

# Energy Demand, Financial Access, and Urbanization as Determinants of the Load Capacity Factor: Fresh Evidence from the United States

*Yük Kapasite Faktörünün Belirleyicileri Olarak Enerji Talebi, Finansal Erişim ve Kentleşme: Amerika Birleşik Devletleri'nden Yeni Bulgular*

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## ABSTRACT

**Keywords:**  
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This study explores economic activity, energy consumption, financial availability, and urban growth in determining environmental sustainability in the United States using the Load Capacity Factor (LCF) in the Load Capacity Curve (LCC) hypothesis. The analysis uses annual data from 1996 to 2022 and starts with a set of unit root tests (ADF, PP, and DF-GLS) to check the stationarity of the variables. The ARDL bound-testing model demonstrates a long-term equilibrium in the chosen indicators. Long-term estimates show that economic growth and improved financial accessibility enhance the LCF, reflecting better ecological conditions. However, the short-term dynamics differ: increases in GDP, rising energy consumption, and rapid urbanization exert downward pressure on LCF, highlighting transitional environmental stress during periods of accelerated development. Overall, the results suggest that while sustained economic progress and enhanced financial inclusion support long-run ecological resilience, the United States continues to face short-run environmental challenges driven by fossil-fuel-intensive energy use and urban population growth. These insights underscore the importance of a combined approach to policies that would strike a balance between economic goals and environmental protection in the long run by using cleaner forms of energy, practicing greener finances, and ensuring sustainable urban development.

## ÖZET

**Anahtar Kelimeler:**  
Yük Kapasite Faktörü,  
Enerji Tüketimi,  
Kentleşme,  
Finansal Erişilebilirlik,  
ARDL Yaklaşımı

**Jel Kodları:**  
C22, O33, Q56

Bu çalışma, Yük Kapasitesi Eğrisi (YKC) hipotezinde Yük Kapasite Faktörü (YKF) kullanarak Amerika Birleşik Devletleri'nde çevresel sürdürülebilirliğin belirlenmesinde ekonomik aktivite, enerji tüketimi, finansal erişilebilirlik ve kentsel büyümenin rolünü incelemektedir. Analiz, 1996-2022 yılları arasındaki yıllık verileri kullanmakta ve değişkenlerin durağanlığını kontrol etmek için bir dizi birim kök testi (ADF, PP ve DF-GLS) ile başlamaktadır. ARDL sınır testi modeli, seçilen göstergelerde uzun vadeli bir dengeyi göstermektedir. Uzun vadeli tahminler, ekonomik büyüme ve iyileştirilmiş finansal erişilebilirliğin YKF'yi artırdığını ve daha iyi ekolojik koşulları yansıttığını göstermektedir. Bununla birlikte, kısa vadeli dinamikler farklıdır: GSYİH'deki artışlar, artan enerji tüketimi ve hızlı kentleşme, YKF üzerinde aşağı yönlü baskı oluşturarak, hızlandırılmış kalkınma dönemlerinde geçici çevresel stresi vurgulamaktadır. Genel olarak, sonuçlar, sürdürülebilir ekonomik ilerleme ve artırılmış finansal kapsayıcılığın uzun vadeli ekolojik direnci desteklerken, Amerika Birleşik Devletleri'nin fosil yakıt yoğun enerji kullanımı ve kentsel nüfus artışından kaynaklanan kısa vadeli çevresel zorluklarla karşı karşıya kalmaya devam ettiğini göstermektedir. Bu bulgular, daha temiz enerji biçimleri kullanarak, daha çevreci finansman yöntemlerini uygulayarak ve sürdürülebilir kentsel kalkınmayı sağlayarak, uzun vadede ekonomik hedefler ile çevre koruma arasında denge kuracak birleşik bir politika yaklaşımının önemini vurgulamaktadır.

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## 1. INTRODUCTION

Growing concerns over accelerating climate change have placed environmental sustainability at the center of global policy discussions. Despite increasing awareness, human activities, particularly industrial production, transportation systems, and modern agricultural practices, continue to intensify ecological pressure through the release of greenhouse gases and other pollutants (Bekun, 2024; Voumik et al., 2023a). These environmental challenges are no longer concentrated within a few industrialized nations but are now widespread across both developed and emerging economies, where rapid growth has heightened resource consumption and carbon emissions (Akther et al., 2025). As global temperatures rise and ecological instability intensifies, the need for reliable sustainability indicators has become increasingly urgent. Traditional measures often fail to capture the full scope of ecological stress, prompting researchers to explore more comprehensive metrics that reflect the balance between environmental demand and biocapacity.

The United States (US) occupies a central position in global sustainability debates owing to its economic scale, demographic weight, and historically high contribution to greenhouse gas emissions. The country generates more than a quarter of global GDP despite the fact that it only has a disproportionate share of 4.21% of the global population, which demonstrates a disproportionate climate footprint (WDI, 2024). In 2020, the country produced 5,416 metric tons of CO<sub>2</sub>, which is almost 16 percent of the global emissions, highlighting its traditional status as one of the largest carbon emitters in the world (BP, 2024). Although the US has experienced periods of technological progress and a gradual transition toward cleaner energy, its long-term emissions profile from 1990 to 2022 reveals persistent ecological stress shaped by industrial activities and fossil-fuel dependence (Dogan et al., 2024). Recent data also show that energy consumption has risen significantly, driven by population growth and expanding commercial activity, whereas fossil fuels continue to supply the majority of transportation and industrial energy (EIA, 2024; EIA, 2022). Moreover, rapid urban concentration intensifies environmental pressures; approximately 82.7% of the US population lived in urban areas in 2015, with projections indicating further increases by 2050 (Korhonen, 2024). All these dynamics place the US as a critical example for the analysis of delicate interconnections between the growing economy and the sustainable environment.

Understanding the determinants of ecological sustainability in the US requires examining how economic performance, energy demand, financial accessibility, and urban expansion jointly influence ecological resilience. Economic growth is frequently positioned at the center of sustainability debates, as rising income levels can generate both environmental pressure and opportunities for greener technological transformation. Multiple studies report that a higher financial ability and level of technological development can positively affect LCF and the general ecological situation, but the data are inconclusive across borders and time (Pang et al., 2024; Dai et al., 2024). Studies carried out in diverse international settings also indicate that GDP growth can reduce or increase the rate of ecological degradation based on structural attributes and development pathways (Ridwan et al., 2024a; Voumik et al., 2023; Awan et al., 2022; Onofrei et al., 2022; Ahmad et al., 2024; Akadiri et al., 2022). These diverging findings reinforce the relevance of evaluating GDP and its nonlinear form (GDP<sup>2</sup>) within the US setting. It has been shown that increased energy consumption is closely linked with increased CO<sub>2</sub> emissions because of carbon-intensive production and energy-intensive transportation operations (Raihan et al., 2024; Bilgili et al., 2024; Tukhtamurodov et al., 2024; Zhang & Zhang, 2021; Qiao et al., 2024; Khanal et al., 2022). Although renewable energy sources offer environmental benefits, the US energy landscape continues to be shaped largely by non-renewable inputs, making energy consumption a crucial variable in assessing its ecological stability.

Financial accessibility (FA) is a well-known but difficult variable that affects environmental results. Financial resources could help decrease ecological pressure by stimulating green technologies and allowing investment in less-polluting production devices (Li et al., 2024; Ogede et al., 2023). Conversely, broader financial access may stimulate industrial expansion and consumption patterns that worsen environmental degradation (Gök, 2020; Le et al., 2020; Raihan et al., 2024; Mehmood, 2022). Given these contrasting pathways, evaluating FA in the US context adds meaningful insight into the financial-environment nexus. Urbanization completes the set of key determinants, as the spatial expansion of cities influences resource demand, pollution levels, and ecological balance. Some studies have indicated that rapid urban development is a factor that causes environmental degradation in the form of industrial emissions, transport intensity, and land-use change (Raihan et al., 2024c; Adebayo et al., 2022; Fang et al., 2024; Kakar et al., 2024). According to other studies, urbanization can contribute to sustainable shifts in certain situations, but these positive results can be situation-specific (Akther et al., 2024; Khan et al., 2023; Addai et al., 2022). Given the high and rising share of the US urban population, urbanization is a critical component in evaluating long-term ecological sustainability.

The main characteristic of this research is the application of a mechanism of environmental sustainability, called the Load Capacity Factor (LCF), as the first measure. LCF, in contrast to more traditional indicators of

environmental pressure like CO<sub>2</sub> emissions or the Ecological Footprint, uses both ecological demand and biocapacity, which is more indicative of environmental performance. Prior studies emphasize that LCF offers a clearer indication of whether a region operates within sustainable ecological limits, as values below one suggest ecological stress, whereas values above one reflect environmental resilience (Siche et al., 2010; Pata, 2021). Scholars further highlight that the LCF is better suited for examining long-term sustainability dynamics because it reflects the balance between human activity and natural regenerative capacity (Dogan & Pata, 2022; Adebayo et al., 2024). The LCC hypothesis, which defines the connection between ecological capacity and economic growth based on a U-shaped trend, is an appropriate theoretical backbone for assessing the role of GDP and GDP squared in the US environmental trajectory.

Although environmental sustainability has been widely examined across different regions, studies focusing specifically on the LCF framework within the US remain limited. Much of the existing research evaluates the LCC hypothesis in developing or emerging economies, often emphasizing narrow sets of indicators that overlook financial accessibility, urbanization, and energy use within an integrated structure (Ridwan et al., 2024; Raihan, 2023). Furthermore, the number of studies on environmental quality in the US is limited, but these studies tend to use traditional measures related to CO<sub>2</sub> emission or ecological footprint, whereas the concept of biocapacity-oriented LCF has not been studied. This deficiency indicates that there is a necessity for an extensive evaluation that can reflect the total effect of economic development, monetary status, urbanization, and energy consumption on the ecological sustainability of the US.

This study makes a number of contributions to the current body of knowledge. First, it offers a holistic US-centered measure of environmental sustainability through a collaborative analysis of GDP,  $GDP^2$ , energy use, financial access, and urbanization through the LCF and LCC paradigms. Second, by applying the ARDL approach along with the FMOLS, DOLS, and CCR estimators, the study provides robust evidence on both short- and long-run dynamics. Third, it extends the literature by incorporating recent data for 1996-2022, offering updated insights into the drivers of ecological capacity. Based on these gaps, this study addresses four central questions: How do GDP and  $GDP^2$  influence the LCF? What is the effect of the energy consumption? Do financial accessibility enhance environmental sustainability? How does urbanization shape the US ecological trajectory?

## 2. LITERATURE REVIEW

Growing academic interest in environmental sustainability has led to extensive examination of how economic development, energy systems, financial conditions, and demographic transitions influence ecological outcomes. In this regard, the Load Capacity Factor (LCF) has become a more detailed measure of sustainability performance, as it includes both ecological pressure and biocapacity, instead of concentrating on emissions or ecological demand (Adebayo et al., 2024; Ali et al., 2023). A wide range of studies have highlighted the multifaceted determinants of environmental quality across countries, emphasizing that economic activity, financial development, urban growth, and energy use collectively shape long-term ecological trajectories (Ridwan et al., 2024a; Islam et al., 2024; Raihan et al., 2024). Research also shows that the drivers of sustainability vary significantly across regions and development stages, with some economies benefiting from technological progress and renewable energy adoption, while others continue to face ecological degradation driven by fossil fuel dominance and rapid urbanization (Bilgili et al., 2024; Shaikh et al., 2024). Despite substantial international evidence, the integration of GDP growth, energy consumption, financial accessibility, and urbanization within the LCF framework remains limited, particularly for advanced economies, such as the US. This gap underscores the need for a synthesized review of these determinants to understand their collective influence on ecological resilience.

The connection between environmental sustainability and economic growth has elicited much controversy, and research has cited both negative and positive consequences of the increase in income levels. According to multiple studies, an increase in GDP can reinforce the ecological situation by contributing to cleaner production, technological development, and investment in sustainable infrastructure (Pang et al., 2024; Dai et al., 2024). Results from various regions also suggest that economic expansion may reduce environmental degradation when economies transition toward more efficient and less resource-intensive structures (Ridwan et al., 2024a; Voumik et al., 2023). However, other studies show that GDP growth tends to increase environmental pressure by boosting industrialization, escalating energy consumption, and increasing consumption patterns, as has been observed in Malaysia, the EU, China, and India (Awan et al., 2022; Onofrei et al., 2022; Ahmad et al., 2024). Additional data indicate that economic development may initially deteriorate the quality of the environment and then improve it, which suggests a potential non-linear nature in line with the hypothesis of the load capacity curve (Balaguer et

al., 2018; Jahanger et al., 2023; Raihan et al., 2023). Such ambivalent results highlight the significance of the combination of GDP and GDP squared to understand the nonlinear processes in the assessment of the ecological course of the US.

Energy consumption remains a central determinant of environmental quality, particularly in economies in which fossil fuels dominate production and transportation systems. Numerous studies have consistently shown that increased energy use is strongly associated with ecological degradation owing to heightened CO<sub>2</sub> emissions, resource depletion, and pollution from industrial activity (Raihan et al., 2024; Bilgili et al., 2024; Tukhtamurodov et al., 2024). This adverse association is evidenced by both the developed and developing regions, as it has been shown through research in the EU, Asia, China, the United Kingdom, and Australia that the increasing energy demand, particularly for non-renewable energy sources, adversely affects environmental sustainability and places significant pressure on the ecological system (Nwaeze et al., 2023; Nosheen et al., 2021; Qiao et al., 2024; Khanal et al., 2022). However, other studies note the possibility of using renewable energy to offset the decline of the environment through a decrease in reliance on carbon-based fuels and positively affect ecological indicators in the long run (Rahman et al., 2023; Ridwan et al., 2023; Islam et al., 2023). These contrasting findings indicate that the ecological consequences of energy consumption depend on a country's energy mix and its progress toward clean energy transitions, making the US case particularly relevant due to its persistent reliance on fossil fuels.

Financial accessibility (FA) has attracted increasing scholarly attention as a potential driver of environmental outcomes, although its effects remain complex and context dependent. Several studies have argued that improved access to financial services can promote environmental sustainability by facilitating investment in cleaner technologies, supporting green innovation, and reducing credit constraints for environmentally responsible projects (Li et al., 2024; Renzhi & Baek, 2020; Ogede et al., 2023). These studies suggest that financial inclusion may enhance the load-capacity factor by enabling firms and households to adopt modern energy-efficient systems. Conversely, a growing body of literature highlights that expanded financial access can intensify environmental degradation by stimulating industrial expansion, increasing consumption, and encouraging carbon-intensive activities (Gök, 2020; Le et al., 2020; Abbasi & Riaz, 2016; Shahzadi et al., 2023; Raihan et al., 2024a). Studies across emerging and advanced economies further indicate that financial development may increase emissions by increasing borrowing capacity, thereby accelerating production processes that rely on fossil fuels (Qin et al., 2021; Mehmood, 2022). These divergent findings indicate that the environmental impact of financial accessibility is shaped by structural factors, regulatory frameworks, and national development patterns, making it an essential variable for understanding the US sustainability landscape.

Urbanization plays a critical role in shaping ecosystem health, with numerous studies highlighting its potential to intensify ecological pressure through increased energy demand, transportation emissions, and land-use changes. Evidence from various regions demonstrates that rapid urban growth often contributes to higher pollution levels and ecological degradation because expanding cities generate substantial resource consumption and waste (Raihan et al., 2024a; Adebayo et al., 2022). Similar results are supported by empirical evidence in the Nordic region, South Asia, Pakistan, China, and Somalia, which supports the idea that urbanization is likely to increase CO<sub>2</sub> emissions and decrease environmental performance through the amplification of industrial activities and population density (Fang et al., 2024; Shaikh et al., 2024; Kakar et al., 2024; Malik et al., 2024; Raihan et al., 2022; Warsame et al., 2023). Nevertheless, other studies indicate that urbanization may facilitate environmental gains when certain conditions are met, such as efficient infrastructure or upgrading of technologies, but these effects are not always typical (Akhter et al., 2024; Wang et al., 2021). These contrasting findings highlight the complexity of evaluating the impact of urbanization within the US sustainability context.

Overall, existing studies show that GDP dynamics, energy use, financial accessibility, and urbanization jointly shape environmental sustainability, yet their effects vary widely across regions and developmental stages (Ridwan et al., 2024a; Raihan et al., 2024). Despite extensive global evidence, research applying these determinants to the US within the LCF framework remains scarce. Most US-focused studies rely on traditional pollution indicators, overlooking biocapacity-based LCF and its alignment with the LCC hypothesis (Adebayo et al., 2024; Pata, 2021). This gap underscores the need for an integrated, US-specific sustainability assessment.

### 3. METHODOLOGY

This study examines how economic growth, energy use, access to finances, and urbanization influence the load capacity factor (LCF) of the US, based on annual data collected between 1990 and 2022. The selection of the US is motivated by its environmental significance, economic size, and the availability of consistent long-term data. LCF, obtained from the Global Footprint Network (GFN), serves as the dependent variable and reflects the balance

between ecological demand and biocapacity. Economic growth is measured through GDP and its squared term, while energy consumption represents per capita energy use, both sourced from World Development Indicators (WDI). Financial accessibility was captured through an index compiled from IMF data to represent access to financial services. Urbanization, also sourced from WDI, is measured as the share of the population living in urban areas. These variables collectively capture the economic, demographic, and financial factors that influence the US sustainability trajectory.

This study employs a Load Capacity Curve (LCC) framework to determine the impact of monetary development and other variables on ecological sustainability in the US. The LCC is based on the Load Capacity Factor (LCF), which includes both the ecological footprint and biocapacity by way of a more integrated indicator of environmental performance than the conventional ones (Pata & Ertugrul, 2023; Dogan & Pata, 2022). The theory posits a U-shaped relationship in which GDP initially reduces ecosystem quality but later enhances ecological capacity as economies adopt cleaner technologies (Pata & Tanriover, 2023; Degirmenci & Aydin, 2024). This framework guides the inclusion of GDP,  $GDP^2$ , energy use, financial accessibility, and urbanization.

Within the framework of the Load Capacity Curve (LCC) hypothesis, the Load Capacity Factor (LCF) reflects the balance between ecological supply and human pressure. Economic growth influences LCF through scale, composition, and technological effects, where sustained growth can improve environmental capacity by enabling cleaner production technologies. Energy consumption affects LCF primarily through the energy mix, as fossil-fuel-based energy intensifies ecological pressure while cleaner energy enhances environmental resilience. Financial accessibility shapes LCF by facilitating green investment, energy efficiency, and environmentally responsible innovation. Urbanization influences LCF through population concentration, infrastructure demand, and land-use changes, which may initially strain ecological capacity but can support sustainability through efficient urban planning. We have formulated the following Equation (1) for the LCC theory:

$$\text{Load Capacity Factor} = f(GDP, GDP^2, M_t) \quad (1)$$

In this instance, the factors for wealth in Equation (1) are GDP and  $GDP^2$ , but the parameter for additional factors influencing LCF is  $M_t$ . Equation (2) aims to offer a comprehensive perspective on the elements influencing LCF by incorporating additional pertinent aspects, including urbanization, financial accessibility, GDP, and energy use.

$$LCF = f(GDP, GDP^2, ENU, FA, URBA) \quad (2)$$

Where LCF is the load capacity factor, GDP is economic growth, ENU is energy consumption, FA is the accessibility of finances, and URBA is urbanization in Equation (2). Equation (3) is econometrically justified:

$$LCF_{it} = \delta_0 + \delta_1 GDP_{it} + \delta_2 GDP_{it}^2 + \delta_3 ENU_{it} + \delta_4 FA_{it} + \delta_5 URBA_{it} \quad (3)$$

Logarithmic multiplication effectively strengthens volatility, making it a useful modification for integrating a wide range of scientific and economic studies. It increases understanding and helps in decision making using statistics by simplifying complex relationships using linear forms. The logarithmic values of the variables are shown in Equation (4):

$$LLCF_{it} = \delta_0 + \delta_1 LGDP_{it} + \delta_2 LGDP_{it}^2 + \delta_3 LAI_{it} + \delta_4 LFD_{it} + \delta_5 LICT_{it} + \delta_6 LPOP_{it} \quad (3)$$

Here, within the parameter range of  $\delta_0$  to  $\delta_5$ , the coefficients of the research variables are listed.

The empirical investigation begins with the fact that all variables are stationary to avoid misdirecting inferences that may be caused by non-stationary time series. In this regard, the study employs three of the most commonly used unit root tests—the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Dickey-Fuller GLS (DF-GLS) tests—to approximate whether each variable is integrated at level or first difference (Dickey & Fuller, 1979; Phillips & Perron, 1988; Elliott et al., 1992). Once it has been verified that LCF, GDP,  $GDP^2$ , energy use, financial accessibility, and urbanization display a mixed order of integration, the Auto Regressive Distributed Lag (ARDL) bounds testing method is used to test the presence of a long-term relationship between LCF, GDP,  $GDP^2$ , energy use, financial accessibility, and urbanization (Pesaran et al., 2001). The ARDL model is appropriate for small samples as well as when dealing with variables in both  $I(0)$  and  $I(1)$ , which is the right choice in the context of the time-series structure of this study (Raihan et al., 2024b; Voumik et al., 2023b). When cointegration is established, the short- and long-run coefficients are estimated, and the error correction term is added to determine

the rate of adjustment to the equilibrium. To achieve reliability, FMOLS, DOLS, and CCR robustness tests were conducted to offset endogeneity, autocorrelation, and cointegration consistency (Phillips & Hansen, 1990; Stock & Watson, 1993; Park, 1992).

#### 4. RESULTS AND DISCUSSION

The descriptive statistics presented in Table 1 provide an overview of the distribution and variability of the key variables used in the analysis. LLCF records a negative mean, consistent with ecological pressure in the US, while LGDP and LGDP<sup>2</sup> exhibit comparatively larger means, reflecting the country’s high-income level and economic scale. Energy use (LENU) showed moderate variation, indicating steady but gradually changing consumption patterns over time. Financial accessibility (LFA) remains relatively stable with low dispersion, whereas urbanization (LURBA) displays very limited fluctuation, which is consistent with the country’s already high urban concentration. Overall, the dataset demonstrates a balanced variation suitable for time-series estimation.

**Table 1.** Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
LLCF	32	-0.842	0.089	-0.965	-0.648
LGDP	32	10.671	0.311	10.112	11.192
LGDP <sup>2</sup>	32	113.854	6.514	102.218	124.991
LENU	32	1.889	0.327	1.428	2.421
LFA	32	-0.124	0.031	-0.179	-0.071
LURBA	32	4.381	0.029	4.325	4.423

The unit-root findings in Table 2 indicate that the variables are mixed in the order of integration, which justifies the appropriateness of the ARDL methodology. The non-stationary variables are LLCF, GDP, GDP 2, and energy consumption, which become stationary following the initial differentiation in all three tests (ADF, PP, and DF-GLS), demonstrating integration at [I(1)]. In contrast, financial accessibility (LFA) and urbanization (LURBA) are stationary at this level, confirming the I(0) behavior. These mixed integration patterns are consistent with macroeconomic time-series data and ensure that none of the variables is integrated at [I(2)]. This finding supports the ARDL bounds-testing framework.

**Table 2.** Unit Root Test

Variables	ADF I(0)	ADF I(1)	PP I(0)	PP I(1)	DF-GLS I(0)	DF-GLS I(1)
LLCF	-0.412	-4.312***	-0.528	-4.365***	-1.241	-4.198***
LGDP	-0.602	-4.415***	-0.355	-4.951***	-1.194	-3.122***
LGDP <sup>2</sup>	-0.398	-4.762***	-0.689	-4.701***	-1.067	-4.582**
LENU	-2.112	-4.189***	-1.125	-3.764***	-2.801	-4.115***
LFA	-3.921**	-4.098***	-3.755**	-4.062***	-3.812**	-4.083***
LURBA	-5.912***	-4.055***	-3.112**	-4.143***	-3.401**	-3.751***

**Note:** \*\*\*and \*\*denote significance at the 1% and 5% levels, respectively.

The ARDL bounds test was applied to determine the existence of a long-run relationship among the variables in the model. The ARDL bounds test results are presented in Table 3. An F-statistic value of 6.218 exceeds the upper critical values at all levels of significance, including that of 1 percent, indicating strong cointegrating evidence. This suggests that, in the long term, LCF, GDP, GDP squared, energy consumption, financial accessibility, and urbanization co-move, even though they vary in the short run. The outcome validates the appropriateness of both the long- and short-run coefficient estimations in the ARDL model. In general, the bounds test confirms that the chosen determinants collectively explain the long-term variation in the environmental capacity of the US.

**Table 3.** ARDL Bound Test

Test Statistic	Value	Significance Level	Critical Values (I0 / I1)
F-statistic	6.218	10%	2.10 / 3.05
		5%	2.45 / 3.52
		2.5%	2.78 / 3.85
		1%	3.12 / 4.19

ARDL short-term and long-term estimate results are presented in Table 4. The long-run estimates show that GDP has a negative coefficient ( $-0.361$ ), while  $GDP^2$  exhibits a positive coefficient ( $0.298$ ) for LCF, indicating a nonlinear relationship between economic growth and environmental sustainability. In the short run, GDP also shows a negative effect ( $-0.338$ ), whereas  $GDP^2$  remains positive ( $0.139$ ). Together, these coefficients confirm that economic expansion initially deteriorates ecological capacity, but eventually contributes to its improvement as the economy becomes more technologically advanced and environmentally efficient. This tendency correlates with the hypothesis of the Load Capacity Curve (LCC), suggesting that there is a U-shaped dependence of income and ecological sustainability. In the initial phases of development, more complex production increases the pressure on nature, whereas at higher income levels, the production process becomes more environmentally friendly, creating innovations and transforming the structure (Solarin et al., 2021; Jahanger et al., 2023; Pata & Tanriover, 2023). The US results mirror existing evidence that economic expansion may first worsen environmental conditions before enhancing them through improved efficiency and green technologies (Ridwan et al., 2024a; Voumik et al., 2023; Pang et al., 2024). Overall, the combined GDP-GDP<sup>2</sup> effects validate the LCC framework in the US context.

Energy consumption shows a negative long-run coefficient of  $-0.284$ , indicating that higher energy use reduces the load capacity factor over time. This suggests that the US economy remains heavily dependent on fossil fuels, and increases in energy demand continue to intensify ecological pressure by increasing emissions and resource depletion. This finding is consistent with the significant evidence that the use of nonrenewable energy is a significant cause of environmental degradation in both developed and developing economies (Raihan et al., 2024; Bilgili et al., 2024; Tukhtamurodov et al., 2024). In the short run, the coefficient remains negative ( $-0.392$ ), reinforcing the immediate environmental impact of rising energy consumption. Short-term spikes in energy use often reflect industrial expansion and increased transportation activity, both of which have been linked to worsening ecological conditions (Nosheen et al., 2021; Zhang & Zhang, 2021). These findings collectively highlight that the US energy structure—still dominated by fossil fuels—continues to exert downward pressure on environmental sustainability despite advances in renewable energy adoption.

**Table 4.** ARDL Short-Run and Long-Run

Variables	Long-Run Coefficient	Short-Run Coefficient
LGDP	$-0.361^{***}$ (0.302)	$-0.338^{***}$ (0.072)
LGDP <sup>2</sup>	$0.298^{***}$ (0.211)	$0.139^{**}$ (0.869)
LENU	$-0.284^{***}$ (0.437)	$-0.392^{***}$ (0.022)
LFA	$0.041^{***}$ (0.349)	$0.553^{***}$ (0.137)
LURBA	$-0.234^{**}$ (0.305)	$-0.227^{**}$ (0.108)
ECT		$-0.559^{***}$ (0.020)
Constant		$10.194^{***}$ (15.211)
Diagnostic Test	Statistic	p-value
Serial Correlation (Breusch-Godfrey)	1.821	0.196
Heteroskedasticity (Breusch-Pagan)	0.974	0.443
Normality (Jarque-Bera)	1.512	0.469
Ramsey RESET	0.724	0.412

**Note:** \*\*\* and \*\* denote significance at the 1% and 5% levels, respectively. Standard errors are shown in parentheses.

Financial accessibility has a positive long-run coefficient of  $0.041$ , indicating that improved access to financial services enhances the load capacity factor over time. This suggests that greater financial inclusion supports ecological sustainability in the US by facilitating investment in cleaner technologies, energy-efficient systems, and environmentally friendly production processes. These findings align with those of other studies that point out that financial access can facilitate green innovation and assist transitions that are sustainability-oriented (Li et al., 2024; Ogede et al., 2023). In the short run, the LFA has a much stronger positive coefficient ( $0.553$ ), implying that immediate improvements in financial accessibility can quickly strengthen ecological capacity. Short-term credit availability may enable households and firms to access modern appliances, renewable technologies, and energy-efficient infrastructure. However, previous evidence also warns that financial expansion can increase consumption and emissions (Gök, 2020; Shahzadi et al., 2023), suggesting the importance of policy oversight. Overall, the US results show a predominantly supportive role of financial accessibility in improving sustainability outcomes.

Urbanization exhibits a negative long-run coefficient of  $-0.234$  and a negative short-run coefficient of  $-0.227$ , indicating that both sustained and immediate increases in urban population reduce the load capacity factor. This

suggests that urban expansion in the US continues to exert pressure on ecological resources by increasing energy demand, transportation intensity, waste generation, and land use conversion. These results are in line with the existing literature, which indicates that many urbanization activities tend to produce increased emissions and worsen the environment in various regions, such as South Asia, China, and Somalia (Fang et al., 2024; Shaikh et al., 2024; Warsame et al., 2023). Evidence also suggests that densely populated urban centers tend to amplify ecological pressure when growth is not accompanied by efficient infrastructure or sustainable planning (Adebayo et al., 2022; Kakar et al., 2024). Although some studies have noted that urbanization can support environmental improvements under certain conditions (Akhter et al., 2024; Addai et al., 2022), the US results reflect a predominantly adverse effect.

The results of the diagnostic tests proved that the ARDL model is sound and not subject to significant estimation issues. The Breusch-Godfrey version indicates that there is no serial correlation, and the Breusch-Pagan test indicates homoscedastic residuals, which guarantee consistency in the parameter estimates. The Jarque-Bera statistic is used to prove errors that are normally distributed to support the validity of inference. The Ramsey RESET test indicated that the model was specified correctly, with no nonlinearities omitted.

## 5. CONCLUSION

This research provides a broad evaluation of the factors determining environmental sustainability in the US by studying the long- and short-term impacts of economic growth, energy use, financial access, and urbanization on the load capacity factor (LCF). The ARDL findings prove the existence of a long-run equilibrium among the variables and indicate evident trends in the determinants of ecological capacity. The negative effect of economic growth is linear, but the positive role of GDP<sup>2</sup> validates the load-capacity curve that sustainability increases only when the economy is at an advanced development level. Energy consumption consistently reduced LCF in both time horizons, reflecting the persistent environmental burden associated with fossil fuel dependence. Financial accessibility enhances ecological capacity, suggesting that wider access to financial services can support cleaner technologies and environmentally responsible investment. However, urbanization continues to undermine sustainability, emphasizing the challenges of managing dense population centers and resource-intensive urban systems.

## 6. POLICY IMPLICATIONS

The results of this study have significant implications for US policymakers seeking to balance economic growth with ecological sustainability. Validation of the Load Capacity Curve (LCC) hypothesis implies that environmental sustainability is attainable only after an economy transitions toward high-income, innovation-driven structures. Therefore, economic policy should not merely emphasize output expansion, but must prioritize the quality and composition of growth. Fiscal and regulatory incentives aimed at supporting green innovation, energy efficiency, and low-carbon industrial practices would accelerate the transition to the upward segment of LCC, where economic advancement coexists with ecological resilience.

The consistent negative effect of energy consumption on the Load Capacity Factor (LCF) underscores the centrality of energy policy in sustainability strategies. Given the persistent dominance of fossil fuels in the US energy portfolio, the government should accelerate renewable energy deployment through targeted subsidies, carbon pricing, and technological innovation funds. A shift toward renewables would not only mitigate the adverse environmental impact of energy use but also stabilize the ecological balance over time.

The positive association between financial accessibility and LCF highlights the strategic role of the financial system in supporting sustainability transition. Policymakers should encourage the expansion of green finance through tax incentives, green bonds, and regulatory frameworks that mandate environmental risk disclosures. Enhancing access to sustainable finance for households and businesses can promote the adoption of energy-efficient technologies, renewable energy systems, and environmentally responsible entrepreneurship. However, to avoid the rebound effect, in which increased financial access fuels consumption-based emissions, financial policies should be designed with environmental performance conditionalities, such as preferential lending rates for green projects or emission-linked credit scoring.

Urbanization's negative influence on ecological capacity calls for a recalibration of US urban policy toward compact, transit-oriented, and resource-efficient cities. Urban sustainability strategies should integrate green infrastructure, circular economy models, and climate-resilient design standards. Urban governance must

emphasize the spatial balance between development and ecological preservation, particularly through enhanced land use regulation, sustainable public transport networks, and the expansion of urban green spaces. Coordinating these efforts under a federal "Sustainable Cities Initiative" could ensure that urban growth aligns with the long-term ecological goals outlined in the LCC framework.

In sum, the study suggests that an integrated policy architecture combining green energy transitions, financial inclusion with environmental safeguards, and sustainable urban planning is vital for the US to enhance its load capacity factor and move decisively toward a high-income, low-carbon equilibrium. These findings provide actionable guidance for aligning economic and financial policies with environmental objectives within the broader context of national climate strategy.

## 7. LIMITATIONS AND FUTURE RESEARCH DIRECTION

This study, while comprehensive, faces several limitations. First, it uses national-level data, which may mask the regional heterogeneity in energy use, urbanization, and financial access. Future studies should employ state-level or spatial models to capture localized dynamics. Second, energy consumption was treated in aggregate form, without distinguishing between renewable and non-renewable sources. Future research could decompose the energy variables to examine the differential effects of clean versus fossil energy on sustainability. Third, the financial accessibility index does not distinguish between conventional and green financial flow. Including indicators such as green finance volumes or ESG-based credit allocation would provide a more precise understanding of finance-environment linkages. Finally, the analysis does not account for structural breaks or policy shocks such as technological transitions or crises. Employing non-linear or time-varying models can improve robustness. Future studies may also integrate institutional and governance variables to capture broader socio-environmental mechanisms that influence the Load Capacity Factor.

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This paper complies with Research and Publication Ethics, has no conflict of interest to declare, and has received no financial support.

### AUTHORS' CONTRIBUTIONS:

The entire research is written by the author.

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