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RESEARCH ARTICLE

Enhancing Load Capacity Factor: The Influence of Financial Accessibility, AI Innovation, and Institutional Quality in the United States

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Abstract
The investigation analyzes the impact of financial accessibility, AI innovation, urbanization, and institutional quality on the load capacity factor in the United States from 1990 to 2019. A series of stationarity tests were conducted to detect the presence of unit root problems, revealing a mixed order of integration with no significant unit root issues. To explore the cointegration among variables, the ARDL bounds test was employed, confirming long-run cointegration. The ARDL model's short-run and long-run estimations demonstrate that the Load Capacity Curve hypothesis holds in the United States, with a U-shaped relationship between income and load capacity factor. The results also reveal that financial accessibility, AI innovation, and institutional quality positively influence the load capacity factor in both the short and long run. Conversely, urbanization significantly reduces the load capacity factor over both time horizons. Furthermore, the study utilized further approaches, including Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Canonical Cointegrating Regression (CCR), all of which validated the ARDL estimation results. Diagnostic tests confirmed the robustness of the model, showing that the variables are free from specification errors, serial correlation, and heteroscedasticity. These findings provide valuable insights for policymakers aiming to enhance load capacity through financial and technological advancements while considering the implications of urbanization.

Keywords: AI Innovation; Financial Accessibility; Institutional Quality; Load Capacity Factor; United States

Introduction

Over the past few years, conservation economics has prioritized ecological problems. Contamination, widespread societal shifts, and habitat loss have endangered natural diversification (Rai & Singh 2020; Raihan et al.,2024e; Raihan et al.,2024g). A rising need for natural resources is contributing to ecosystem issues such as climate change, soil erosion, air and water pollution, biodiversity damage, and the threat of global warming (Azam et al., 2023; Mithun et al.,2023; Raihan et al.,2024f). The USA, one of the six superpowers and the most developed nation in the world, with 52 developed states, is the subject of our study's analysis of environmental deterioration. The US significantly contributes to global carbon dioxide (CO2) emissions, thereby significantly influencing the overall concentration of greenhouse gases in the environment. Between 1990 and 2022, GDP growth causes to a boost in emission level in the 1990s, which peaked in the early 2000s due to changes in efficiency and policy. The 2010s saw a decrease in pollution due to rising natural gas usage, and the 2020s saw further impact from green energy and technological advancements (Dogan et al., 2024). The USA remains the second-largest contributor of CO2 emissions globally, following China (Ozan et al., 2023). However, the US Environmental Protection Agency (2022) indicated that the US has seen a 7% decrease in greenhouse gas (GHG) emissions since 1990. Additionally, the US ranks 7th on the globe for GDP per capita and has the greatest GDP in the world (Khan et al., 2021). Despite the perception that the US financial system is deep and sophisticated, many people still face barriers to financial access. The truth is that 16.7 million Americans are unbanked, meaning that they do not access a standard financial deposit account, and 50.9 million individuals in the US are underbanked, having used Alternative Financial Services (AFS) (Karp and Nash-Stacey, 2015). Furthermore, making use of AI technologies delivers the ability to profoundly revolutionize ways of handling waste in underprivileged areas and improve environmental conditions in the USA (Nwokediegwu & Ugwuanyi, 2024). These worrying statistics for the chosen criteria highlight the importance of the present investigation from a US perspective. The study adopted the load capacity factor (LCF), a vital way to measure a nation's ecological performance. LCF quantifies the extent to which people's actions harm the world and how the ecosystem compensates for it (Kartal et al., 2023). Most analyses focus on CO2 emission and ecological footprint (EF), primarily examining the demand side of ecological issues, potentially overlooking the supply side (Pata and Isik, 2021). An LCF less than 1 jeopardizes ecological sustainability, whereas an LCF above 1 signifies biocapacity exceeding EF and sufficient natural resources for sustainability concerns. Although a thorough study of panel data has not yet taken place, the literature on LCF is developing (Pata and Samour, 2023). Financial industry, commercial activity, population rates, modernization velocity, and usage of new technologies are the primary drivers of environmental pollution and greenhouse gas emissions that the USA must deal with due to its highly developed economy (Khan et al., 2019; Sohail et al.,2019). AI, the key technology of the latest industrial age, is increasingly playing a role in driving societal progress and global economic growth (Borges et al., 2021; Shiam et al.,2024b; Faruk et al.,2024; Abir et al.,2024). AI has demonstrated enormous promise for preserving the environment (Sohail et al.,2018a; Kar et al., 2022; Shiam et al..,2024a). Furthermore, it examines large amounts of past data to generate efficient forecasting models, enhancing the use of green power (Sohail et al.,2018b). In the context of the United States, our inquiry considers financial access, institution quality, and AI innovation as key policy factors, as well as the execution of the advanced ARDL technique. Based on such variables, our work is significant to the existing corpus of recent studies. The global urbanization process is accelerating. The United Nations reports that South America's urban population grew from 37% in 1960 to 82% in 2020 (Nations, 2018). Economic expansion results in a heavy use of power, natural assets, and production inputs, which initially pollutes and puts more strain on the natural world (Nurgazina et al., 2022). However, the finance-environment discourse widely acknowledges that the finance sector plays a crucial role in mitigating pollution by providing appropriate ecological financing (Kirikkaleli et al., 2022). Poor governance in nations may lead to a detrimental impact on GDP development when the governmental sphere is large (Khan et al., 2024). Enforcing laws, regulations, corruption control, and rights of ownership, all of which minimize greenhouse gas emissions while promoting more productive and efficient practices, requires strengthening institutions (Ali et al., 2019; Ahmad et al., 2024b). Our work significantly contributes to the current field in multiple key areas. This investigation is unique as it is the first to directly explore the connection among AI innovation, institutional quality, and the LCF in the USA. The investigation uses ARDL methods to examine patterns and significant areas of study concerning AI, financial accessibility (FA), institutional quality (IQ), GDP expansion, and urbanization (URBA) within the framework of the USA's LCF from 1990 to 2018. By focusing on LCF, this analysis offers new insights for scholars and makes a notable contribution to the field. In order to provide a more thorough study, a comprehensive environmental evaluation should include biocapacity, CO2 emissions, and the EF, which emphasizes humans' demand for natural assets (Pata et al., 2023). Consequently, the LCF is defined as the ratio of biocapacity to EF (Siche et al., 2010). By considering environment related variables from the viewpoints of supply and demand, this technique provides a more comprehensive evaluation (Pata, 2021). This investigation, the first comprehensive examination of the LCF literature, addresses the following questions: What implications do FA, IQ, and AI have on LCF in the US? What additional implications do GDP and urbanization have on LCF? Comprehending these variables might help lawmakers and strategists in encouraging ecologically conscious behavior. Our study additionally uses FMOLS, DOLS, and CCR approaches to verify the robustness of its findings. This research finding is very enlightening for legislators in the United States, as well as for those who work to achieve the SDGs, encourage green growth, and improve ecosystem quality.

The arrangement of the subsequent sections is controlled by the following sequence: Literature evaluations are the primary focus of the subsequent section. The theoretical framework, technique, and information are all provided in the third chapter. The empirical results are illustrated and discussed in the fourth chapter. The final section of the paper examines its conclusion and policy recommendations.

Literature Review

Several empirical studies have explored the implication of financial inclusion, ICT use, and GDP development on the LCF. While many analyses have employed the ARDL model, most have concentrated on the implications of financial globalization and renewable energy on the LCF. The study of ecological degradation in the U.S. context is still relatively new and lacks extensive research. This investigation, however, builds on previous studies to inform the selection of variables and methodologies used in the analysis. Risks related to environmental pollution, air quality, and ecosystems correlate with economic expansion (Awan et al., 2024). Throughout this period, multiple researches have analyzed the link between the natural world and financial prosperity. We need to further look at the relationship between the economic development and LCF in the USA. Covering 1965 to 2017, Pata and Balsalobre-Lorente (2021) conducted a study in Turkey and found an opposite connection between the LCF and GDP growth. Ahmed et al. (2020) using bootstrap causality analysis and the Bayer-Hanck cointegration test performed a work in China. Their findings highlight environmental issues associated with China's economic growth, demonstrating how GDP development leads to an increasing impact on the environment and pollution. Similar findings were made by Pata and Isik (2021) across China, Agila et al. (2022) in South Korea, Shang et al. (2022) within ASEAN economies, Raihan et al.(2024d) within Indonesia, Ridwan et al. (2024a) in South Asia, and Yang et al. (2024) for BRICS zone. Balcilar et al. (2018) carried out an examination of the economic expansion of the G-7 countries in relation to GHG emissions. They argue that rise in GDP is not degrades the ecosystem level in Germany and the UK. Acar et al. (2023) revealed an inverse U-shaped EKC and showed that while the initial boost in GDP led to more biodiversity loss, growth above a certain threshold led to increases in natural health after that.

Environmental degradation and the global warming problem are extremely complicated issues that need cutting-edge and innovative remedies (Nishant et al., 2020; Ridzuan et al.,2023). AI promotes advanced, efficient, and sustainable industrial frameworks (Wei et al., 2021; Hossain et al.,2023; Arif et al.,2024; Ferdous et al.,2023; Rana et al.,2024), which impact atmospheric conditions. Additionally, Dong et al. (2023) examined data from 30 provinces in China to explore the impacts and mechanisms of AI on CO2 emissions. Empirical research indicates that AI significantly reduces CO2 emissions. In order to examine the relationship between AI innovation, urbanization, GDP, stock market capitalization, and banking advancement, Shiam et al. (2023c) examined an analysis conducted in the Nordic region between 1990 and 2020. Utilizing the STIRPAT framework, they determined that progress in AI has an inverse relationship with the ecological footprint in the specified region. Akther et al. (2024) conducted a study in the USA with the ARDL bound test, analyzing data from 1990 to 2019. They discovered a positive correlation between private investment in AI and LCF. Likewise, Ridwan et al. (2024b) conducted an investigation in the USA from 1990 to 2019 to examine the impact of AI on natural health. They employed the ARDL technique and demonstrated that AI-related technology may ensure ecosystem sustainability. In the G-7 region, Ridwan et al. (2024c) did additional research employing the MMQR approach to examine the impact of AI innovation on the LCF. Their findings indicated that the implementation of AI yields beneficial effects at the ecosystem level. Additionally, Hossain et al. (2024) conducted an analysis in the Nordic region utilizing the LCC hypothesis and the ARDL approach. They also noted that AI innovation has beneficial ramifications at the ecosystem level.

Much of the literature indicates that there is conflicting evidence linking finance and environmental concerns. Financial accessibility, on the one hand, provides businesses and green economies with affordable and attractive financing schemes (Le et al., 2020; Islam et al.,2023). Conversely, nations with relatively easy access to financial services and funds are experiencing an increase in industrial activities, leading to high emissions and contaminated atmospheres (Hasanov et al., 2021). By adopting the ARDL framework Raihan et al. (2024b) explore the relationship within FA and CO2 pollutions in the G-7 region covering 1990 to 2019. Their results show that access to finance worsens environmental conditions and raises CO2 emissions. AMG and CCEMG estimates and PMG for testing causality are also used by Ali et al. (2022) to look into how monetary integration affected the environment in ECOWAS countries from 1990 to 2016. They demonstrated that accessibility in finances increases the ecosystem burden. Following the same principles, Hussain et al. (2022) in OECD countries, Anu et al. (2023) in developed and emerging areas, Fareed et al. (2022) in the Eurozone, and Yurtkuran and Güneysu (2023) in Turkiye have indicated that financial accessibility negatively impacts the state of ecosystems. Conversely, Saqib et al. (2023) deployed the implications of FA on developing nations' EF between 1990 and 2019. Using sophisticated panel estimation techniques, they demonstrated that monetary integration reduces environmental harm. Feng et al. (2022) and Zhong (2022) from China also hold similar views. Furthermore, Barut et al. (2023) described that financial accessibility did not affect contamination.

Institutional excellence, which includes factors such as law operation, effective administration, regulation quality, and political stability, has a significant impact on natural assets, temperature rise, and financial growth (Byaro et al., 2024). Therefore, inadequate policies regarding these concerns could potentially threaten ecological stability. Several current studies (Borghi et al., 2023; Chhabra et al., 2023) have highlighted the interaction between quality of institutions (IQ) and environmental sustainability. Similarly, during 1990 to 2019, Aydin et al. (2024) explored the consequences of IQ on 10 European Union nations that invest the most in environmental technologies. They discovered that improved institutional quality raises LCF in Germany and

France and lowers LCF in Austria. Furthermore, they established that the LCC theory applies exclusively to Spain. According to Zakaria and Bibi (2019), a 1% improvement in the IQ in South Asia turns a 0.114% reduction in pollution. According to Ali et al. (2019), in 47 developing nations, organizational excellence, which includes measures of the legal system, bureaucratic superiority, and corruption control, reduces emissions. Beside, Dam et al. (2024) investigate how IQ affects LCF in OECD nations and find that, over time, IQ has favorable consequence on degradation. In a similar way, findings by Anwar and Malik (2022) and Farooq et al. (2023) further confirmed the idea that institutional excellence might reduce environmental degradation. Achuo et al. (2024) additionally highlight how important it is for policymakers to promote legislation by improving institutional quality to foster a sustainable environment.

Urbanization has significant implications for environmental quality. By promoting cost-effective innovation, urban centers, and raising awareness about global warming through marketing and education, URBA has the capacity to enhance the general welfare of ecosystems (Kocoglu et al., 2021). In China scholars like Ahmad et al. (2019) indicate that they are very interested in green technology, suggesting that URBA has a favorable link with the ecosystem. Similarly, Chien et al. (2023) analyzed the implication of URBA on CO2 pollutions in the G-7 nations and found that growing populations reduce pollution in high-emission countries. Moreover, using the dynamic ARDL model, Danish and Hassan (2023) argued that urbanization in Pakistan contributes to pollution control. On the other hand, Raihan et al. (2022b) examined how urbanization has affected CO2 emissions in the USA. They demonstrated that for every 1% increase in urbanization, CO2 emissions increased by 0.56% immediately and 0.20% in the long run. In a similar vein, Tanveer et al. (2024) in Pakistan, Azam and Qayyum (2016) in the USA, and Voumik et al. (2023a) in Kenya also observed that urban growth is harmful for the environment. However, Xu et al. (2022) conducted research in Brazil and discovered that URBA does not affect LCF using ARDL-bound testing. In the same way, Sui et al. (2024) used the ECM model in China to demonstrate that, over time, the growth of urbanization will not deteriorate the ecological environment. Moreover, Ridwan (2023) found that urbanization has no consequences on natural world. Economic growth, urbanization, financial accessibility (FA), institutional quality (IQ), artificial intelligence (AI) innovation, and load capacity factor (LCF) have not been comprehensively examined in the United States. Although these components have been the subject of individual studies in the past, comprehensive assessments have been absent, particularly in the context of the United States' relationship. The appropriate implementation of AI technologies could potentially mitigate climate change by promoting energy efficiency, green technologies, and sustainable urban planning. Furthermore, modern institutions can promote the development of effective pollution-reduction strategies, and financial accessibility can promote conservation efforts. In the United States, an emerging area for analysis is comprised of these three interconnected factors: IQ, FA, and AI. In order to address the research gaps, we implement robust statistical methodologies such as ARDL, FMOLS, DOLS, and CCR. The objective of this investigation is to aid lawmakers in the development of policies that are suitable for the unique ecological and macroeconomic dynamics of the United States, thereby promoting equitable growth by underscoring the importance of LCF in environmental preservation.

Methodology

Data and Variables

The first table is a vital component of this research because it contains a detailed review of all the factors investigated. We derived the LCF statistics for the United States from the Global Footprint Network (GFN), a more appropriate source than other environmental proxies. The study additionally included a large number of independent variables, all of which were based on precisely the information obtained. The World Development Indicators (WDI) provided reliable figures on GDP, GDP squares, and urbanization. We designed Our World in Data to gather statistics on other crucial factors like AI innovation and institutional excellence. However, we collected information about financial accessibility from the IMF. As a result, through enhancing the availability and dependability of the study's approach, extensive proof ensures an explicit and integrated analysis.

Table 1. Source and Description of Variables

Variables	Description	Logarithmic Form	Unit of Measurement	Source
LCF	Load Capacity Factor	LLCF	Gha per person	GFN
GDP	Gross Domestic Product	LGDP	GDP per capita (current US$)	WDI
GDP^2	Square of Gross Domestic Product	$LGDP^2$	GDP per capita (current US$)	WDI
AI	Artificial Intelligence Innovation	LAI	Annual patent applications related to artificial intelligence	Our World in Data
FA	Financial Accessibility	LFA	Financial Institution Access Index	IMF
IQ	Institutional Quality	LIQ	Government Effectiveness, Estimate	Our World in Data
URBA	Urbanization	LURBA	Urban Population (% of population)	WDI

Theoretical Framework

In environmental studies, the load capacity curve (LCC) is a vital tool that sheds light on the complex linkages among ecological health, financial stability, and human development. This emphasizes the equilibrium or imbalance between the planet's ability to recover its resources and its use of human assets. The LCF provides an additional environmental evaluation by contrasting ecological footprint and biocapacity (Dogan and Pata, 2022). A more robust EF and higher LCF are indicators of a more salubrious ecosystem (Pata and Kartal, 2023). Due to the significance of these key features, we choose to utilize the LCF as a substitute for assessing damage to the ecosystem in our analysis.

It is believed that the LCC connects in a U-formation, with income acting as the primary drive. This link highlights the knowledge of how resource utilization expands in tandem with GDP growth and advances in individual affluence as an essential aspect of environmental sustainability (Degirmenci & Aydin, 2024). According to Ulucak et al. (2020), several industries alter manufacturing processes and greenhouse gases; financial growth exacerbates commercial polluting substances; and expanding economies are disadvantaged. We previously mentioned that there might be multiple links between factors such as GDP growth, private investment in artificial intelligence, technical innovation, urbanization, financial globalization, and LCF. We now develop equation (1) for LCC theory to enhance the understanding of previous studies.

$$Load\ Capacity\ Factor = f(GDP, GDP^2, Q_t) \qquad (1)$$

In this case, Q_t denotes other factors changing the LCF, while GDP stands for wealth in equation (1). The 2nd equation attempts to give a deeper understanding of the LCF by including factors such as economic growth, AI innovation, financial accessibility, institutional quality, and urbanization.

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

The load capacity factor (LCF) is denoted in equation (2), while finance availability (FA), AI innovation (AI), quality of institutions (IQ), and urbanization (URBA) constitute distinctive concepts. The econometric explanation of equation (3) was stated previously.

$$LCF_{it} = \delta_0 + \delta_1 GDP_{it} + \delta_2 GDP^2{}_{it} + \delta_3 PAI_{it} + \delta_4 FGOB_{it} + \delta_5 TI_{it} + \delta_6 URBA_{it} \quad (3)$$

The next equation illustrates the logarithmic values of the factors, which makes statistical information less complicated to interpret and constitute conclusions upon. Moreover, logarithmic scales assist in managing information with different dimensions while tackling obstacles such as heteroscedasticity, which is particularly relevant when working on large datasets. In this case, the research's coefficients are displayed in the parameter range of δ_0 to δ_6 .

$$LLCF_{it} = \delta_0 + \delta_1 LGDP_{it} + \delta_2 LGDP^2{}_{it} + \delta_3 LAI_{it} + \delta_4 LFA_{it} + \delta_5 LIQ_{it} + \delta_6 LURBA_{it} \ (4)$$

Empirical Methods

In the USA, the analysis used the ARDL method for data assessment to explore the link across LCF and variables such as GDP, GDP2, AI innovation, FA, IQ, and URBA. Additionally, we used the FMOLS, DOLS, and CCR approaches to ensure robustness. We conducted unit root assessments (DF-GLS, ADF, and P-P) at the start of the inquiry to explore stationarity. We then applied the ARDL bound analysis, given the nature of the time series data. We then performed estimates for the short and long-term ARDL. Next, we undertook multiple diagnostic tests in addition to the pairwise Granser causality analysis. After a rigorous process of evaluation, we managed to determine which econometric approach was the most precise and effective.

Unit Root Tests

A time series is considered to have a unit root when it displays a stochastic trend (Polcyn et al., 2023). Many studies have recommended running multiple stationarity analyses to assess the sequence integration categorization because the efficiency of such tests varies depending on the sample size (Voumik et al.,2023c).The present study used the ADF (Dickey and Fuller, 1979), the P-P (Philips and Perron, 1968), and the DF-GLS (Elliot et al., 1992) examinations to see if the data set was stationary. Due to its ability to control serial autocorrelation, the ADF technique has grown in favor (Dickey and Fuller, 1981). Compared to the DF approach, the ADF technique is more dependable and appropriate for more complicated tasks (Fuller, 2009).

ARDL Methodology

When variables exhibit stationarity, Pesaran et al. (2001) created the ARDL limits testing technique. Raihan and Voumik (2022a) assert that this technique offers the benefit of deployment in any series integration situation. As a result, the ARDL cointegration method offers precise and effective estimates of the variables' long-term relationship (Raihan and Voumik, 2022b). Moreover, scholars can effortlessly detect dynamic adjustment mechanisms by incorporating lagged terms of variables with ARDL (Raihan et al., 2024c). Therefore, one can apply the ARDL bounds analysis technique regardless of whether the basic returning system separates in I(2) and the cointegration order occurs at I(0) or I(1) (Raihan et al., 2022a; Voumik & Ridwan, 2023). Equation (5) displays the bounds assessment for the ARDL in the following manner:

$$\Delta \mathrm{LLCF_t} = \delta_0 + \rho_1 \mathrm{LLCF_{t-1}} + \rho_2\, \mathrm{LGDP_{t-1}} + \rho_3 \mathrm{L}GDP^2{}_{\mathrm{t-1}} + \rho_4 \mathrm{LAI_{t-1}} + \rho_5 \mathrm{LFA_{t-1}} + \rho_6 \mathrm{LIQ_{t-1}} + \rho_7 \mathrm{L}URBA_{\mathrm{t-1}} + \sum_{\mathrm{i=1}}^{\mathrm{q}} \delta_1\, \Delta \mathrm{LLCF_{t-i}} + \sum_{\mathrm{i=1}}^{\mathrm{q}} \delta_2\, \Delta \mathrm{LGDP_{t-i}} + \sum_{\mathrm{i=1}}^{\mathrm{q}} \delta_3\, \Delta \mathrm{L}GDP^2{}_{\mathrm{t-i}} + \sum_{\mathrm{i=1}}^{\mathrm{q}} \delta_4\, \Delta \mathrm{LAI_{t-i}} + \sum_{\mathrm{i=1}}^{\mathrm{q}} \delta_4\, \Delta \mathrm{LFA_{t-i}} + \sum_{\mathrm{i=1}}^{\mathrm{q}} \delta_4\, \Delta \mathrm{LIQ_{t-i}} + \sum_{\mathrm{i=1}}^{\mathrm{q}} \delta_4\, \Delta \mathrm{LURBA_{t-i}} + \varepsilon_\mathrm{t} \quad (5)$$

Pesaran et al. (2001) illustrated the use of the upper and lower bounds as fundamental values to facilitate the comparison of the F-statistics.. If the test results fall within the lowest and highest bounds, they are considered ambiguous (Raihan et al., 2023a; Voumik et al.,2023b). Engel and Granger (1987) established long-term connections before introducing the ECM to assess short-term correlations and ECT. For the long-term evaluation of the ARDL, we use Equation (6).

$$\Delta LLCF_t = \delta_0 + \sum_{i=1}^{q} \rho_1\, \Delta LLCF_{\mathrm{t-1}} + \sum_{i=1}^{q} \rho_2\, \Delta \mathrm{LGDP_{t-1}} + \sum_{i=1}^{q} \rho_3 \Delta GDP^2{}_{\mathrm{t-1}} + \sum_{i=1}^{q} \rho_4\, \Delta\, LAI_{t-1} + \sum_{i=1}^{q} \rho_5 \Delta \mathrm{LFA_{t-1}} + \sum_{i=1}^{q} \rho_6\, \Delta LIQ_{t-1} + \sum_{i=1}^{q} \rho_7\, \Delta LURBA_{t-1} + \theta ECM_{t-1} + \varepsilon_t \quad (6)$$

Robustness Check

We deployed the FMOLS, DOLS, and CCR methods to assess the dependability of the ARDL results. According to Ahmad et al. (2024a), the FMOLS method can produce accurate results and is capable of handling bias resulting from missing variables, variability, serial correlation, error in measurement, and smaller sample sizes. The DOLS method tries to figure out a long-term link in a model where the factors are cointegrated but have different levels of integration, endogeneity and autocorrelation issues (Stock and Watson, 1993; Begum et al., 2020). Furthermore, without requiring any modifications, the CCR regression model applies to both multivariate and single equation regression methods, thereby preserving efficiency (Park, 1992). It separates zero-regularity independent factors from error terms in cointegrating models (Pattak et al., 2023).

Pairwise Granser Causality Test

Granger causality is a theory of statistics that assesses whether previous values of one parameter provide valuable information for finding the other to explore the link between the two variables (Rose and Paparas, 2023). Our work made use the pairwise Granger-causality test Granger, 1969). We say that another time series

X "granser-causes" a time series Y if it can predict the future of the latter (Raihan and Tuspekova, 2022a).However, a bivariate autoregressive model may display the variables Xt and Yt.

$$X_t = \gamma_1 + \sum_{i=1}^{n} \alpha_i Y_{t-i} + \sum_{i=1}^{n} \mu_i X_{t-1} + e_t \quad (7)$$

$$Y_t = \gamma_2 + \sum_{i=1}^{n} \Omega_i Y_{t-1} + \sum_{i=1}^{n} ¥_i X_{t-i} + u_t \quad (8)$$

Here, n denotes the number of lags.

Diagnostic Test

We employed the LM test, the Jarque-Bera test (Jarque and Bera, 1987), and the BPG test (Breusch and Pagan, 1979), to identify significant problems that could directly affect the precision of the predicted coefficients. To ensure that errors do not correlate with time and produce skewed and deceptive calculations, the LM technique examines residuals for serial correlation. Because of heteroscedasticity, the Breusch-Pagan-Godfrey test may produce inaccurate estimates and standard errors. We also check how well the short-term beta coefficients in the ARDL method fit together by comparing the repeated residuals to the CUSUM and CUSUMQ tests.

Results and Discussion

The following section includes actual figures generated from predetermined estimating methods, whereas Table 2 highlights the statistical properties of the variables under consideration. Because every data point had the same number of observations (32), the box delivers an extensive evaluation that includes key statistical measurements, including the mean, median, maximum, minimum, standard deviation, and probability value. Most variables had positive means, except LLCF and LFA, and LGDP2 had the highest mean. Furthermore, the standard deviations of all variables were low, indicating little change over time and a high concentration of data points around the mean.

Table 2. Summary statistics of the variables

Variables	LLCF	LGDP	LGDP2	LAI	LFA	LIQ	LURBA
Mean	-0.835416	10.64393	113.3917	7.505506	-0.129338	0.471661	4.377885
Median	-0.822656	10.71885	114.8942	7.157725	-0.13288	0.444502	4.382195
Maximum	-0.63269	11.15938	124.5318	9.724421	-0.065403	0.692247	4.417309
Minimum	-0.970971	10.08116	101.6297	6.320768	-0.183003	0.243055	4.32148
Std. Dev.	0.093945	0.318778	6.76113	1.035853	0.032861	0.110563	0.027091
Skewness	0.065531	-0.255693	-0.219087	1.155679	0.25722	0.257958	-0.500595
Kurtosis	1.965479	1.888894	1.876795	2.992345	1.75315	2.707801	2.252894
Jarque-Bera	1.449882	1.994763	1.938117	7.123243	2.425709	0.468734	2.08073
Probability	0.484353	0.368844	0.37944	0.028393	0.297347	0.791071	0.353326
Sum	-26.73331	340.6058	3628.534	240.1762	-4.138819	15.09316	140.0923
Sum Sq. Dev.	0.273596	3.150205	1417.099	33.26275	0.033476	0.378947	0.022751
Observations	32	32	32	32	32	32	32

Moreover, the variables LLCF, LAI, LFA, and LIQ exhibited positive skew, whereas the remaining variables displayed negative skew. We executed the Jarque-Bera Normality Test to ensure each factor in this investigation had a normal distribution.
Table 3 illustrates the stationarity tests for the log-transformed factors at both I(0)and I(1) levels. The results demonstrate that financial accessibility, institutional quality, and urbanization are stationary at the level I(0) form. Conversely, LCF, GDP, GDP squared, and AI innovation were non-stationary at the level; however, they became stationary after accounting for the initial difference I(0). Given the heterogeneous order of integration, we can employ the ARDL methodology in further section.

Table 3. Results of Unit root test

Variables	ADF		P-P		DF-GLS		Decision
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	
LLCF	-0.588	-5.743***	-0.643	-5.432***	-1.576	-4.110***	I(1)
LGDP	-0.725	-4.148***	-0.359	-4.928***	-1.118	-3.731***	I(1)
$LGDP^2$	-0.416	-5.903***	-0.740	-4.863***	-1.241	-3.655**	I(1)
LAI	-2.061	-4.134***	-1.068	-3.671***	-2.341	-4.061***	I(1)
LFA	-3.871**	-4.071***	-3.703**	-4.021***	-3.771**	-4.052***	I(0)
LIQ	-4.052***	-5.007***	-3.054**	-4.090***	-3.342**	-3.770***	I(0)
LURBA	-4.115***	-7.043***	-7.654***	-8.453***	-3.065**	-4.432***	I(0)

The ARDL bound assessment results reject the null hypothesis of no co-integration at the 1% significance threshold. The F-test statistic result of 8.345 achieved the stipulated value. Consequently, it is feasible to contend that the parameters of the model exhibit specific co-integrating interactions. These attributes facilitate the framework's rapid adaptation to a typical stochastic disturbance. Therefore, we can deduce that the variations in all identified factors influence the LCF in the United States.

Table 4. Results of ARDL bound test

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	8.34532	10%	1.99	2.94
K=6		5%	2.27	3.28
Asymptotic: n=1000		2.50%	2.55	3.61
		1%	2.88	3.99

Once the bound testing procedure confirmed the cointegration, we could assess the long-term connection among those factors. Table 5, which incorporates the dynamic ARDL paradigm, illustrates the both period effects of LGDP, LGDP2, LAI, LFA, LIQ, and LURBA on LLCF in the United States. According to the research, the US environment's load capacity appears to go up with GDP growth but falls with economic growth over time. Our findings indicate that due to financial growth, the ecosystem increasingly loses its natural characteristics. The result provides a theoretical explanation because the US economy has grown larger and heavily relies on sources like oil and gas, which damage the natural world. According to Table 5's conclusions, for every 1% expansion in GDP, the LCF declines by 1.687% over the long term and by 0.738% during the short term. Rising economic growth and ecosystem damage are linked to increased consumption and development efforts to meet social

expectations (Raihan and Tuspekova, 2022b). Several studies, such as those by Ridwan et al. (2023), Bekun (2024), Islam et al.(2024), Kirikkaleli et al. (2023), Raihan et al.(2023c) Raihan et al.(2023b) and Wang et al. (2023), back up the idea that GDP and ecosystem degradation are linked in a good way. However, Guo et al. (2024) observed that in China, the effect of per capita GDP on the natural world will eventually lessen. Similarly, Raihan et al.(2024a) aligned with this outcome in India. But Onwe et al.(2024) found asymmetric effect of GDP on environment condition in Japan. In contrast, each unit of GDP2 boost results in a 1.644% long-term and 0.668% short-term enhancement of LCF. Given that the coefficient for LGDP is unfavorable and for LGDP2 is beneficial, both of these are statistically significant, it appears that atmospheric pressure decreases over time, validating the recently proposed LCC hypothesis for the US. However, Dogan et al. (2020) discovered that GDP2 worsens the degree of environmental adaptability in the BRICS.
The LAI coefficients exhibit a positive association with LLCF, predicting a 0.077% long run and a 0.030% short run increase in LLCF for every 1% increase in AI innovation. According to Platon (2024) and Rahman et al.(2024), artificial intelligence is an important component that could improve and hasten the rise of the circular economy. Furthermore, AI reduces carbon emissions in China by strengthening information facilities, advancing green technology innovations, and optimizing industry structure (Chen et al., 2022). In a similar vein, LCF is positively associated with FA in both the long and short runs, and this association is statistically significant.

Table 5. Results of ARDL short-run and Long-run Estimation

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Long-run estimation				
LGDP	-1.687	0.0400	-2.080804	0.000
LGDP2	1.644	0.2359	3.971924	0.000
LAI	0.077	0.0305	1.525705	0.023
LFA	0.602	0.3552	1.696772	0.110
LIQ	0.257	0.1159	2.222973	0.042
LURBA	-1.715	0.6682	-4.765392	0.000
C	7.638	8.4340	6.135154	0.000
Short-run estimation				
D(LLCF(-1))	-0.047	0.0601	-0.7883	0.428
D(LGDP)	-0.738	3.3020	-4.7658	0.003
D(LGDP2)	0.668	0.1505	4.4436	0.005
D(LAI)	0.030	0.0178	3.7343	0.033
D(LFA)	0.853	0.1492	5.7165	0.000
D(LIQ)	0.112	0.0211	5.2924	0.000
D(LURBA)	-1.198	2.1359	7.1157	0.000
CointEq(-1)*	-0.7604	0.0718	-10.5823	0.000

These findings suggest that access to the financial system might be advantageous to the USA ecosystem. Particularly, a 1% development in FA causes a 0.602% long-term rise in LCF and a 0.853% short-term increase.

Similarly, Alam et al. (2024) revealed that financial inclusion minimizes CO2 emissions and improves the environmental quality across oil-producing countries. However, our result is agreed with Le et al. (2020) in Asia, which indicates that the expansion of FA is harmful to biodiversity. Furthermore, having easy access to finance requires more energy, which increases CO2 emissions and harms our planet (Acheampong 2019).

Moreover, there exits an encouraging relationship between LIQ and LLCF, with each 1% increase in LIQ increasing LCF by 0.257% in the long term and 0.112% in the short run, and this result is significant at the conventional level. Our research indicates that strong institutional structures preserve the ecosystem by executing legislation and encouraging green growth. Zheng et al. (2024) in the E-7 economies, Hussain and Dogan (2021) in the BRICS country, and Ashraf and Javed (2023) in the BRI countries have found that enhanced institutional quality contributes to a better atmosphere and significantly reduces pollution. However, Sibanda et al. (2023) within sub-Saharan Africa and Amin et al. (2023) across South Asia have discovered that the rising quality of institutions is contributing to ecological destruction. Conversely, the negative and statistically significant URBA coefficients indicate that both long-term and short-term increases in LURBA negatively affect environmental quality. A 1% expansion in URBA raises LCF by 1.715% in the long run and 1.198% in the short run. Similarly, Voumik et al. (2024) in Bangladesh, Khalid et al. (2022) in the G-7 area, and Ramzan et al. (2024) in China found that population growth boosts CO2 emissions. However, Wang et al. (2021) investigated in OECD territories that urbanization improves environmental sustainability by lowering CO2 emissions.

In Table 6, robustness testing results confirm the findings obtained through ARDL calculations. At the 1% range, the GDP factors in the FMOLS, DOLS, and CCR models are statistically significant and have a negative trend. A 1% rise in GDP diminishes LCF by 1.517%, 1.321%, and 1.508%, respectively. In contrast, GDP2 has an upward and substantial relationship with LCF at the 1% significance threshold in all models. A 1% increase in GDP2 increases LCF by 1.469%, 1.701%, and 1.464%, respectively, implying that greater GDP levels have a favorable impact on LCF.

A 1% development in LAI boosts LCF by 0.041% in the FMOLS model, 0.156% in DOLS, and 0.049% in CCR. This finding highlights that agricultural investment positively influences LCF. Furthermore, an extra 1% in LFA causes an improvement in LCF of 1.012%, 1.387%, and 0.837% in the FMOLS, DOLS, and CCR simulations, respectively. The results reported here are significant at the 1% level and correlate with both term ARDL evidence. According to the FMOLS estimation, a 1% increase in LIQ improves LCF by 0.126%, 0.141%, and 0.147%, respectively. Such results are significant at the 5% level for FMOLS and DOLS, as well as at the 1% level for CCR, which supports the ARDL findings. Conversely, a 1% expansion in LURBA falls to the LCF by 0.801% and 1.504% in the FMOLS and DOLS methods. On the other hand, a 1% spike in LURBA will increase the LLCF by 2.831% in the CCR estimation, resulting in a significant 5% threshold. These outcomes also align with the ARDL short- and long-run estimation.

Table 6. Results of Robustness check

Variables	FMOLS	DOLS	CCR
LGDP	-1.517***	-1.321***	-1.508***
$LGDP^2$	1.469***	1.701***	1.464***
LAI	0.041**	0.156**	0.049**
LFA	1.012***	1.387***	0.837***
LIQ	0.126**	0.141**	0.147***
LURBA	-0.801***	-1.504***	2.831***
C	6.975***	5.968***	6.990***

The insights provided by Table 7 demonstrate the causal links between several kinds of economic variables. The F-statistic of 3.38826 and p-value of 0.0499 reject the null hypothesis of no connection at the 5% significance range, indicating that LLGDP does not cause Granger-cause LLCF. Furthermore, p-values below the standard significance threshold rule out the null hypothesis that there is no linkage in these circumstances, supporting the existence of one-way causality between LGDP2, LAI, LFA, LURBA, and LLCF. However, we found no causative association between LLCF and LIQ. Because p-values above the conventional significance level suggest no significant causal correlations between LLCF and LGDP, LLCF and LGDP2, LLCF and LAI, LFA and LLCF, and LURBA and LLCF, we cannot reject the null hypothesis that there is no causality in these interactions.

Table 7. Results of pairwise Granger Causality test

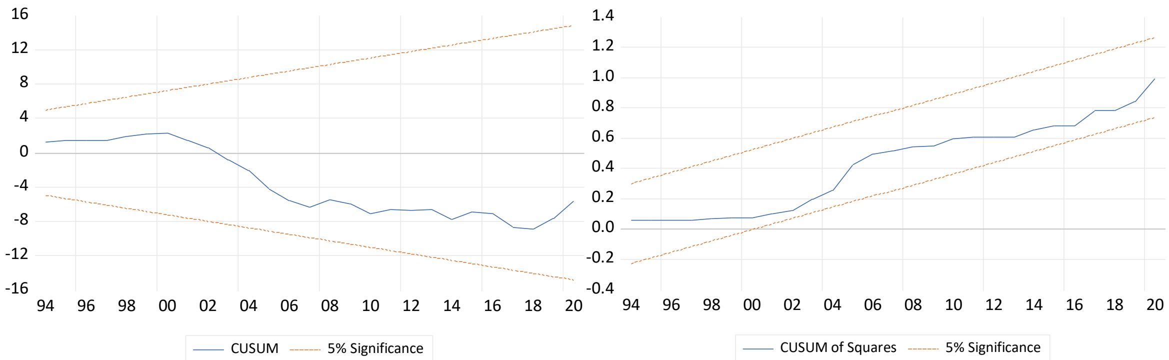
Null Hypothesis	Obs	F-Statistic	Prob.
LGDP $\neq$ LLCF	30	3.38826	0.0499
LLCF $\neq$ LGDP		0.44313	0.6471
LGDP2 $\neq$ LLCF	30	3.4843	0.0463
LLCF $\neq$ LGDP2		0.44696	0.6446
LAI $\neq$ LLCF	30	2.38966	0.0123
LLCF $\neq$ LAI		1.48366	0.2461
LFA $\neq$ LLCF	30	1.20508	0.3165
LLCF $\neq$ LFA		6.46444	0.0055
LIQ $\neq$ LLCF	30	1.81009	0.1844
LLCF $\neq$ LIQ		1.18981	0.3209
LURBA $\neq$ LLCF	30	2.68762	0.0877
LLCF $\neq$ LURBA		5.37891	0.0114

Table 8 shows that none of the diagnostic techniques support the null hypothesis, thus ruling it out. The p-value of 0.4231 from the Jarque-Bera assessment confirms the constant distribution of the residuals. With a p-value of 0.3612, the Lagrange multiplier analysis confirms no serial correlation in the residuals. Ultimately, having a p-value of 0.4123, the Breusch-Pagan-Godfrey assessment validates that the residuals have no evidence of heteroscedasticity.

Table 8. The results of diagnostic tests

Diagnostic tests	Coefficient	p-value	Decision
Jarque-Bera test	2.5671	0.4231	Residuals are normally distributed
Lagrange Multiplier test	1.054	0.3612	No serial correlation exits
Breusch-Pagan-Godfrey test	0.8741	0.4123	No heteroscedasticity exists

Additionally, we apply the CUSUM and CUSUM-SQ statistics to search for structural stability in residuals over both long and short periods. The outcomes are within critical limits, with the CUSUM-SQ plot remaining on the crucial line, as shown in the following figure. This indicates that the parameters are consistent and adequately stated at the 5% level of significance.



Conclusion and Policy Implications

The study investigated the multifaceted connections across economic growth, AI innovation, financial accessibility, institutional quality, and urbanization, as well as their effects on the LCF in the USA between 1995 and 2021. Using sophisticated econometric techniques, the investigation studied the load capacity factor to identify the variables affecting environmental sustainability in the chosen area. We used various unit root analyses, like ADF, P-P, and DF-GLS, to confirm that the factors were not stationary and to make sure the investigation was strong. This created opportunities for assessing the short and long-term influences using the novel ARDL methodology. Robustness testing using FMOLS, DOLS, and CCR confirms the validity and accuracy of the ARDL findings, thereby enhancing the credibility of the results. Finally, we employed three diagnostic tests to check for heterocesdaticity and autocorrelation issues in the selected data set. The ARDL analysis outcomes indicate multiple significant feedbacks. The outcomes showed that GDP growth and urbanization had a negative association with LCF in both the short and long run. These results underscore that the expansion of financial activities and the rise in urban population will lead to increased pollution due to the utilization of more fossil fuels and natural assets. However, GDP squares demonstrate a favorable implication on ecological condition of the USA in both periods, suggesting that a higher GDP can introduce more advanced environmentally-friendly approaches. Similarly, we found a positive association between LCF and AI innovation, financial accessibility, and institutional quality, suggesting that the use of modern AI technologies, improvements in institutional quality, and increased financial inclusion can enhance the natural health of the selected country. The Pairwise Granger causality test revealed a unidirectional causality from LGDP, LGDP2, and LAI to LLCF, as well as from LLCF to LFA and LURBA. However, there is no evidence that LLCF Granger causes LGDP, LGDP2, or LAI. Similarly, we found no causal relationship between LIQ and LLCF, and neither LFA nor LURBA cause LLCF. These relationships highlight the importance of how investments in artificial intelligence, financial accessibility, and good institutions impact the dynamics of ecological sustainability in the United States. Therefore, policymakers can create targeted strategies and regulations to reduce ecological degradation while promoting sophisticated technological innovation, a stable financial system, and standard institutions in the selected area.

The findings of our paper have important policy suggestions for improving the load capacity factor in the United States. Policymakers should give priority to policies that enhance financial accessibility, as research has demonstrated their favorable impact on the load capacity factor. One such approach is to develop strategies that facilitate increased availability of credit and financial services, specifically targeting small and medium-sized firms (SMEs). These enterprises are essential for driving economic growth and maximizing resource utilization. Furthermore, the beneficial influence of AI advancement on the ability to handle heavy loads implies that there should be support for expenditures in technology and innovation. Policymakers have the ability to encourage and support research and development in the field of artificial intelligence (AI), offer tax advantages to corporations that embrace AI technology, and establish a regulatory framework that promotes advancement while also guaranteeing adherence to ethical norms. The study urges the importance of institutional excellence in improving load capacity, emphasizing the requirement for robust governance, transparency, and the implementation of laws that safeguard property rights and encourage equitable competition. Conversely, the disastrous consequences of urbanization on the load capacity factor highlight the necessity for meticulous urban planning and development strategies. Policymakers should take into account the possible burden on infrastructure and resources that rapid urbanization might impose and adopt sustainable urban development measures that alleviate these impacts. This may involve allocating funds towards environmentally friendly infrastructure, advocating for distributed development, and ensuring that urban growth is in line with the available local resources and infrastructure. Policymakers may achieve a balanced approach by considering these factors: financial, technological, and institutional improvements. This strategy will boost the load capacity factor while also reducing the negative impacts of urbanization.

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