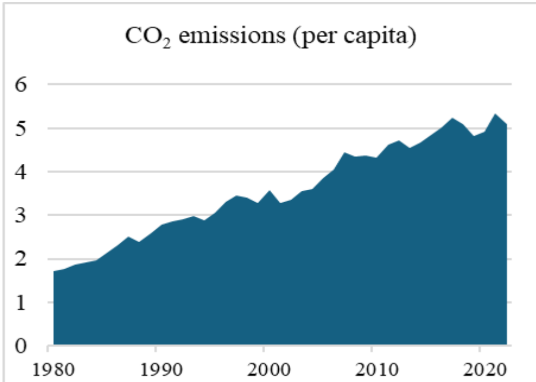
Figure 1.

Energy mix, CO_2 emissions, technological innovation, and human capital in Türkiye



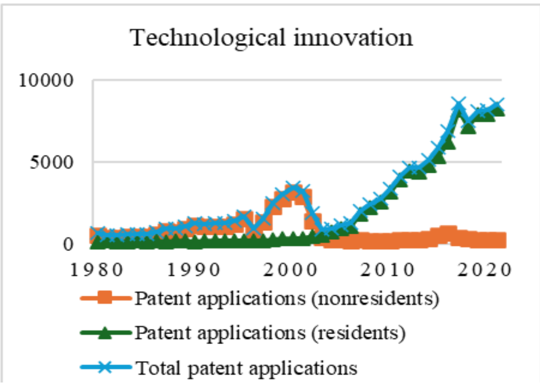
Panel-A

Source (*Our World in Data, 2023a*)



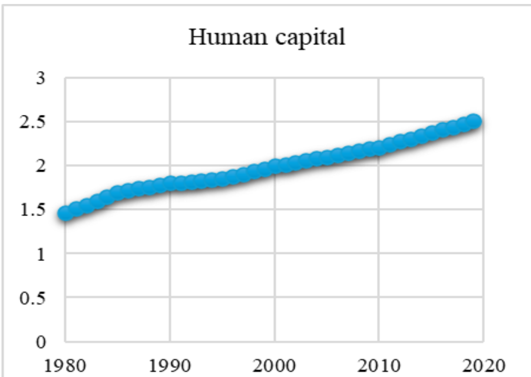
Panel-B

Source (*Our World in Data, 2023b*)



Panel-C

Source (World Bank, 2024)



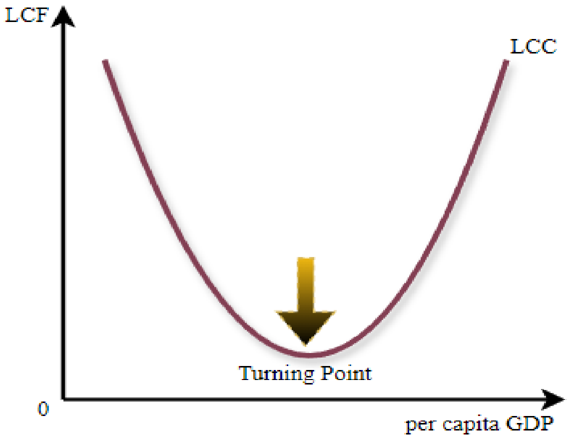
Panel-D

Source (Feenstra et al., 2015)

From a theoretical standpoint, the interplay between GDP growth and environmental quality (EQ) is frequently scrutinized through the lens of the "Environmental Kuznets Curve" (EKC). Within this analytical framework, the majority of empirical studies utilize "CO_2 emissions" and "ecological footprint" as primary environmental indicators. Although these metrics provide insight into the scale of human-induced environmental degradation, they fall short of comprehensively recognizing nature's resilience to such degradation. Indeed, while "CO_2 emissions" are confined to evaluating atmospheric pollution, the "ecological footprint" serves as a mechanism for monitoring the environmental influences of human activity. Thus, these indices overlook the inherent regenerative capacity intrinsic to natural ecosystems (Guloglu et al., 2023). To bridge this disparity, Siche et al. (2010) put forth the notion of the "load capacity factor" (LCF), which quantifies the ratio of "biocapacity" to "ecological footprint." By encompassing both the supply ("biocapacity") and demand ("ecological footprint") dimensions of the ecological system, the LCF emerges as the prevailing indicator of EQ within contemporary scholarly discourse. Employing the LCF as an environmental gauge, Dogan and Pata (2022) introduced the concept of the "load capacity curve" (LCC), presenting an inverted counterpart to the EKC. The "LCC hypothesis" posits that in the nascent stages of economic expansion, EQ undergoes a notable decline due to the predominance of fossil fuel-driven economic activities. However, upon reaching a certain threshold of prosperity, economic endeavors transition towards clean energy sources and witness a surge in demand for eco-friendly products. Subsequent to this pivotal transition, the "ecological footprint" diminishes while "biocapacity" experiences a parallel increase, mirroring the trajectory of per capita income growth (Caglar et al., 2024a). This "U-shaped" correlation between economic progression and LCF, depicted in Figure 2, epitomizes the "LCC hypothesis."

Figure 2.

Load Capacity Curve Hypothesis



The present investigation adds to the extant literature in several aspects. Firstly, the research probes the environmental ramifications of REC, TEI, and HCA in Türkiye by expanding the STIRPAT model. Secondly, it utilizes LCF as a metric of EQ, which offers a complete assessment of ecosystem compared to "CO_2 emissions" and "ecological footprint", as it encompasses both the supply and demand extents of the nature. Thirdly, it evaluates the validity of the "LCC hypothesis" and employs an innovative econometric methodology, the "augmented autoregressive distributed lag" (A-ARDL) approach, using Fourier terms. Therefore, the research constructs a second-order model incorporating per capita GDP and its square and controls for smooth changes to ensure more reliable results. Lastly, the research presents practical policy recommendations tailored specifically to the context of Türkiye.

The succeeding sections of the paper unfold as follows: Section I delves into the literature review, delineating the gaps in existing research and underscoring the significance of this paper. Section II exemplifies the data and model. Section III outlines the econometric procedure, and presents the empirical findings, while Section IV concludes by highlighting policy recommendations.

1. Literature Review

Following the investigation of Grossman and Krueger (1991), a plethora of research has delved into the environmental ramifications of diverse variables, with particular emphasis on economic growth, as factors influencing EQ under the scope of the "EKC hypothesis." Exploring the interplay between the REC, TEI, HC, and EQ, numerous studies have utilized "CO_2 emissions" and "ecological footprint" as proxies for assessing environmental deterioration (i.e., Bilgili et al., 2016; Solarin et al., 2017; Koc and Bulus, 2020; Pata and Caglar, 2021; Ozbek and Naimoglu, 2022; Yang et al., 2022). Nonetheless, building on the work of Pata (2021), recent research endeavors have started to investigate the driving factors of the LCF (Pata and Isik, 2021; Abdulmagid Basheer Agila et al., 2022; Liu et al., 2022; Caglar et al., 2023a, Yang et al., 2023a; Guloglu et al., 2023; Awosusi et al., 2023; Sun et al., 2024). Regarding the role of GDP growth on the environment, studies have produced divergent findings contingent upon geographical regions, nations, time periods, and econometric methodologies. For instance, some authors find that economic prosperity can result in environmentally favorable outcomes, confirming the accuracy of "LCC hypothesis" (Dogan and Pata., 2022; Wang et al., 2024; Caglar et al., 2024a,b; Sun et al., 2024; Aydin and Degirmenci, 2023; Erdogan, 2023; Moussaid et al., 2023; Fang et al., 2024, Dai et al., 2024), others posit that the environmental degradation effect of economic growth may remain persistent over the long term (Pata and Tanriover, 2023; Alola et al., 2023; Deng et al., 2024; Shahzad et al., 2024; Caglar et al., 2024c).

Regarding the impact of REC on LCF, numerous investigations evince a positive link between the two variables (Guloglu et al., 2023; Yang et al., 2023b; Khan et al., 2023; Hakkak et al., 2023; Dai et al., 2024). For instance, Guloglu et al. (2023) scrutinized the impact of REC on LCF across 26 OECD countries spanning the years 1980 to 2018, employing the QMG estimator. Their analysis revealed a notable enhancement in the LCF attributable to REC. Similarly, Khan et al. (2023) explored the environmental ramifications of REC in the G7 and E7 nations, drawing upon data spanning the years 1997 to 2018. Findings from regression analysis underscored that the incorporation of renewable energy into energy infrastructures holds promise for bolstering EQ by elevating the LCF. Utilizing the ARDL model, Hakkak et al. (2023) dissected the connection between REC and LCF in Russia, analyzing data from 1992 to 2018. Their inquiry yielded compelling evidence suggesting that renewable energy manifests short-term and long-term ecological advantages. Nevertheless, there exists a subset of studies positing that REC may diminish the LCF (Abdulmagid Basheer Agila et al., 2022; Xu et al., 2022; Huilan et al., 2024) or, alternatively, exert no discernible environmental impact (Daştan and Eygü, 2023).

HCA stands out as another crucial factor with the potential to enhance the trajectory of the LCF. Utilizing the "dynamic ARDL simulation", Pata and Isik (2021) examined the elements influencing the LCF in China from 1981 to 2016. Their investigation unveiled that HCA significantly contributes to the upgrade of EQ. Based on the "augmented ARDL" model, Çamkaya and Karaaslan (2024) uncovered that a higher level of HCA bolsters the LCF, whereas REC has no significant influence on EQ in the United States for the period 1965-2018. Pata and Ertugrul (2023) employed the "augmented ARDL" approach, incorporating a dummy variable to track the impact of the "Kyoto Protocol" from 1988 to 2018. Their findings underscored the pivotal role of HCA as an environmentally friendly factor in India. Similarly, Caglar et al. (2023b) analyzed the interaction between REC, HCA, and LCF in APEC nations for the period 1992-2018 by using the "Cup-FM" and "Cup-BC" estimators. The authors showed that REC and HCA significantly elevate the level of EQ.

Another facet of the extant literature has directed attention towards exploring the potential influences of TEI on the LCF. Awosusi et al. (2022) studied the nexus between TEI, globalization, and EQ in South Africa, utilizing data from 1980 to 2017. Based on the ARDL approach, the authors proved that TEI and globalization enhance LCF. Aydin et al., (2024), analyzed the environmental impact of TEI in the high investment freedom economies between 1995 and 2019 using the "regularized common correlated effects" estimator. Specifically, the authors observed that TEI exerts a negative effect on the LCF in Singapore, while conversely amplifying it in Germany. Mehmood et al., (2023) evaluated the synergies among TEI, green energy, digitalization, and environmental dynamics employing the CS-ARDL model across G8 nations from 1990-2018. Utilizing the MMQR model, Jahangar et al. (2023) illustrated that TEI and REC contribute to the enhancement of the LCF in the foremost ten nations aligned with the SDGs for the period 1994-2018. In contrast to the aforementioned results, employing the CS-ARDL model, Zhao et al. (2023) demonstrated that TEI does not significantly impact the LCF in BRICS-T countries from 1990 to 2018. Additionally, Özkan et al. (2024) delved into the dynamic influences of financial development, energy efficiency, GDP growth, and TEI on EQ in India spanning from 1980 to 2020. Findings derived from the "dynamically simulated ARDL model" unveil that TEI manifests an adverse impact on the LCF.

It is important to note that Caglar et al. (2024b) are the sole researchers who have undertaken an investigation into the LCF concerning Türkiye. The authors prove the accuracy of the "LCC hypothesis" by utilizing the "augmented ARDL" model with Fourier terms from 1986 to 2022. In addition, they discerned that HCA augmentation positively influences EQ, while natural resource utilization contributes to environmental deterioration. The authors also identified that the energy efficiency has no significant environmental impact. In contrast to the research conducted by Caglar et al. (2024b), this current investigation directs its attention towards examining the intricate interconnections among REC, TEI, HCA, and LCF, and employs the STIRPAT model which is widely implemented by empirical studies to investigate the factors influencing the EQ.

2. Model and Data

This study delves into the assessment of Türkiye's EQ, analyzing data spanning from 1980 to 2019, a timeframe determined by data availability constraints[1]. The focal point lies in the examination of the LCF, a composite variable that concurrently considers both the supply and demand facets of the nature. Beyond the exploration of the environmental ramifications associated with REC, TEI, and HCA, the research also scrutinizes the accuracy of the "LCC hypothesis". To measure the driving forces of environmental pressure, the study utilizes STIRPAT model introduced by Dietz and Rosa (1997) which is stochastic form of the Ehrlich and Holdren's (1971) IPAT approach. The model is presented as follows:

$$I_t = \gamma P_t^n A_t^a T_t^z \mu_t \qquad (1)$$

where t, γ, μ illustrate the time dimension, model coefficient, and error term, respectively. n, a, and z show elasticities.

I: Environmental impact (i.e., the LCF in our case)

P: Population

A: Affluence (per capita GDP)

T: Technology

By taking natural logarithm on both sides of the Equation 1, the model can be rewrites as follow:

$$L(I_t) = \gamma + nL(P_t) + aL(A_t) + zL(T_t) + \omega_t \qquad (2)$$

Given the STIRPAT model's versatility in accommodating additional variables, the study extends Equation 2 to investigate the "LCC hypothesis" and the environmental ramifications of REC and HCA in Türkiye, as depicted below:

$$LLCF_t = \delta_0 + \delta_1 LGDP_t + \delta_2 LGDPS_t + \delta_3 LPOP_t + \delta_4 LREC_t + \delta_5 LTEI_t + \delta_6 LHCA_t + \varepsilon_t \qquad (3)$$

where L denote the logarithm, δ_0 and ε_t represent the intercept and residual term, and $GDPS$ is the square of per capita GDP. δ_1 … δ_6 show the estimated parameters. Table 1 demonstrates the data sources, abbreviations, measurement units of the variables.

Table 1.

Definitions and sources of the variables

Variable	Abbreviations	Measures	Source
Log (Load capacity factor)	LLCF	Log (Biocapacity/Ecological Footprint, per capita, global hectares)	Global Footprint Network (2024)
Log (Gross Domestic	LGDP	Log (Per capita Gross Domestic	World Bank (2024)

[1] Data on the TEI variable is available from 1980, while the data on the HCA variable ends in 2019.

Product (economic growth))		Product-GDP (2015, US$))	
Log (Square of per capita GDP)	LGDPS	Log (Per capita GDP (2015, US$)	
Log (Technological innovation)	LTEI	Log (Total patent applications (resident and non-resident))	
Log (Population)	LPOP	Log (Population, total)	
Log (Renewable energy consumption)	LREC	Log (Per capita renewable energy consumption (kWh-equivalent))	Our World in Data (2023a)
Log (Human capital)	LHCA	Log (Human capital index, "based on years of schooling and returns to education")	Feenstra et al. (2015)

3. Methodology and Findings

The empirical inquiry in this study initiates by identifying the stationary properties of the examined variables. In pursuit of this objective, the study uses both conventional and "Fourier Augmented Dickey-Fuller" (F-ADF) unit root tests, recognizing the prevalence of structural changes within most macroeconomic series. The F-ADF approach, pioneered by Enders and Lee (2012), incorporates smooth transitions through the utilization of sine and cosine functions. Consequently, it eliminates the necessity to ascertain the quantity and type of structural shifts (Naimoglu, 2022; Caglar et al., 2024b). As depicted in Table 2, the two tests produce consistent outcomes, except the GDPS, POP, and REC, and confirm that all the variables are stationary, at least at their first differences.

Table 2.

Unit root test results

Variables	Level				
	ADF	Fourier-ADF			
	test-stat.	test-stat.	Fourier (*k*)	Lag	F-stat.
LLCF	-4.889***	-5.150***	4	0	2.196
LGDP	-2.633	-2.764	1	3	8.006*
LGDPS	-2.498	-4.944**	1	3	9.189*
LPOP	-4.003**	-0.671	1	0	9.099*
LREC	-3.010	-4.282*	1	0	4.642
LTEI	-2.833	-2.153	4	0	3.748
LHCA	-4.339***	-4.778**	1	2	2.557
	First Differences				
ΔLLCF	-	-	-	-	-
ΔLLCF	-6.409***	-6.391***	1	0	0.558
ΔLGDPS	-6.375***	-	-	-	-
ΔLPOP	-	-4.646**	1	0	8.645*
ΔLREC	-7.649***	-	-	-	-
ΔLTEI	-4.842***	-5.351***	4	0	2.632
ΔLHCA	-	-	-	-	-

Note: The notation "Δ" is used to denote the first difference. The symbols *, **, and *** indicate statistical significance at the 1%, 5%, and 10% levels. The critical values for the ADF test statistic at the 1%, 5%, and 10% significance levels are -4.21, -3.52, and -3.19, respectively. The number of frequencies (*k*) is determined based on the smallest sum of squared residuals. Regarding the Fourier-ADF test statistics, the critical values at the 1%, 5%, and 10% significance levels for (*k=1*) and (*k=4*) are (-4.95, -4.35, and -4.05) and (-4.29, -3.65, and -3.29), respectively. The critical values for the F-statistic corresponding to the 1%, 5%, and 10% significance levels are 12.21, 9.14, and 7.78, respectively (see Enders and Lee, 2012).

In the second phase, the investigation delves into the long-term relationships between the variables through the utilization of the A-ARDL model integrated with Fourier terms. For this purpose, the study formulates the following equation:

$$\Delta LLCF_t = \theta_0 + \theta_1 sin\left(\frac{2\pi kt}{T}\right) + \theta_2 cos\left(\frac{2\pi kt}{T}\right) + \theta_3 LLCF_{t-1} + \theta_4 LGDP_{t-1} + \theta_5 LGDPS_{t-1}$$

$$+\theta_6 LPOP_{t-1}+\theta_7 LREC_{t-1}+\theta_8 LTEI_{t-1}+\theta_9 LHCA_{t-1}+\theta_{10}\sum_{i=1}^{e}\Delta LLCF_{t-i}+\theta_{11}\sum_{i=1}^{l}\Delta LGDP_{t-i}$$
$$+\theta_{12}\sum_{i=1}^{f}\Delta LGDPS_{t-i}+\theta_{13}\sum_{i=1}^{n}\Delta LPOP_{t-i}+\theta_{14}\sum_{i=1}^{a}\Delta LREC_{t-i}+\theta_{15}\sum_{i=1}^{z}\Delta LTEI_{t-i}$$
$$+\theta_{16}\sum_{i=1}^{d}\Delta LHCA_{t-i}+u_t \quad (4)$$

where $\theta_1$and θ_2 denote the amplitude and displacement, respectively. k, t, and T stand for trigonometric counts, trend, and time. θ_3 … θ_9 illustrate the long-term coefficients, whereas θ_{10} … θ_{16} represent short-term coefficients. The variables in the model have been converted to natural logarithms to diminish the extent of fluctuations within the series and alleviate concerns associated with multicollinearity.

The A-ARDL model assesses the presence of cointegration using three distinct test statistics: "F-test for all variables" ($F_{OVERALL}$), "F-test for the lagged independent variables" (F_{IND}), and "t-test for the lagged dependent variable" (t_{DEP}). $F_{OVERALL}$ and t_{DEP} tests are provided by Pesaran et al. (2021). The t_{DEP} test is crucial since the standard ARDL model requires the dependent variable to be stationary at the first difference. Nevertheless, researchers may overlook this condition, potentially resulting in misleading outcomes (McNown et al., 2018). In response, McNown et al. (2018) and Sam et al. (2019) propose a new F-test for lagged levels of explanatory variables (F_{IND}) within the model. Thus, if all three tests provided in the following equations yield significant results, one can attain a comprehensive and reliable conclusion confirming a cointegration relationship among the variables under examination.

$F_{OVERALL;}\ H_0=\theta_3=\theta_4=\theta_5=\theta_6=\theta_7=\theta_8=\theta_9=0$

$t_{DEP;}\ H_0=\theta_3=0$

$F_{IND;}\ H_0=\theta_4=\theta_5=\theta_6=\theta_7=\theta_8=\theta_9=0$

Table 3 presents the cointegration results derived from the A-ARDL model with Fourier terms. Given that all three test statistics surpass the upper bounds of critical values, the null hypothesis of "no cointegration" can be rejected at the 1% significance level. The study also performs several diagnostic tests, encompassing the "White test" for heteroscedasticity, "LM test" for serial correlation, "Jarque-Bera test" for normality, and "Ramsey-Reset test" for functional misspecification. Furthermore, the study assesses the stability of the parameters through the examination of "Cusum" and "Cusum of squares" graphs. As depicted in Table 3, all diagnostic tests confirm the absence of "serial correlation", "heteroscedasticity", and "misspecification" problems within the model. The "Jarque-Bera test" indicates that the residuals adhere to a normal distribution. Additionally, the "Cusum" and "Cusum of squares" graphs demonstrate the stability of the parameters, as illustrated in Figure 3.

Table 3.

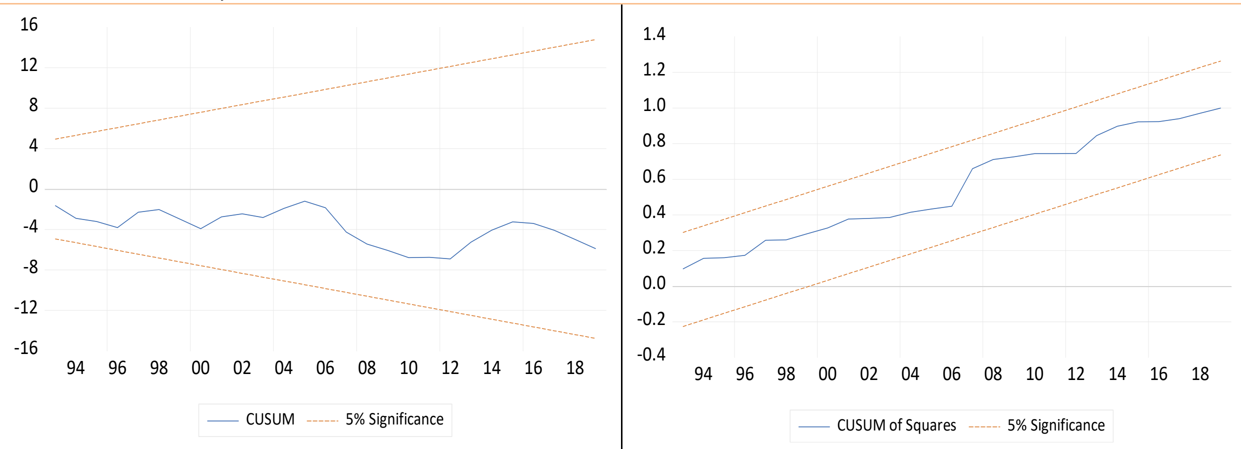
Cointegration test results

Model	statistics	test-stat.	Critical values			Decision
			%10	%5	%1	
(1,0,0,1,0,0,1)	$F_{OVERALL}$	13.762	3.599	4.211	5.643	
k=1	t_{DEP}	-8.854	-4.040	-4.380	-4.990	Cointegration
	F_{IND}	12.189	3.490	4.150	5.740	
Diagnostic tests				stat.	prob.	
White test for heteroscedasticity				0.883	0.558	
LM test for serial-correlation				1.816	0.183	
Jarque-Bera test for normality				1.559	0.458	
Ramsey-Reset test for functional misspecification				1.472	0.153	
Cusum				Stable		
Cusum of squares				Stable		

Note: k is the Fourier number that precisely minimizing the residual sum of squares. The tests statistics for $F_{OVERALL}$, t_{DEP}, and F_{IND} are obtained from Narayan (2005), Pesaran et al. (2001), and Sam et al. (2019), respectively.

Figure 3.

Parameter Stability



Blue line-Cusum, Red lines-5% significance

Blue line-Cusum of Squares, Red lines-5% significance

Having satisfied the prerequisite for establishing long-term connections among the variables, the study proceeds to estimate Equation 4, aiming to evaluate the short and long-term influences of REC, TEI, HCA, and POP on the LCF within the scope of the "LCC hypothesis". The findings from the analysis are reported in Table 4.

Table 4.

Estimation results

Variables	Coeff.	Std. Err.	t-stat	p-value
Panel A. Long-run results				
LGDP	-18.265	4.169	-4.381	0.000
LGDPS	0.331	0.078	4.218	0.000
LPOP	-1.352	0.702	-1.924	0.065
LREC	0.055	0.029	1.890	0.070
LTEI	-0.012	0.013	-0.920	0.366
LHCA	1.758	0.603	2.917	0.007
Panel B. Short-run results				
ΔLGDP	-21.442	5.976	-3.588	0.001
ΔLGDPS	0.388	0.112	3.454	0.002
ΔLPOP	11.291	6.231	1.812	0.081
ΔLREC	0.064	0.041	1.564	0.130
ΔLTEI	-0.014	0.019	-0.752	0.458
ΔLHCA	-3.277	1.859	-1.763	0.089
ΔSin	-0.053	0.014	-3.706	0.001
ΔCos	-0.112	0.013	-8.399	0.000
C	321.782	29.663	10.848	0.000
ECT	-1.174	0.108	-10.851	0.000

Concerning the impact of economic prosperity on EQ, the outcomes affirm the accuracy of the "LCC hypothesis" in Türkiye, both in the short and long term. Specifically, the estimates of GDP and GDPS are negative and positive, respectively, suggesting that after a specific level of affluence is attained, rapid economic activity may indeed function as an environmentally friendly factor. This result aligns with the outcomes drawn by Caglar et al. (2024b), who also suggested that "LCC hypothesis" applies in Türkiye.

Moreover, the findings suggest that POP has a favorable influence on EQ in the short term. However, in the long term there is a robust negative interaction between POP and the LCF. To be precise, a 1% rise in POP is accompanied by an approximately

1.35% reduction in LCF. This finding is in line with the results of Dimnwobi et al. (2021), Pham et al. (2020), and Khan et al. (2021), indicating that population growth revs the depletion of natural resources, thereby diminishing biocapacity, and heightens conventional energy consumption, consequently reducing ecological welfare.

Regarding the environmental impacts of REC, the results depicts that there is a positive but statistically insignificant correlation among REC and LCF in the short run. Nevertheless, in the long run, REC emerges as a significant contributor to EQ. More specifically, a 1% rise in REC correlates with a 0.055% upgrade in LCF, underscoring the crucial role of clean energy in tackling the diverse challenges posed by climate change and achieving Türkiye's long-term sustainable development objectives. The outcome is in line with that of Guloglu et al. (2023), Khan et al. (2023), and Hakkak et al. (2023), who similarly demonstrated that REC serves as an effective tool for enhancing LCF in OECD nations, E7-G7 countries, and Russia, respectively.

Furthermore, the estimated results of the A-ARDL model with smooth shifts reveal that TEI has no significant impact on EQ in Türkiye both in the short and long term. This result corroborates the observation made by Chen and Lee (2020), who argued that TEI has no significant mitigating effect on environmental deterioration across a panel of 96 countries. It also supports the observations of Zhao et al. (2023) who provided evidence demonstrating that there is no significant interaction between TEI and LCF in BRICS nations. However, the outcome contradicts with our expectations and findings of Awosusi et al. (2022) for South Africa, Jahangar et al. (2023) for top ten SDG nations. One plausible explanation for this finding could be that the predominant strategies in TEI initiatives in Türkiye prioritize the production of energy-intensive technological products. Indeed, a wide array of technological progressions, ranging from electronic devices to transportation infrastructure, require considerable energy consumption. Frequently derived from conventional energy sources, this energy utilization is a major driver of greenhouse gas emissions, thereby hindering the capacity of TEI to function as an environmentally sustainable factor. Another possible explanation for this finding is that the research measures TEI using patent applications, a metric that may rise with increased manufacturing activity in countries, particularly in newly industrializing nations like Türkiye. The escalation in industrial capacity, fostering greater technological advancement, could be linked to an upsurge in the production of non-green products. Consequently, this scenario suggests that TEI may not necessarily yield a positive impact on EQ (Sinha et al., 2020).

Additionally, while a short-term negative correlation is observed between HCA and EQ, the coefficient of HCA is found to be positive in the long-term. Specifically, a 1% upsurge in HCA results in a 1.758% rise in LCF, suggesting that long-term progress in HCA stands as one of the significant determinants of EQ in Türkiye. This result is consistent with the observations of Pata and Isik (2021) for China, Çamkaya and Karaaslan (2024) for the United States, Pata and Ertugrul (2023) for India, and Caglar et al. (2023b) for APEC nations.

Finally, the findings indicate that the estimation of the "error correction term" (ECT) takes negative value (-1.174) and statistically significant, implying that any discrepancies within the series can be rectified within approximately one year and that the analyzed series convergence toward long-run equilibrium. Besides, both smooth and abrupt breaks demonstrate statistically significant impacts on the LCF.

Conclusion

This investigation examines the influence of renewable energy consumption, technological innovation, and human capital on ecological welfare of Türkiye from 1980 to 2019 by extending the STIRPAT model. In doing so, it utilized the "load capacity factor" as a measure of ecological welfare, which offers a more reasonable evaluation of environmental stress compared to "CO2 emissions" and "ecological footprint", it takes into account both the input and output dimensions of the ecosystem. Moreover, the research tested whether the "load capacity curve hypothesis" applies in Türkiye.

In the empirical investigation, the study commenced by scrutinizing the stationarity characteristics of the variables through the application of standard ADF and Fourier ADF tests. The outcomes unveiled that, for the most part, the variables exhibit stationarity at the first difference. In the subsequent phase, the study assessed the presence of a long-term interactions among the analyzed variables by utilizing the A-ARDL approach with smooth transitions. It was established that cointegration exists, and the model successfully passed several diagnostic tests. After assessing the long-term interactions between the variables, the study proceeded to estimate the short- and long-term environmental impacts of per capita GDP, the square of per capita GDP, population, renewable energy consumption, technological innovation, and human capital.

The empirical findings indicated that economic development becomes an environmentally friendly factor after reaching a specific output level, thereby validating the LCC hypothesis. Moreover, the findings illustrate that population growth positively influences LCF in the short-term, whereas in the long-term, it harms the environmental well-being. The outcome suggests that population growth amplifies the dependence on fossil fuels and the depletion of natural resources, ultimately degrading the ecological welfare in Türkiye. Hence, Turkish policymakers ought to develop and enhance incentive systems aimed at boosting demand for green products within the country, fostering the adoption of sustainable practices across society, and mitigating the environmental degradation associated with population growth. The outcomes also revealed that advancements in renewable energy consumption and human capital significantly contribute to ecological welfare in the long run. Therefore, Türkiye should augment its investments in renewable energy and education. Indeed, allocating resources to renewable energy sources can decline reliance on fossil fuels, strengthen energy security, stimulate employment, and enhance production efficiency. Undoubtedly, expanding the usage of renewable energy plays a crucial role in relieving Türkiye's vulnerability to fluctuations in foreign energy prices. Furthermore, well-educated individuals are more attuned to environmental issues and integral role in the dissemination of green energy, given their propensity to develop and utilize cutting-edge technologies. Nevertheless, the results suggest that technological innovation has not yielded a significant impact on Türkiye's environmental welfare. This outcome may stem from the prevailing focus within Türkiye's technological innovation sector on advancing conventional energy technologies. Therefore, for technological advancement to emerge as a catalyst for environmental sustainability in Türkiye, there is a pressing need for innovations to be more closely aligned with environment-related technologies. Given that the study employs patent applications as a metric for technological innovation, a measure that could potentially escalate with heightened industrial activity, it becomes imperative to juxtapose these results with recent findings from research utilizing clean energy or environment-related innovations as indicators of technological development.

References

Abdulmagid Basheer Agila, T., Khalifa, W. M., Saint Akadiri, S., Adebayo, T. S., & Altuntaş, M. (2022). Determinants of load capacity factor in South Korea: does structural change matter?. *Environmental Science and Pollution Research*, 29(46), 69932-69948. https://doi.org/10.1007/s11356-022-20676-2

Alola, A. A., Özkan, O., & Usman, O. (2023). Role of non-renewable energy efficiency and renewable energy in driving environmental sustainability in India: evidence from the load capacity factor hypothesis. *Energies*, 16(6), 2847.

Alvarado, R., Deng, Q., Tillaguango, B., Méndez, P., Bravo, D., Chamba, J., Alvarado-Lopez, M., & Ahmad, M. (2021). Do economic development and human capital decrease non-renewable energy consumption? Evidence for OECD countries. *Energy*, 215, 119147. https://doi.org/10.1016/j.energy.2020.119147

Awosusi, A. A., Adebayo, T. S., Kirikkaleli, D., Rjoub, H., & Altuntaş, M. (2023). Evaluating the determinants of load capacity factor in Japan: The impact of economic complexity and trade globalization. In *Natural Resources Forum*. Oxford, UK: Blackwell Publishing Ltd. https://doi.org/10.1111/1477-8947.12334

Awosusi, A. A., Kutlay, K., Altuntaş, M., Khodjiev, B., Agyekum, E. B., Shouran, M., Elgbaily, M., & Kamel, S. (2022). A roadmap toward achieving sustainable environment: evaluating the impact of technological innovation and globalization on load capacity factor. *International Journal of Environmental Research and Public Health*, 19(6), 3288. https://doi.org/10.3390/ijerph19063288

Aydin, M., & Degirmenci, T. (2023). The impact of clean energy consumption, green innovation, and technological diffusion on environmental sustainability: New evidence from load capacity curve hypothesis for 10 European Union countries. *Sustainable Development*. https://doi.org/10.1002/sd.2794

Aydin, M., Erdem, A., Sogut, Y., & Ahmed, Z. (2024). A path towards environmental sustainability: exploring the effects of technological innovation and investment freedom on load capacity factor. *International Journal of Sustainable Development & World Ecology, 1-12*. https://doi.org/10.1080/13504509.2024.2326855

Caglar, A. E., Avci, S. B., Daştan, M., & Destek, M. A. (2024a). Investigation of the effect of natural resource dependence on environmental sustainability under the novel load capacity curve hypothesis. *International Journal of Sustainable Development & World Ecology*, 31(4), 431-446. https://doi.org/10.1080/13504509.2023.2296495

Caglar, A. E., Daştan, M., & Rej, S. (2024c). A new look at China's environmental quality: how does environmental sustainability respond to the asymmetrical behavior of the competitive industrial sector?. *International Journal of Sustainable Development & World Ecology*, 31(1), 16-28. https://doi.org/10.1080/13504509.2023.2248584

Caglar, A. E., Daştan, M., Mehmood, U., & Avci, S. B. (2023a). Assessing the connection between competitive industrial performance on load capacity factor within the LCC framework: Implications for sustainable policy in BRICS economies. *Environmental Science and Pollution Research*, 1-18. https://doi.org/10.1007/s11356-023-29178-1

Caglar, A. E., Destek, M. A., & Manga, M. (2024b). Analyzing the load capacity curve hypothesis for the Turkiye: A perspective for the sustainable environment. *Journal of Cleaner Production*, 141232. https://doi.org/10.1016/j.jclepro.2024.141232

Caglar, A. E., Pata, U. K., Ulug, M., & Zafar, M. W. (2023b). Examining the impact of clean environmental regulations on load capacity factor to achieve sustainability: evidence from APEC economies. *Journal of Cleaner Production*, 429, 139563. https://doi.org/10.1016/j.jclepro.2023.139563

Çamkaya, S., & Karaaslan, A. (2024). Do renewable energy and human capital facilitate the ımprovement of environmental quality in the United States? A new perspective on environmental ıssues with the load capacity factor. *Environmental Science and Pollution Research*, 31, 17140-17155. https://doi.org/10.1007/s11356-024-32331-z

Carfora, A., Pansini, R. V., & Scandurra, G. (2022). Energy dependence, renewable energy generation and import demand: Are EU countries resilient?. *Renewable energy*, 195, 1262-1274. https://doi.org/10.1016/j.renene.2022.06.098

Chen, W., & Lei, Y. (2018). The impacts of renewable energy and technological innovation on environment-energy-growth nexus: New evidence from a panel quantile regression. *Renewable energy*, 123, 1-14. https://doi.org/10.1016/j.renene.2018.02.026

Cheng, Y., Awan, U., Ahmad, S., & Tan, Z. (2021). How do technological innovation and fiscal decentralization affect the environment? A story of the fourth industrial revolution and sustainable growth. *Technological Forecasting and Social Change*, 162, 120398. https://doi.org/10.1016/j.techfore.2020.120398

Dai, J., Ahmed, Z., Alvarado, R., & Ahmad, M. (2024). Assessing the nexus between human capital, green energy, and load capacity factor: policymaking for achieving sustainable development goals. *Gondwana Research*, 129, 452-464. https://doi.org/10.1016/j.gr.2023.04.009

Daştan, M. (2024). Yenilenebilir Enerji Tüketiminin İşsizlik Üzerindeki Etkileri: BRICS-T Ülkeleri Üzerine Ampirik Bir İnceleme. *Gaziantep University Journal of Social Sciences*, 23(2), 633-653. https://doi.org/10.21547/jss.1412409

Daştan, M., & Eygü, H. (2023). An empirical investigation of the link between economic growth, unemployment, and ecological footprint in Turkey: Bridging the EKC and EPC hypotheses. *Environment, Development and Sustainability*, 1-

32. https://doi.org/10.1007/s10668-023-04106-y

Deng, S., Tiwari, S., Khan, S., Hossain, M. R., & Chen, R. (2024). Investigating the load capacity curve (LCC) hypothesis in leading emitter economies: Role of clean energy and energy security for sustainable development. *Gondwana Research*, 128, 283-297. https://doi.org/10.1016/j.gr.2023.10.020

Dietz, T., & Rosa, E. A. (1997). Effects of population and affluence on CO2 emissions. *Proceedings of the National Academy of Sciences*, 94(1), 175-179. https://doi.org/10.1073/pnas.94.1.175

Dimnwobi, S. K., Ekesiobi, C., Madichie, C. V., & Asongu, S. A. (2021). Population dynamics and environmental quality in Africa. *Science of the Total Environment*, 797, 149172. https://doi.org/10.1016/j.scitotenv.2021.149172

Dincer, I. (2000). Renewable energy and sustainable development: a crucial review. *Renewable and sustainable energy reviews*, 4(2), 157-175. https://doi.org/10.1016/S1364-0321(99)00011-8

Dogan, A., & Pata, U. K. (2022). The role of ICT, R&D spending and renewable energy consumption on environmental quality: Testing the LCC hypothesis for G7 countries. *Journal of Cleaner Production*, 380, 135038. https://doi.org/10.1016/j.jclepro.2022.135038

Ehrlich, P. R., & Holdren, J. P. (1971). Impact of Population Growth: Complacency concerning this component of man's predicament is unjustified and counterproductive. *Science*, 171(3977), 1212-1217.

Enders, W., & Lee, J. (2012). The flexible Fourier form and Dickey–Fuller type unit root tests. *Economics Letters*, 117(1), 196-199. https://doi.org/10.1016/j.econlet.2012.04.081

Erdogan, S. (2023). Linking natural resources and environmental sustainability: a panel data approach based on the load capacity curve hypothesis. *Sustainable Development*. https://doi.org/10.1002/sd.2836

Fang, Z., Wang, T., & Yang, C. (2024). Nexus among natural resources, environmental sustainability, and political risk: Testing the load capacity factor curve hypothesis. *Resources Policy*, 90, 104791. https://doi.org/10.1016/j.resourpol.2024.104791

Feenstra, R. C., Inklaar, R., & Timmer, M. P. (2015). The next generation of the Penn World Table. *American economic review*, 105(10), 3150-3182.

Global Footprint Network (2024). Country Trends. https://www.footprintnetwork.org (Accessed 5 February 2024).

Gross, R., Leach, M., & Bauen, A. (2003). Progress in renewable energy. *Environment international*, 29(1), 105-122. https://doi.org/10.1016/S0160-4120(02)00130-7

Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement. NBER WORKING PAPER 3914. https://doi.org/10.3386/w3914

Guloglu, B., Caglar, A. E., & Pata, U. K. (2023). Analyzing the determinants of the load capacity factor in OECD countries: evidence from advanced quantile panel data methods. *Gondwana Research*, 118, 92-104. https://doi.org/10.1016/j.gr.2023.02.013

Hakkak, M., Altintaş, N., & Hakkak, S. (2023). Exploring the relationship between nuclear and renewable energy usage, ecological footprint, and load capacity factor: A study of the Russian Federation testing the EKC and LCC hypothesis. *Renewable Energy Focus*, 46, 356-366. https://doi.org/10.1016/j.ref.2023.07.005

Huilan, W., Akadiri, S. S., Haouas, I., Awosusi, A. A., & Odu, A. T. (2024). Impact of trade liberalization and renewable energy on load capacity factor: Evidence from novel dual adjustment approach. *Energy & Environment*, 35(2), 795-814. https://doi.org/10.1177/0958305X221137559

IEA (2021), Turkey 2021, IEA, Paris. https://www.iea.org/reports/turkey-2021, Licence: CC BY 4.0 (Accessed 20 March 2024).

Jahanger, A. (2022). Impact of globalization on CO2 emissions based on EKC hypothesis in developing world: the moderating role of human capital. *Environmental Science and Pollution Research*, 29(14), 20731-20751. https://doi.org/10.1007/s11356-021-17062-9

Jahanger, A., Ogwu, S. O., Onwe, J. C., & Awan, A. (2024). The prominence of technological innovation and renewable energy for the ecological sustainability in top SDGs nations: Insights from the load capacity factor. *Gondwana Research*, 129, 381-397. https://doi.org/10.1016/j.gr.2023.05.021

Khan, I., Hou, F., & Le, H. P. (2021). The impact of natural resources, energy consumption, and population growth on environmental quality: Fresh evidence from the United States of America. *Science of the Total Environment*, 754, 142222. https://doi.org/10.1016/j.scitotenv.2020.142222

Khan, U., Khan, A. M., Khan, M. S., Ahmed, P., Haque, A., & Parvin, R. A. (2023). Are the impacts of renewable energy use on load capacity factors homogeneous for developed and developing nations? Evidence from the G7 and E7 nations. *Environmental Science and Pollution Research*, 30(9), 24629-24640. https://doi.org/10.1007/s11356-022-24002-8

Koc, S., & Bulus, G. C. (2020). Testing validity of the EKC hypothesis in South Korea: role of renewable energy and trade openness. *Environmental Science and Pollution Research*, 27(23), 29043-29054.

Küçük, G., & Yüce Dural, B. (2024). Türkiye'nin Avrupa Yeşil Mutabakatına Uyumu Kapsamında Yeşil Ekonomi Performansı: Değerlendirme ve Perspektifler. *Sosyoekonomi*, 32(60), 445-467. https://doi.org/10.17233/sosyoekonomi.2024.02.21

Lindsey, R. (2022). Climate Change: Global Sea Level. Climate. gov. https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

Lindsey, R., & Dahlman, L. (2024). Climate Change: Global Temperature. Climate. gov. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

Liu, X., Olanrewaju, V. O., Agyekum, E. B., El-Naggar, M. F., Alrashed, M. M., & Kamel, S. (2022). Determinants of load capacity factor in an emerging economy: the role of green energy consumption and technological innovation. *Frontiers in Environmental Science*, 10, 1028161. https://doi.org/10.3389/fenvs.2022.1028161

Markandya, A., Arto, I., González-Eguino, M., & Román, M. V. (2016). Towards a green energy economy? Tracking the employment effects of low-carbon technologies in the European Union. *Applied energy*, 179, 1342-1350. https://doi.org/10.1016/j.apenergy.2016.02.122

McNown, R., Sam, C. Y., & Goh, S. K. (2018). Bootstrapping the autoregressive distributed lag test for cointegration. *Applied Economics*, 50(13), 1509-1521. https://doi.org/10.1080/00036846.2017.1366643

Mehmood, U., Tariq, S., Aslam, M. U., Agyekum, E. B., Uhunamure, S. E., Shale, K., Kamal, M., & Khan, M. F. (2023). Evaluating the impact of digitalization, renewable energy use, and technological innovation on load capacity factor in G8 nations. *Scientific Reports*, 13(1), 9131. https://doi.org/10.1038/s41598-023-36373-0

Menyah, K., & Wolde-Rufael, Y. (2010). CO2 emissions, nuclear energy, renewable energy and economic growth in the US. *Energy policy*, 38(6), 2911-2915. https://doi.org/10.1016/j.enpol.2010.01.024

Ministry of Foreign Affairs of the Republic of Türkiye (2024), Türkiye's International Energy Strategy. https://www.mfa.gov.tr/turkeys-energy-strategy.en.mfa

Mishra, A. K. (2019). Quantifying the impact of global warming on precipitation patterns in India. *Meteorological Applications*, 26(1), 153-160. https://doi.org/10.1002/met.1749

Moussaid, F. Z., Bachegour, H., Jerry, M., & Qafas, A. (2023). Probing the asymmetric impact of clean energy technologies on environmental quality: testing load capacity curve hypothesis in Spain. *Environment, Development and Sustainability*, 1-20. https://doi.org/10.1007/s10668-023-04083-2

Naimoglu, M. (2022). The impact of economic growth, trade openness and technological progress on renewable energy use in Turkey: Fourier EG cointegration approach. *Ege Akademik Bakis*, 22(3), 309-321. https://doi.org/10.21121/eab.984127

Narayan, P. K. (2005). The saving and investment nexus for China: evidence from cointegration tests. *Applied economics*, 37(17), 1979-1990. https://doi.org/10.1080/00036840500278103

NASA (2024). Vital Signs, Carbon Dioxide. https://climate.nasa.gov/vital-signs/carbon-dioxide/?intent=121#:~:text=Since%20the%20onset%20of%20industrial,ice%20age%2020%2C000%20years%20ago (Accessed 10 March 2024).

NOAA (2023). Broken record: Atmospheric carbon dioxide levels jump again. https://www.noaa.gov/news-release/broken-record-atmospheric-carbon-dioxide-levels-jump-again (Accessed 10 March 2024).

Our World in Data (2023a). Energy, Explore Data on Energy. https://ourworldindata.org/energy (Accessed 5 February 2024)

Our World in Data (2023b). CO_2 and Greenhouse Gas Emissions, Explore Data on CO2 and Greenhouse Gas Emissions. https://ourworldindata.org/co2-and-greenhouse-gas-emissions (Accessed 5 February 2024)

Ozbek, S., & Naimoglu, M. (2022). Çevre Kalitesi-Ekonomik Karmaşıklık İlişkisi: Türkiye ekonomisi üzerine fourier eşbütünleşme analizi. *İstanbul İktisat Dergisi - Istanbul Journal of Economics*, 72(1), 407-431. https://doi.org/10.26650/ISTJECON2022-1061837.

Özkan, O., Saleem, F., & Sharif, A. (2024). Evaluating the impact of technological innovation and energy efficiency on load capacity factor: empirical analysis of India. *Environmental Science and Pollution Research*, 31(4), 5610-5624. https://doi.org/10.1007/s11356-023-31233-w

Pata, U. K. (2021). Do renewable energy and health expenditures improve load capacity factor in the USA and Japan? A new approach to environmental issues. *The European Journal of Health Economics*, 22(9), 1427-1439. https://doi.org/10.1007/s10198-021-01321-0

Pata, U. K., & Caglar, A. E. (2021). Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization and trade openness for China: evidence from augmented ARDL approach with a structural break. *Energy*, 216, 119220. https://doi.org/10.1016/j.energy.2020.119220

Pata, U. K., & Ertugrul, H. M. (2023). Do the Kyoto Protocol, geopolitical risks, human capital and natural resources affect the sustainability limit? A new environmental approach based on the LCC hypothesis. *Resources Policy*, 81, 103352. https://doi.org/10.1016/j.resourpol.2023.103352

Pata, U. K., & Isik, C. (2021). Determinants of the load capacity factor in China: a novel dynamic ARDL approach for ecological footprint accounting. *Resources Policy*, 74, 102313. https://doi.org/10.1016/j.resourpol.2021.102313

Pata, U. K., & Tanriover, B. (2023). Is the load capacity curve hypothesis valid for the top ten tourism destinations?. *Sustainability*, 15(2), 960. https://doi.org/10.3390/su15020960

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics*, 16(3), 289-326. https://doi.org/10.1002/jae.616

Pham, N. M., Huynh, T. L. D., & Nasir, M. A. (2020). Environmental consequences of population, affluence and technological progress for European countries: A Malthusian view. *Journal of environmental management*, 260, 110143. https://doi.org/10.1016/j.jenvman.2020.110143

Sam, C. Y., McNown, R., & Goh, S. K. (2019). An augmented autoregressive distributed lag bounds test for cointegration. *Economic Modelling*, 80, 130-141. https://doi.org/10.1016/j.econmod.2018.11.001

Saqib, N., Sharif, A., Razzaq, A., & Usman, M. (2023). Integration of renewable energy and technological innovation in realizing environmental sustainability: the role of human capital in EKC framework. *Environmental Science and Pollution Research*, 30(6), 16372-16385. https://doi.org/10.1007/s11356-022-23345-6

Shabani, Z. D. (2024). Renewable energy and CO2 emissions: Does human capital matter?. *Energy Reports*, 11, 3474-3491. https://doi.org/10.1016/j.egyr.2024.03.021

Shahgedanova, M. (2021). Climate change and melting glaciers. *The impacts of climate change*, 53-84. https://doi.org/10.1016/B978-0-12-822373-4.00007-0

Shahzad, U., Tiwari, S., Mohammed, K. S., & Zenchenko, S. (2024). Asymmetric nexus between renewable energy, economic progress, and ecological issues: testing the LCC hypothesis in the context of sustainability perspective. *Gondwana Research*, 129, 465-475. https://doi.org/10.1016/j.gr.2023.07.008

Siche, R., Pereira, L., Agostinho, F., & Ortega, E. (2010). Convergence of ecological footprint and emergy analysis as a sustainability indicator of countries: Peru as case study. *Communications in Nonlinear Science and Numerical Simulation*, 15(10), 3182-3192. https://doi.org/10.1016/j.cnsns.2009.10.027

Sinha, A., Sengupta, T., & Alvarado, R. (2020). Interplay between technological innovation and environmental quality: formulating the SDG policies for next 11 economies. *Journal of Cleaner Production*, 242, 118549. https://doi.org/10.1016/j.jclepro.2019.118549

Solarin, S. A., Al-Mulali, U., & Ozturk, I. (2017). Validating the environmental Kuznets curve hypothesis in India and China: The role of hydroelectricity consumption. *Renewable and Sustainable Energy Reviews*, 80, 1578-1587. https://doi.org/10.1016/j.rser.2017.07.028

Sun, A., Bao, K., Aslam, M., Gu, X., Khan, Z., & Uktamov, K. F. (2024). Testing load capacity and environmental Kuznets curve hypothesis for China: Evidence from novel dynamic autoregressive distributed lags model. *Gondwana Research*, 129, 476-489. https://doi.org/10.1016/j.gr.2023.07.018

Sun, Y., Usman, M., Radulescu, M., Pata, U. K., & Balsalobre-Lorente, D. (2024). New insights from the STIPART model on how environmental-related technologies, natural resources and the use of the renewable energy influence load capacity factor. *Gondwana Research*, 129, 398-411. https://doi.org/10.1016/j.gr.2023.05.018

Tang, C. F., & Tan, E. C. (2013). Exploring the nexus of electricity consumption, economic growth, energy prices and technology innovation in Malaysia. *Applied Energy*, 104, 297-305. https://doi.org/10.1016/j.apenergy.2012.10.061

U.S. Department of Energy (2024). Office of Energy Efficiency & Renewable Energy, Renewable energy. https://www.energy.gov/eere/renewable-energy#:~:text=Renewable%20energy%20comes%20from%20unlimited,%2C%20natural%20gas%2C%20and%20oil. (Accessed 20 March 2024)

United Nations (2024). Department of Economic and Social Affairs, Sustainable Development, the 17 Goals. https://sdgs.un.org/goals (Accessed 26 March 2024)

Wang, S., Zafar, M. W., Vasbieva, D. G., & Yurtkuran, S. (2024). Economic growth, nuclear energy, renewable energy, and environmental quality: Investigating the environmental Kuznets curve and load capacity curve hypothesis. *Gondwana Research*, 129, 490-504. https://doi.org/10.1016/j.gr.2023.06.009

Williamson, P., & Guinder, V. A. (2021). Effect of climate change on marine ecosystems. *The impacts of climate change*, 115-176. https://doi.org/10.1016/B978-0-12-822373-4.00024-0

World Bank (2024). World Deevelopment Indicator. https://databank.worldbank.org/source/world-development-indicators (Accessed 5 February 2024).

Xu, D., Salem, S., Awosusi, A. A., Abdurakhmanova, G., Altuntaş, M., Oluwajana, D., Kirikkaleli, D., & Ojekemi, O. (2022). Load capacity factor and financial globalization in Brazil: the role of renewable energy and urbanization. *Frontiers in Environmental Science*, 9, 823185. https://doi.org/10.3389/fenvs.2021.823185

Yang, M., Magazzino, C., Awosusi, A. A., & Abdulloev, N. (2023a). Determinants of Load capacity factor in BRICS countries: A panel data analysis. In *Natural Resources Forum*. Oxford, UK: Blackwell Publishing Ltd. https://doi.org/10.1111/1477-8947.12331

Yang, M., She, D., Abbas, S., Ai, F., & Adebayo, T. S. (2023b). Environmental cost of financial development within the framework of the load capacity curve hypothesis in the BRICS economies: Do renewable energy consumption and natural resources mitigate some burden?. *Geological Journal*, 58(10), 3915-3927. https://doi.org/10.1002/gj.4817

Yang, Q., Huo, J., Saqib, N., & Mahmood, H. (2022). Modelling the effect of renewable energy and public-private partnership in testing EKC hypothesis: evidence from methods moment of quantile regression. *Renewable Energy*, 192, 485-494. https://doi.org/10.1016/j.renene.2022.03.123

Yilanci, V., Gorus, M. S., & Andreoni, V. (2023). Reinvestigation of the validity of the EKC hypothesis extended with energy: A time-varying analysis for the United Kingdom. *Journal of Cleaner Production*, 428, 139284. https://doi.org/10.1016/j.jclepro.2023.139284

Zafar, M. W., Zaidi, S. A. H., Khan, N. R., Mirza, F. M., Hou, F., & Kirmani, S. A. A. (2019). The impact of natural resources, human capital, and foreign direct investment on the ecological footprint: the case of the United States. *Resources Policy*, 63, 101428. https://doi.org/10.1016/j.resourpol.2019.101428

Zhao, W. X., Samour, A., Yi, K., & Al-Faryan, M. A. S. (2023). Do technological innovation, natural resources and stock market development promote environmental sustainability? Novel evidence based on the load capacity factor. *Resources Policy*, 82, 103397. https://doi.org/10.1016/j.resourpol.2023.103397

Araştırma ve Yayın Etiği Beyanı

Araştırmacılar verilerin toplanmasında, analizinde ve raporlaştırılmasında her türlü etik ilke ve kurala özen gösterdiklerini beyan ederler.

Yazarların Makaleye Katkı Oranları

Makale tek yazarlı olarak hazırlanmıştır.

Çıkar Beyanı

Yazarın herhangi bir kişi ya da kuruluş ile çıkar çatışması yoktur. Ayrıca herhangi bir potansiyel çıkar çatışması bulunmamaktadır.