**Discover** Sustainability

Research

# Determinants of environmental sustainability in the United States: analyzing the role of financial development and stock market capitalization using LCC framework

**Mohammad Ridwan[1] · Nazhat Nury Aspy[1] · Shewly Bala[2] · Md. Emran Hossain[3,4] · Afsana Akther[5] · Md. Eleais[1] · Miguel Angel Esquivias[6]**

Received: 18 August 2024 / Accepted: 1 October 2024
Published online: 10 October 2024


**Abstract**
This research investigates how the USA's load capacity factor (LCF) has been impacted by trade openness, financial development, stock market capitalization, and industrialization over the period 1990–2022. This study also tests the "Load Capacity Curve (LCC)" hypothesis. Various unit root tests were conducted to determine the stationarity of the dataset, revealing that the variables are free from unit root problems and exhibit mixed orders of integration. The "Autoregressive Distributed Lag (ARDL)" bounds test confirmed co-integration among the variables. The results from the ARDL model validated the existence of the LCC hypothesis in the USA. The findings also demonstrated that industrialization is positively correlated with LCF, whereas financial development, stock market capitalization, and trade openness are negatively correlated with LCF. To ensure the robustness of the ARDL estimations, the study also employed several regressions, all of which confirmed the validity of the ARDL results. Additionally, pairwise Granger causality tests revealed unidirectional causal relationships between GDP and LCF, stock market capitalization and LCF, and industrialization and LCF, while no causal relationships were found between financial development and LCF and trade openness and LCF. The findings advocate that the USA should advance eco-friendly industrial practices to ensure environmental sustainability, alongside regulated financial markets and institutions that mandate the utilization of green investments.

**Keywords** Financial development · Load capacity factor · LCC hypothesis · Stock market capitalization · Global Trade

## 1 Introduction

Environmental and fiscal issues are currently at the top of national agendas in the modern world. Human activities, industrial operations, and transportation persist in releasing significant quantities of pollutants that detrimentally affect the environment, despite increasing public awareness of the necessity to combat climate change [1, 2]. The environmental conditions in several nations have been severely compromised due to their rapid industrial and

✉ Miguel Angel Esquivias, miguel@feb.unair.ac.id; Mohammad Ridwan, m.ridwan.econ@gmail.com; Nazhat Nury Aspy, nazhatnuryaspy@gmail.com; Shewly Bala, eden19shewly@gmail.com; Md. Emran Hossain, emranaerd@gmail.com; Afsana Akther, afsana.rinkey.5789@gmail.com; Md. Eleais, eleais1213@student.nstu.edu.bd | [1]Department of Economics, Noakhali Science and Technology University, Noakhali 3814, Bangladesh. [2]Department of Finance, University of Dhaka, Dhaka 1000, Bangladesh. [3]Department of Agricultural Sciences, Texas State University, San Marcos, TX 78666, USA. [4]Jadara University Research Center, Jadara University, Irbid, Jordan. [5]Department of Economics, Noakhali Science and Technology University, Noakhali 3814, Bangladesh. [6]Faculty of Economics and Business, Airlangga University, Surabaya 60286, Indonesia.

financial growth [3]. The United States (USA) stands out among these nations due to its transformation into a powerhouse in both production and consumption. The USA contributed 13.3% of the world's GDP in 2024 and about 4.21% of the world's population [4]. In the meanwhile, the USA emitted 5,416 metric tons (MT) of $CO_2$ in 2020, accounting for approximately 16% of the global emissions [5]. Hence, the USA bears substantial responsibility for the climate crisis and global warming, as it is one of the primary emitters of greenhouse gases; therefore, examining its environmental sustainability is a significant concern.

Society has traditionally prioritized monetary and economic issues, erroneously believing these are the principal avenues for societal and individual prosperity. However, a recent study indicates that this type of reasoning adversely affects environmental sustainability measured through various proxies. Several researchers have utilized ecological footprint (EF) as an indication of ecological contamination, while others have looked at $CO_2$ emissions [6–8]. The use of the LCF has been preferred in more recent investigations [9]. As suggested by Siche, Pereira [10], the LCF considers both the supply and demand sides of the environment, which has made it a novel and popular approach recently [11]. The LCF is measured as the ratio between per capita biocapacity and per capita EF. A greater LCF number, approaching 1, is beneficial for the environment, and vice versa. Research on the LCF has traditionally relied on economic growth as an indicator [12, 13]. A U-shaped association between LCF and income is possible. This is because, as incomes rise, there is a risk that emerging nations will lose sight of environmental concerns, leading to worsening ecological quality and, ultimately, LCF [14, 15]. However, improved LCF is the result of increased awareness of sustainability when a nation's GDP surpasses a certain level. Thus, according to the "load capacity curve (LCC)" theory, the path from LCF to income is structured like a U-shape.

One important consideration when talking about the environmental impact is financial development (FD). When it comes to liberalizing the financial system and expansion, there's a chance that it will attract FDI and higher levels of R&D investments. This, in turn, can accelerate economic growth, which may affect environmental performance in a good or bad way [16]. Due to its correlation with energy consumption, economic expansion resulting from these FDs could outcome in increased industrial contamination, which comes along with the destruction of the environment [9, 17, 18]. In terms of the eco-friendliness of the finance sector, investments in polluting companies by private companies will probably slow down environmental progress [19]. However, it is widely acknowledged in the finance-environment discourse that the finance sector plays a crucial role in mitigating pollution by providing appropriate ecological financing [20].

Current discussions should encompass not just economic growth and financial development but also the relationship between sustainability in the environment and stock market capitalization (SMC) [21]. Stock markets facilitate the sharing of resources and the expansion of economic activity by linking all relevant parties. SMC serves as a conduit for financial market resources, according to Altan [22] while Bai [23] classify the stock market as an influential gauge and economic barometer. Given that companies often struggle to afford environmentally friendly technologies, the size of their stock market accounts can have a major impact on how long it takes for renewable energy to solve the problem of environmental sustainability [24].

However, from the explanatory variable standpoint, several factors have been investigated for their effects on the environment, including trade openness, economic growth, and industrialization. Scholars have continued to consider additional factors, but trade openness has gained traction as a sociocultural component. Trade liberalization has benefited countries by expanding trade volume and income from a more diverse range of inputs and outputs [25], but it has also increased environmental concerns. Economic growth, new job opportunities, and improved living standards were all aided by the rise of industrial output along with advanced technology. Notwithstanding the advantages, increasing industrial output is the leading cause of waste production and energy use [26, 27]. While industrialization has long been a key engine of economic expansion in the USA—including a stock market valuation of $50–60 trillion USD and an expenditure of roughly 10–15% of GDP—it has additionally led to environmental deterioration. Nevertheless, insufficient emphasis has been devoted to the industrialization-LCF as well as stock market-financial development-LCF nexus in the context of the USA. Therefore, the purpose of this study is to respond to the following research question:

(i) What effects do trade openness, financial growth, capitalization of the stock market, and industrialization have on the USA's LCF between 1990 and 2022?
(ii) Does the LCC theory hold validity within the context of the USA?

This study enhances existing research in the following manners: Firstly, this is one of the pivotal studies that investigate the stock market and LCF nexus for the USA. Secondly, unlike previous studies that mostly examined underdeveloped

nations, this research focused on one of the world's most industrialized countries with a strong financial system to investigate and demonstrate a clear relationship between financial systems and environmental sustainability. Additionally, the USA, chosen for its significant ecological deficit and developed economy, offers an ideal context to investigate the correlation between economic activity and environmental sustainability. Thirdly, this study reveals that, although industrialization increases LCF, financial expansion, and stock market capitalization mitigate environmental degradation, contradicting the traditional belief that economic progress invariably harms the environment. This unique contribution is vital for stakeholders as it offers tangible insights into how developed countries, like the USA, may harmonize economic growth with environmental sustainability. This study substantiates the LCC hypothesis in the USA, indicating that the financial sector may substantially alleviate environmental impacts. This analysis offers politicians, corporations, and environmental advocates scientifically substantiated recommendations for reconciling economic and environmental objectives, particularly through financial and industrial modifications. Finally, the results directly augment the broad notion of sustainable development, as outlined in this journal, by clarifying how economic policies can be designed to promote resilience in economic stability and ecological systems. This study provides a foundation for informed decision-making that fosters long-term sustainability in industrialized economies.

## 2 Literature review

### 2.1 Economic growth-LCF Nexus

People think that more economic activity means more $CO_2$ emissions as the economy grows. However, when we look at other metrics for environmental quality, including LCF, instead of only $CO_2$ emissions, the situation gets trickier. Numerous studies have been conducted on the link between economic expansion and a sustainable environment. Based on their analysis using the ARDL approach, Pata and Balsalobre-Lorente [28] found that between 1965 and 2017, GDP growth had a statistically significant negative effect on LCF in Turkey. In a similar vein, Ni et al. [29] used the CS-ARDL method to determine that resource-rich nations had a negative correlation between LCF and economic growth. The study conducted by Khan et al. [30] examined the G7 and E7 nations between 1997 and 2018. The researchers discovered that as economies developed, the LCF decreased. Also, between 1970 and 2017, Xu et al. [31] discovered that Brazil's GDP per capita decreased the LCF. In the study of South Africa spanning 1980–2017, Awosusi et al. [32] found that the LCF was negatively correlated with economic prosperity. Similarly, the analysis of ASEAN nations from 1980 to 2018 by Shang, Razzaq [12] found that the LCF was negatively impacted by economic expansion. On the other hand, Saliba et al. [33] revealed a strong positive correlation between economic expansion and increased carbon emissions in China. In a related study, Özbay et al. [34] explored the combined effects of economic growth and globalization on environmental pollution in China. Their research demonstrated that both economic growth and the forces of globalization contribute significantly to the increase in $CO_2$ emissions.

### 2.2 Financial development (FD)-LCF *Nexus*

Most empirical research pertaining to FD has focused on modeling $CO_2$ emissions and environmental footprint. According to various studies, including those conducted in Pakistan, South Africa, and Malaysia, as well as others in developed and emerging countries, the development of the financial sector has been found to improve environmental quality [35–39]. Fakher et al. [40] have shown that development in the financial sector has positive ecological repercussions. Out of all the empirical studies that have looked at how other economies' FD has affected the environment, only a handful—including Latif and Faridi [41], Akhayere et al. [42], Karta et al. [43] and Caglar and Yavuz [44]—have used the LCF in their models. According to Okezie et al. [45], the Nigerian LCF worsens over time due to FD. Similarly, Akhayer et al. [42] examine the effects of Turkey's FD on the LCF from 1965 to 2018. On the other hand, in ten tourist hotspots, Pata and Tanriover [46] found that LCF decreased because of FD.

Athari [47] investigated the impact of FD on the environment, discovering that it reduces environmental harm in the BRICS region. Gulzar et al. [48] analyzed the relationship between green banking initiatives and environmental performance, concluding that these initiatives contribute to promoting environmental sustainability. Avcı and Sarıgül [49] discovered that FD contributes to the rise in $CO_2$ emissions, indicating a decline in environmental quality. Cetin and Ecevit [50] revealed that FD exacerbates $CO_2$ emissions in Turkey. Building on this, Cetin and Sarıgül [51] extended the analysis to 14 emerging nations, demonstrating that FD significantly contributes to increased environmental pollution across these

economies. In contrast, Cetin and Ozturk [52] examined the OECD region and found that the use of renewable energy, combined with FD, plays a mitigating role in environmental impact. This suggests that while FD can drive pollution in emerging economies, it may support sustainable practices in developed regions when paired with renewable energy initiatives. It is clear that there is still debate on how FD affects the environment.

### 2.3 Stock market capitalization (SMC)-LCF *Nexus*

Many studies have attempted to answer the question of how stock investments affect the natural world. Despite this, there is a lot of research that looks at the correlation between SMC and environmental degradation; however, most of this research relies on carbon emissions. This is why Uysal and Çayir [53] examined the data from 1991 to 2021 to determine the correlation between SMC and the state of the environment. They found that changes in stock market trends have an uneven and substantial impact on Turkey's environmental quality over both the near and long term. Paramati and Alam [54] investigated the link between stock market growth and environmental damage for economies with advanced as well as emerging economies from 1992 to 2011. The authors of this study stated that industrialized economies saw a decrease in $CO_2$ emissions when their stock markets were more capitalized, but they found the opposite to be true for developing market countries. From 1980 to 2017, the effect of Malaysian stock market performance on the atmosphere was studied by Al-mulai and Solarin [55]. According to the NARDL short-term data, $CO_2$ emissions rose in response to higher stock trading levels but fell flat in response to lower levels. In addition, when considering the long-term outcomes, it was discovered that $CO_2$ emissions were greatly reduced with a reduction in stock trading.

Research by Habiba and Xinbang [56] showed that developed economies and the G20 nations saw a decrease in carbon emissions as stock markets developed, whereas emerging nations saw an increase. Mhadhbi et al. [57] revealed that positive stock market shocks had a somewhat smaller impact on carbon emissions in emerging market nations compared to negative shocks. On the other hand, there is new evidence that the stock market can increase renewable power [58]. Consequently, environmental quality is improved because of the decrease in $CO_2$ emissions brought about by the expansion of clean energy capacity. While these studies do find evidence of the stock market's beneficial impact on the environment, they use a linear philosophical framework, which is inadequate for analyzing the market's exponential rise since 1980 [59].

### 2.4 Trade openness-LCF *Nexus*

Pollution levels can rise or fall because of globalization of trade. For instance, using the LCF as a stand-in for environmental state, Huilan et al. [60] investigate how trade liberalization relates to environmental states. Using a twofold adjustment methodology, they found that trade openness was positively correlated with LCF. Using the CCEMG and MG estimate approach for the G-20 countries, Ibrahim and Ajide [61] found that trade openness helps to reduce environmental harm and discovered that a sustainable environment was correlated with trade liberalization. Similarly, Dam and Sarkodie [62] used ARDL to investigate whether Turkey's LCF would have been better off with more trade openness from 1965 to 2018. For developing nations, it is important to verify the link between LCF and trade openness. Wang and Sun [25] found that trade liberalization significantly damaged the environment.

Akhayere et al. [42] found a different view on how trade liberalization affects the LCF. The outcomes showed that the country's LCF was negatively affected by greater trade openness. Similarly, Agila et al. [63] found that trade openness lowers the LCF for almost all percentiles. Consequently, there are no definitive findings from the current body of research on how trade liberalization affects the environment.

### 2.5 Industrialization-LCF *Nexus*

The shift from a subsistence-based agricultural economy to a production-based manufacturing one is known as industrialization [64]. While most of the research has focused on how industrialization affects environmental problems, there is a dearth of study in consideration of the quality of the environment as an LCF. Caglar and Yavuz [44] set out to analyze the impact of competitive industrial performance on LCF in the BRICS economies from 1990 to 2018. The findings indicated that environmental quality is improved when industrial competitiveness is higher.

When looking at the G-7 economies specifically, Wang et al. [65] found that industrialization did not negatively correlate with ecological deterioration. Patel and Mehta [66] assessed the unequal impact of industrialization on environmental degradation in India using the NARDL model. The study found that industrialization significantly reduces $CO_2$ emissions

over the long run. Sikder et al. [6] found the same thing for a group of 23 emerging nations: industrialization is the main factor influencing $CO_2$ emissions in these developing nations. For China specifically, Aslam et al. [67] discovered a two-way correlation between industrialization and carbon pollution. Opoku and Aluko [68] found the opposite to be true; they looked at 37 African countries between 2000 and 2016 and found that industrialization improved environmental quality.

### 2.6 Literature gap

The analysis of the current literature reveals a sufficient comprehension of the correlation between environmental degradation and variables like industrialization, trade liberalization, SMC, FD, and economic growth. Previous studies have yielded contradictory findings on these relationships, highlighting a key gap. Specifically, the literature on the impact of SMC on environmental quality remains sparse, particularly in its use of comprehensive environmental indicators like LCF. Most studies have predominantly relied on $CO_2$ emissions as a measure of environmental degradation, often overlooking the supply-side factors that contribute to environmental harm. Notably, research that explores the relationship between stock market dynamics and environmental degradation, considering both the demand and supply sides, is limited, especially in the context of the USA. Furthermore, the LCF variable, a crucial measure of environmental stress, has been largely neglected in this line of inquiry. This is particularly important in the USA, where policymakers face a trilemma of balancing domestic economic growth, global influence, and environmental sustainability. This study aims to fill this literature gap by investigating the interrelationship between SMC, industrialization, and the LCF variable within the USA context, contributing new insights into the supply and demand side drivers of environmental degradation.

## 3 Methodology

### 3.1 Data and variables

The research investigates how financial development, SMC, trade openness, and industrialization affect the LCC framework in the USA over the period from 1990 to 2022. The 1990–2022 timeframe was selected because it is important for recording significant changes in the environment and economy. The USA had significant changes starting in 1990, including a rise in globalization, the growth of the financial sector, and important legislative shifts, which affected industrialization and trade openness. This time frame offers a thorough understanding of long-term trends since it encompasses important events like the 2008 financial crisis and current environmental initiatives. Table 1 presents the detail description and sources of data and variables. "The study uses the load capacity factor (LCF) as the dependent variable, while GDP, GDP squared ($GDP^2$), financial development, stock market capitalization, trade openness, and industrialization serves as explanatory variables. FD and SMC are interconnected concepts within finance; however, they pertain to distinct facets of the financial system. FD includes the complete financial system, comprising banks, non-bank institutions, as well as equities and debt markets. SMC specifically denotes the magnitude of the stock market (equity market) and excludes other financial sectors such as banking or insurance. Consequently, we incorporate both variables to articulate their impact on the environment. The Global Footprint Network is the source of the LCF data [69], while GDP, trade openness (TO), and industrialization (INDUS) are obtained from the World Development Indicators [70]. FD data is collected from the International Monetary Fund [71], and stock market data is collected from the Global Financial Development Database [72]. This comprehensive dataset enables a robust analysis of how load capacity interacts with economic variables, offering knowledge of sustainable development strategies for the USA."

### 3.2 Theoretical framework

The Load Capacity Curve (LCC) is an essential instrument in environmental research, offering an insightful comprehension of the intricate interaction among human development, financial prosperity, and ecological sustainability. The importance of this lies in its portrayal of the equilibrium, or lack thereof, between human resource consumption (ecological footprint) and the earth's capacity to replenish those resources (biocapacity). The LCC demonstrates a U-shaped correlation between LCF and per capita income. This relationship highlights a crucial aspect of environmental sustainability: the understanding that as economies expand and individuals' income rises, there is a corresponding increase in resource consumption [73]. Nevertheless, once a certain threshold is reached, additional economic growth results in reduced benefits in terms of resource usage compared to ecological capacity. This is where the curve takes on a distinct shape, illustrating that at higher income

**Table 1** Variables description and sources

| Variables | Description | Logarithmic form | Unit of measurement | Source |
|---|---|---|---|---|
| LCF | Load capacity factor | LLCF | The ratio between per capita biocapacity and per capita EF | GFN |
| GDP | Gross domestic product | LGDP | Per capita income in 2015 constant US$ | WDI |
| $GDP^2$ | Square of gross domestic product | $LGDP^2$ | Square of GDP per capita | WDI |
| FD | Financial development | LFD | Financial development index | IMF |
| SMC | Stock market capitalization | LSMC | Stock market capitalization to GDP (%) | Global financial development |
| TO | Trade openness | LTO | Trade (% of GDP) | WDI |
| INDUS | Industrialization | LINDUS | Industry (including construction) value added (current US$) | WDI |

levels; societies can either exceed their ecological capacity or find a balance between consumption and replenishment [74]. In addition, the rise of the LCC can be credited to advancements in ecological footprint analysis and biocapacity measurement techniques [75]. By utilizing these methods, the LCC becomes a valuable tool for consolidating intricate data into a clear framework, allowing participants to understand the link between human activities and natural well-being. Figure 1 depicts the graphical representation of LCC.

To make the previously mentioned study more understandable, we have developed the following Eq. (1) for LCC theory:

$$Load\ Capacity\ Factor = f\left(GDP, GDP^2, X_t\right). \tag{1}$$

Equation (1) incorporates GDP and $GDP^2$ as variables representing income, with Xt signifying additional factors impacting the LCF. By introducing additional influential factors such as financial development, stock market capitalization, trade openness, and industrialization, Eq. (2) is designed to take a broader view of the factors impacting the LCF:

$$LCF = f\left(GDP, GDP^2, FD, SMC, TO, INDUS\right). \tag{2}$$

In Eq. (2), LCF represents the load capacity factor, FD stands for financial development, SMC denotes stock market capitalization, and INDUS stands for Industrialization. The econometric version of this equation is expressed in Eq. (3):

$$LCF_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_3 FD_{it} + \beta_4 SMC_{it} + \beta_5 TO_{it} + \beta_6 INDUS_{it}. \tag{3}$$

Equation (4) displays the logarithmic values of the variables. Logarithmic variables offer numerous benefits in the case of data analysis. It facilitates the transformation of intricate relationships into more straightforward linear forms, thereby enhancing comprehension and enabling the derivation of statistical inferences. Logarithmic scales are beneficial for condensing extensive ranges, thereby addressing heteroscedasticity and accommodating data with varying magnitudes.

$$LLCF_{it} = \beta_0 + \beta_1 LGDP_{it} + \beta_2 LGDP_{it}^2 + \beta_3 LFD_{it} + \beta_4 LSMC_{it} + \beta_5 LTO_{it} + \beta_6 INDUS_{it}. \tag{4}$$

### 3.3 Econometric framework

Checking stationarity in time series analysis is essential for verifying the soundness and dependability of econometric models. They ascertain the stationarity or non-stationarity of a time series since it is crucial to identify non-stationary data that might lead to misleading outcomes [76]. Unit root tests also enable precise cointegration analysis, which examines long-term equilibrium connections among variables [77]. This study employed "Augmented Dickey-Fuller (ADF) [78], Philips Perron (PP) [79], Dickey Fuller-Generalized Least Squares (DF-GLS) [80]" unit root tests to observe the stationarity within the data set.

This research performed ARDL bound cointegration test, developed by Pesaran et al. [81], is considered superior to traditional cointegration approaches due to its flexibility and robustness in addressing varying degrees of integration across variables. ARDL, in contrast to traditional methods, accommodates a mixture of stationary and non-stationary series without requiring all variables to be integrated in the same order [82]. This quality makes it very versatile and

suitable for real-world data, where variables often exhibit unique integration properties. The ARDL approach is particularly advantageous in scenarios with small sample sizes since it yields reliable and consistent estimates despite the restricted amount of data points [83]. Furthermore, it facilitates the evaluation of both short-term and long-term alterations within the same framework, offering a comprehensive view of the relationships among variables. The "Error Correction Model (ECM)" derived from the ARDL approach facilitates the understanding of short-term adjustments while maintaining long-term equilibrium, hence enhancing the clarity of results. Furthermore, the ARDL model is very successful and extensively used in econometric research because of its ability to capture dynamic interactions and provide comprehensive insights into the temporal correlations among variables. Equation (5) illustrates the ARDL bounds test:

$$\begin{aligned}\Delta LLCF_t = {} & \mathfrak{v}_0 + \pi_1 LCF_{t-1} + \pi_2 LGDP_{t-1} + \pi_3 LGDP^2_{t-1} + \pi_4 LFD_{t-1} + \pi_5 LSMC_{t-1} + \pi_6 LTO_{t-1} \\ & + \pi_7 LINDUS_{t-1} + \sum_{i=1}^{w} \mathfrak{v}_1 \, \Delta LLCF_{2_{t-i}} + \sum_{i=1}^{w} \mathfrak{v}_2 \, \Delta \mathrm{LGDP}_{t-i} + \sum_{i=1}^{w} \mathfrak{v}_3 \Delta \mathrm{LGDP}^2_{t-i} \\ & + \sum_{i=1}^{w} \mathfrak{v}_4 \, \Delta \, LFD_{t-i} + \sum_{i=1}^{w} \mathfrak{v}_5 \Delta \mathrm{LSMC}_{t-i} + \sum_{i=1}^{w} \mathfrak{v}_6 \Delta \mathrm{LTO}_{t-i} + \sum_{i=1}^{w} \mathfrak{v}_6 \Delta \mathrm{LINDUS}_{t-i} \\ & + €_t \end{aligned} \tag{5}$$

We compare the alternatives, which state that there is evidence of cointegration, with the null hypothesis, which states that there is no cointegration. Acceptance of the null hypothesis is contingent upon the F-statistic not exceeding the upper and lower limit threshold values. A look at Eqs. (6) and (7) reveals the null and alternative hypotheses:

$$H_0 = \mathfrak{v}_1 = \mathfrak{v}_2 = \mathfrak{v}_3 = \mathfrak{v}_4 = \mathfrak{v}_5 = \mathfrak{v}_6 \tag{6}$$

$$H_1 = \mathfrak{v}_1 \neq \mathfrak{v}_2 \neq \mathfrak{v}_3 \neq \mathfrak{v}_4 \neq \mathfrak{v}_5 \neq \mathfrak{v}_6 \tag{7}$$

The notations "$H_0$ and $H_1$" denoted the null hypothesis and the alternative hypothesis, respectively.

Following confirmation of parameter cointegration, this research applied the ARDL approach. When establishing long-term relationships, the "Error Correction Term" is employed to assess short-term correlations using the ECM. To analyze ARDL in the long run, we use Eq. (8).

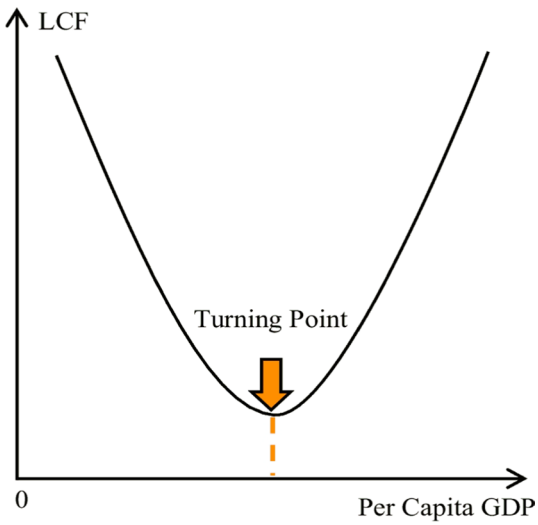


**Fig. 1** Relationship between per capita income and LCF

$$\Delta LLCF_t = \mathrm{v}_0 + \sum_{i=1}^{w} \mathrm{v}_1 \Delta \mathrm{LCF}_{\mathrm{t-i}} + \sum_{i=1}^{w} \mathrm{v}_2 \Delta \mathrm{LGDP}_{\mathrm{t-i}} + \sum_{i=1}^{w} \mathrm{v}_3 \Delta \mathrm{LGDP}^2_{\mathrm{t-i}} + \sum_{i=1}^{w} \mathrm{v}_4 \Delta\, LFD_{t-i} + \sum_{i=1}^{w} \mathrm{v}_5\, \Delta \mathrm{LSMC}_{\mathrm{t-i}} + \sum_{i=1}^{w} \mathrm{v}_6 \Delta \mathrm{LTO}_{\mathrm{t-i}} + \sum_{i=1}^{w} \mathrm{v}_7 \Delta \mathrm{LINDUS}_{\mathrm{t-i}} + \ell ECT_{t-i} + €_t \quad (8)$$

where $\ell$ is the rate of adjustment.

Moreover, this study also utilized the FMOLS, DOLS, and CCR techniques to represent the long-run impact of GDP, GDP Square, FD, SMC, TO, and INDUS on LCF to evaluate the stability within the ARDL long-term estimation. The use of these methods allows one to prove asymptotic coherence while considering serial correlation. When there is evidence of series cointegration, FMOLS and DOLS can be employed. We, therefore, use the FMOLS and DOLS estimators to determine elasticity over the long run. The lag order is confirmed by "Schwarz Information Criterion (SIC)".

Furthermore, this study employed several diagnostic tests to check normality, serial correlation, and heteroscedasticity within data. The Jarque–Bera examination analyses the normality of residuals, which is crucial as many econometric models assume normally distributed errors for valid inference. The Lagrange Multiplier test is used to detect serial correlation in residuals, ensuring that errors are not correlated over time, which could lead to inefficient and biased estimates. The Breusch-Pagan-Godfrey test checks for heteroscedasticity, or non-constant variance of residuals; this may create ineffective estimates and inaccurate standard errors. Identifying and addressing heteroscedasticity helps in improving model accuracy and inference reliability. Figure 2 shows the flow of the estimation approach:

Finally, to determine if prior alterations within a variable have been accountable for the current perception, a causality test can be used. To say that X is causally related to Y would be to say that the sum of X's prior and current values deviates substantially beyond 0. Y and X causality are subject to the same laws; if the results deviate from zero, it indicates the presence of causation on both sides. The analysis used the paired Granger causality [84] test to ascertain if there prevailed a short-term causal link between the components. Equation (9) shows that $X_t$ and $Y_t$ are causally related:

$$E\left(Y_{t+h}|J_t, X_t\right) = E\left(Y_{t+h}|J_t\right), \quad (9)$$

$J_t$ herein stands for the sets of data generated from all of the findings up to a certain point in time (t).

## 4 Findings and discussion

### 4.1 Unit root test

All three stationarity tests—ADF, DF-GLS, and PP—in both the level and first difference for log-transformed variables are displayed in Table 2. It turns out that LCF, FD, SMC, TO, and INDUS weren't stationary before we took their first differences into account in all unit root assessments, but once we did, they became stationary, whereas LGDP and $LGDP^2$ were stationary at level I(0). Hence, we can now perform the evaluation using the ARDL framework due to this mixed order of integration.

### 4.2 Correlation matrix

The correlation matrix results are presented in Table 3. The results indicate that LLCF demonstrates a moderate positive correlation with LGDP and a significantly strong positive correlation with LINDUS. This indicates that with the escalation of economic growth and industrialization, the load capacity factor typically increases correspondingly. The correlation between LLCF and $LGDP^2$ is minimal, suggesting that the impact of economic growth on LLCF remains largely unchanged when considering its squared value. LFD, LSMC, and LTO exhibit robust positive correlations among themselves and with LLCF. LFD and LSMC exhibit a notably high correlation with LLCF, indicating that enhancements in financial development

and stock market capitalization are closely linked to increases in the load capacity factor. LLCF is predominantly associated with industrialization and the financial metrics in the matrix, underscoring their substantial impact on the load capacity factor. No multicollinearity was discovered; therefore, we can proceed with the analysis.

### 4.3 ARDL bounds test

"The results of the analysis of the ARDL methodology are displayed in Table 4 to determine if the factors were cointegrated. It seems feasible to conclude that there is a long-term connection between the factors if the estimated result of the F-test was greater than the upper and lower bounds. In this case, the absolute value of the F-statistic (5.86) exceeds the upper limit of critical values. At a significant level of 1%, the null hypothesis of no cointegration is thereby not accepted. Stated differently, cointegration exists between the LCF and the independent factors.

### 4.4 ARDL long-run and short-run estimation

The effects on LLCF in the USA, both in the short and long run, of LGDP, $LGDP^2$, LFD, LSMC, LTO, and LINDUS are outlined in Table 5. Based on the outcomes, it seems that the USA LCF decreases because of economic expansion over time but that it increases as GDP continues to grow. Industrialization is a key factor in the increase of LCF, but financial growth, stock market capitalization, and trade openness have been demonstrated to reduce the USA's LCF in the long run.

The results in Table 5 indicate that environmental quality declines by 5% over the long run and by 0.26% over the short run for every 1% rise in per capita income. In contrast, a 0.24% long-term enrichment and a 0.04% short-term enrichment of the LCF are achieved for every additional unit of income. As the LGDP coefficient is negative and the $LGDP^2$ coefficient is positive—and both are statistically significant—we can conclude that environmental pressure reduces with time,

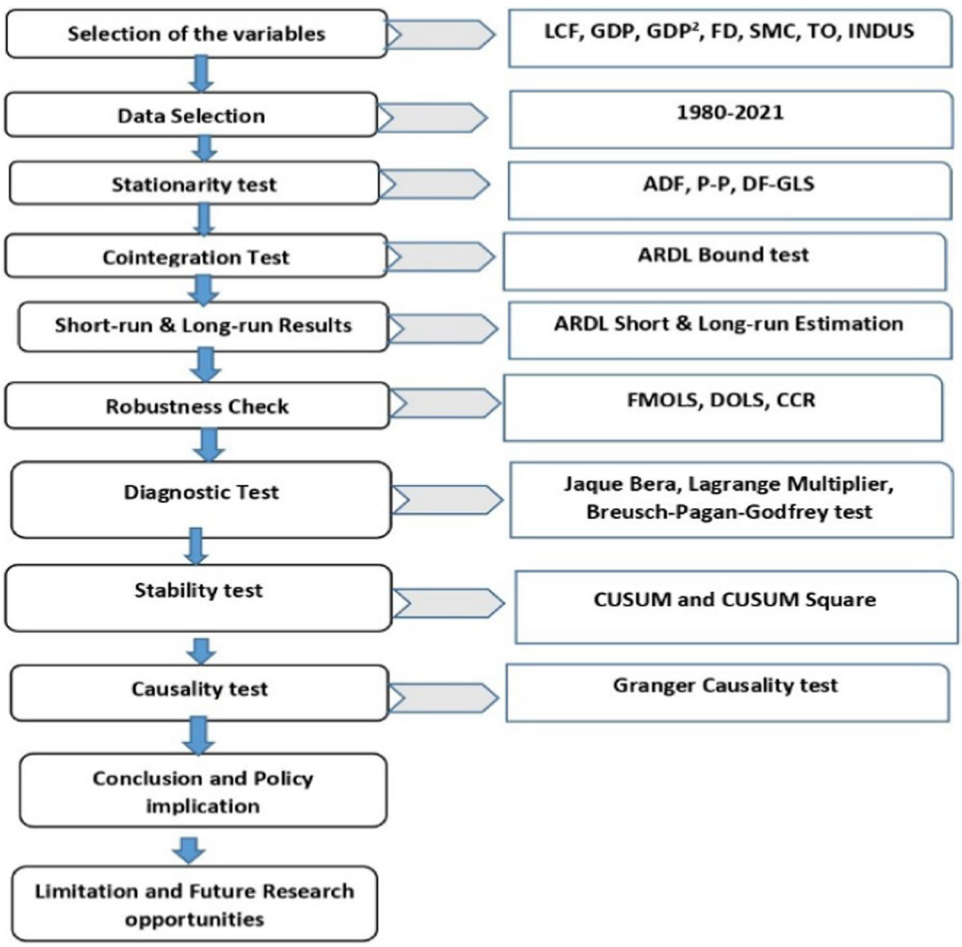


**Fig. 2** Flow of estimation approach

**Table 2** Unit root test

| Variables | ADF | | PP | | DF-GLS | | Decision |
|---|---|---|---|---|---|---|---|
| | I(0) | I(1) | I(0) | I(1) | I(1) | I(0) | |
| LLCF | − 1.260 | − 5.869*** | − 1.293 | − 5.643*** | − 1.654 | − 4.776*** | I(1) |
| LGDP | − 3.618*** | − 5.318*** | − 4.217*** | − 5.293*** | − 1.253 | − 3.504*** | I(0) |
| LGDP2 | − 2.897** | − 5.534*** | − 3.392** | − 5.541*** | − 1.313 | − 3.649*** | I(0) |
| LFD | − 1.471 | − 3.316** | − 2.111 | − 3.451*** | − 2.965 | − 3.142** | I(1) |
| LSMC | − 1.122 | − 7.951*** | − 0.912 | − 8.176*** | − 2.129 | − 5.208*** | I(1) |
| LTO | − 1.140 | − 6.644*** | − 1.061 | − 6.485*** | − 1.930 | − 4.905*** | I(1) |
| LINDUS | 0.066 | − 6.922*** | 0.370 | − 7.049*** | − 1.834 | − 5.996*** | I(1) |

***, and ** represent the significance level at 1% and 5%, respectively

**Table 3** Pairwise correlation matrix

| | LLCF | LGDP | $LGDP^2$ | LFD | LSMC | LTO | LINDUS |
|---|---|---|---|---|---|---|---|
| LLCF | 1.0000 | | | | | | |
| LGDP | 0.3061 | 1.0000 | | | | | |
| $LGDP^2$ | 0.317 | 0.7999 | 1.0000 | | | | |
| LFD | − 0.0734 | 0.618 | 0.6162 | 1.0000 | | | |
| LSMC | 0.0171 | 0.7547 | 0.7523 | 0.3196 | 1.0000 | | |
| LTO | 0.0135 | 0.8043 | 0.8001 | 0.516 | 0.5193 | 1.0000 | |
| LINDUS | 0.4481 | 0.7575 | 0.7597 | 0.6185 | 0.6348 | 0.7962 | 1.0000 |

lending credence to the recently suggested LCC hypothesis for the USA. Accordingly, the results show that income and LCF have a U-shaped connection. The findings of the analysis are similar to those of Wu et al. [85] and Pata and Kartal [86]. There are several explanations for this relationship's unusual shape. A country's environmental impact is likely to be higher in its early phases of economic development because of its emphasis on industrialization and resource-intensive activities [87]. Environmental consciousness and legislation gain traction as economies mature to a certain degree. The environmental impact is reduced, and the natural world's health is improved because of increased spending on environmentally friendly methods and greener technologies [88].

The computed coefficients for LFD reveal a distinct inverse correlation with LLCF. This means that there was a 0.4% long-term degradation and a 0.8% short-term degradation rate due to a 1% surge in FD. Thus, financial expansion in the United States is a big contributor to the country's environmental degradation. This result agrees with what Annor et al. [89] and Yang et al. [90] found. The LCF is also negatively impacted by stock market capitalization; however, this negative effect is only shown over the long term. There is a negligible rise in the environmental impact and a decline in the LCF for every percent increase in the LSMC. The environmental state is unaffected by US stock market capitalization in the short term. These results are reliable with Uysa and Çayir [53]. In industrialized nations like the USA, there are several reasons why FD and stock market capitalization can lower the load capacity factor. A greater focus on short-term profits rather than long-term sustainability is associated with a rise in stock market capitalization, which in turn can raise the demand for energy-intensive sectors and worsen environmental constraints. This has the potential to reduce funding for green technology like renewable energy, which is essential for a long-term ecological solution. In light of this, our research indicates that the rising stock market, which fuels fast US financial growth, is impeding attempts to make things more sustainable and lower the load capacity factor. The already heavy burden on the environment is being worsened by the fact that the highly developed US financial system is currently favoring investments in polluting sectors or projects that offer high financial returns but have poor environmental implications. Therefore, even if financial systems have advanced, efforts to improve environmental resilience in industrialized nations like the US can be impeded by a lack of attention to long-term sustainability.

In addition, the destructive and statistically significant indications of the TO coefficients suggest that an expansion in LTO in both the long-run and short-run has a detrimental effect on environmental quality. According to these findings, it appears that the present trading structure of the United States is not conducive to reducing pollution, as the manufacture of goods for export is contributing to the problem. Put simply, the United States' recent trade agreements may have put monetary development ahead of biodiversity preservation, which could result in loosened rules and restrictions. This

**Table 4** ARDL bounds test

| Test statistic | Value | Sig (%) | 1(0) | 1(1) |
|---|---|---|---|---|
| F-statistic | 5.86 | 10 | 1.99 | 2.94 |
| k | 6 | 5 | 2.27 | 3.28 |
| | | 2.50 | 2.55 | 3.61 |
| | | 1 | 2.88 | 3.99 |

trend towards trade liberalization is lowering the load capacity factor and hurting sustainability initiatives in industrialized countries like the United States. Contrary to what Huilan et al. [60], and Dam and Sarkodie [62] have found, our outcomes align with what Caglar and Yavuz [44] have found.

The results presented in Table 5 reveal that more industrial activities improve environmental quality in the US. The development of industrialization is related to faster GDP growth since it measures a country's capacity to increase production in manufacturing. Additionally, by raising value addition and embracing new, environmentally friendly technology, this component may improve environmental quality. Sustainable growth cannot be achieved without manufacturing, and this is especially true of manufacturing, which is fueled by innovative ideas and the technical rivalry of Industry 4.0 [91]. Consequently, a higher level of industrialization has the potential to accomplish sustainable development goals (SDGs) via the effect of technology and raise living standards by increased employment possibilities and per capita income. The ECT is negative and significant which denoted the long-term convergence of the model by 53.43%.

### 4.5 Robustness check

Validating the ARDL simulation's accuracy and dependability is essential. Therefore, the ARDL model's validity was tested in this study using FMOLS, DOLS, and CCR. The findings of all three procedures are shown in Table 6. The findings indicate that each of the methods shows that LCF and income have a constant U-shaped connection. Findings from FMOLS, DOLS, and CCR corroborate the ARDL model's assertion that LCC exists in the US. Further evidence that the ARDL model's conclusions are supported by the three robustness estimates results is that financial development, stock market capitalization, and trade openness all negatively impact load capacity, and the environmental situation in the USA is improving due to industrialization.

**Table 5** ARDL long-run and short-run estimation

| Variable | Coefficient | Std. error | t-statistic | Prob |
|---|---|---|---|---|
| *Long-run estimation* | | | | |
| LGDP | − 5.18003** | 2.362901 | − 2.19224 | 0.037 |
| $LGDP^2$ | 0.241643** | 0.11712 | 2.063204 | 0.049 |
| LFD | − 0.41992*** | 0.1476 | − 2.845 | 0.008 |
| LSMC | − 0.00759** | 0.071486 | 0.10617 | 0.016 |
| LTO | − 0.44362*** | 0.122578 | − 3.61911 | 0.001 |
| LINDUS | 0.230891** | 0.084723 | 2.72525 | 0.011 |
| C | 29.47331** | 11.70715 | 2.517547 | 0.018 |
| *Short-run estimation* | | | | |
| D(LGDP) | − 0.26088** | 1.474599 | − 0.17691 | 0.026 |
| $D(LGDP^2)$ | 0.03644** | 0.072601 | − 0.50185 | 0.030 |
| D(LFD) | − 0.77021*** | 0.113592 | − 6.78051 | 0.000 |
| D(LSMC) | − 0.00065 | 0.022239 | − 0.02939 | 0.976 |
| D(LTO) | − 0.16649** | 0.081126 | − 2.0522 | 0.050 |
| D(LINDUS) | 0.107933** | 0.029245 | 3.690655 | 0.001 |
| ECT(-1)* | − 0.53431*** | 0.068939 | − 7.75045 | 0.000 |

***, and ** represent the significance level at 1% and 5%, respectively. Positive effect on LCF is good for the environment while negative impact is not good

### 4.6 Pairwise Granger causality test

In this stage, as shown in Table 7, the paired Granger causality test proves that per capita income is considerably caused by LCF, but only in one direction. In the same way, stock market capitalization causes LCF, and industrialization causes LCF. Aside from these factors, there are no additional causal links among the ones revealed in this research.

### 4.7 Diagnostic test

"Finally, we need to make sure that the ARDL model's error correction is a good fit. To ascertain the dependability and precision of the estimated equation predicted using the ARDL approach, Table 8 displays the results of multiple diagnostic examinations. The conclusions of the diagnostic tests demonstrate that there exists no evidence of serial correlation, non-normality, or heteroscedasticity. Figure 3 also shows the results of the cumulative sum (CUSUM) and cumulative sum of the square (CUSUMSQ) studies to further demonstrate the framework's reliability. Given that the statistical line is inside the crucial bounds at the 5% significance level, we can say that the ARDL methods estimated coefficients are stable.

## 5 Conclusion

This research investigates the effects of financial development, stock market capitalization, openness in trade, and industrialization on the LCF in the USA from 1990 to 2022. The study also tries to validate the Load Capacity Curve (LCC) theory. The ARDL calculations support the LCC hypothesis in the USA and highlight the favorable relationship between industrialization and LCF. Contrarily, the inverse relationships between LCF and financial growth, stock market capitalization, and trade openness suggest that these variables have the potential to degrade environmental conditions. The robustness tests conducted using FMOLS, DOLS, and CCR ensure the validity of the ARDL findings, hence bolstering the confidence in the outcomes.

## 6 Policy implications

The findings of this investigation have important policy implications for the USA. It reveals that as GDP grows, the LCF initially decreases but eventually increases. This is crucial for policymakers to prioritize long-term economic growth to address the issue of environmental degradation. First, when GDP growth has negative effects on the environment, it is important to prioritize policies that promote the utilization of naturally sound technologies, enhance energy efficiency, and encourage cleaner production methods. Encouraging businesses to embrace sustainable practices and make investments in sustainable power sources is paramount. Given the importance of sustainable practices, it is crucial to maintain and enhance them as GDP continues to grow and positively impact LCF. It is crucial

**Table 6** Robustness check

| Variable | FMOLS | DOLS | CCR |
|---|---|---|---|
| LGDP | − 3.3168*** (1.09731) | − 5.3021** (2.3851) | − 3.2249*** (1.1626) |
| $LGDP^2$ | 0.16051*** (0.05483) | 0.2407** (0.1148) | 0.1561** (0.0596) |
| LFD | − 0.6240*** (0.07274) | − 0.5578*** (0.0958) | − 0.6288*** (0.0694) |
| LSMC | − 0.13870*** (0.02702) | − 0.0037** (0.0639) | − 0.1385*** (0.0378) |
| LTO | − 0.4788*** (0.06598) | − 0.3087** (0.1225) | − 0.4871*** (0.0647) |
| LINDUS | 0.20161*** (0.04263) | 0.2460*** (0.0757) | 0.2054*** (0.0520) |
| C | 20.4518*** (5.4339) | 30.9684*** (12.1497) | 20.009*** (5.7489) |

***, and ** represent the significance level at 1% and 5%, respectively. Values in the parenthesis denote the standard errors

for policymakers to prioritize the integration of sustainability into economic planning to separate economic growth from environmental degradation. This includes making investments in research for green technology, advocating for sustainable urban planning, and strengthening regulations to reduce emissions.

Financial and trade policies should prioritize and encourage green investments and environmentally friendly practices. Public–private partnerships are effective in mobilizing resources for large-scale environmental projects. Collaboration and sharing of knowledge on a global scale, both within the G-7 and beyond, can enhance efforts to achieve a harmonious blend of economic growth and environmental sustainability. This will ensure that improvements in GDP also contribute to the well-being of our planet in the long run.

The study suggests that fiscal growth, stock market capitalization, and liberalization of trade have a detrimental influence on the LCF, while industrialization has an encouraging consequence on the LCF. Policymakers must utilize economic expansion and transparency of trade as tools to promote a sustainable ecosystem. This is attainable through encouraging green expenditures and providing support for renewable energy projects. Promoting the stock market's support for environmentally friendly companies can help align financial markets with environmental

**Table 7** Granger causality test

| Null hypothesis | F-Statistic | Prob |
|---|---|---|
| LGDP ≠ LLCF | 3.06282* | 0.0595 |
| LLCF ≠ LGDP | 1.70788 | 0.1961 |
| $LGDP^2$ ≠ LLCF | 3.18171* | 0.0538 |
| LLCF ≠ $LGDP^2$ | 1.6121 | 0.2139 |
| LFD ≠ LLCF | 2.39816 | 0.1057 |
| LLCF ≠ LFD | 0.25238 | 0.7783 |
| LSMC ≠ LLCF | 4.45146** | 0.0189 |
| LLCF ≠ LSMC | 0.64906 | 0.5287 |
| LTO ≠ LLCF | 2.22286 | 0.1234 |
| LLCF ≠ LTO | 0.73311 | 0.4876 |
| LINDUS ≠ LLCF | 1.82997* | 0.0754 |
| LLCF ≠ LINDUS | 0.6635 | 0.5214 |

**, and * represent the significance level at 5% and 10%, respectively

**Table 8** Diagnostic test

| Diagnostic tests | Coefficient | p-value | Decision |
|---|---|---|---|
| Jarque–Bera test | 0.81417 | 0.6653 | Residuals are normally distributed |
| Lagrange Multiplier test | 5.7390 | 0.2253 | No serial correlation exists |
| Breusch-Pagan-Godfrey test | 5.6345 | 0.5678 | No heteroscedasticity exists |

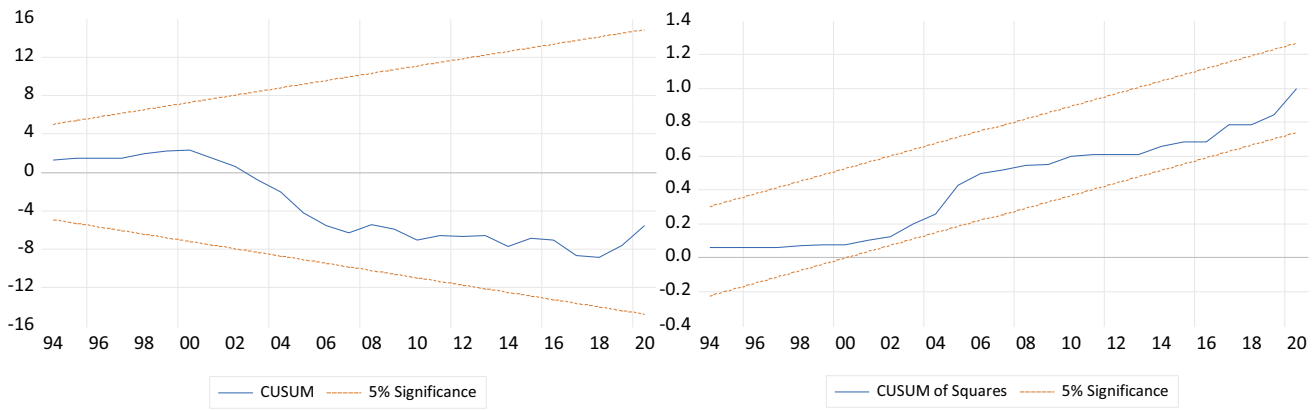


**Fig. 3** CUSUM and CUSUMSQ test

goals. The utilization of green bonds and sustainability indices can accomplish it. Trade policies should prioritize the promotion of the exchange of green technologies and sustainable practices.

The strong link between industrialization and LCF indicates the importance of implementing rigorous environmental regulations in the industrial sector. This includes enforcing strict emission standards, adopting energy-efficient technologies, and implementing cleaner production methods. Collaborative efforts between different sectors could have a role in encouraging environmentally friendly business procedures through the exchange of knowledge, technology, and resources. By incorporating sustainable development principles into industrial policies and promoting circular economy practices, we can effectively decrease the carbon footprint. Through the strategic alignment of financial development, stock market activities, and trade policies with environmental objectives, coupled with effective regulation and modernization of the industrial sector, the USA has the potential to enhance its overall economic well-being while simultaneously promoting ecological preservation.

## 7 Limitations and future research opportunities

This study, while offering insights into how trade openness, financial development, stock market capitalization, and industrialization impact the USA's LCF, has limitations. Its focus on the USA limits generalizability, indicating the need for comparative studies across different regions to better understand diverse economic and environmental dynamics. Though advanced econometric techniques were employed, the exclusion of qualitative factors, such as policy effectiveness, limits the analysis. Future research should integrate quantitative and qualitative approaches to provide a more comprehensive view of how economic growth interacts with sustainability. The study also highlights the need for ongoing updates, as future research must include recent data to reflect the latest economic shifts. A key takeaway from literature is the importance of balancing financial and industrial development with environmental goals. For stakeholders, this research emphasizes the need for policies that promote sustainable growth. Future studies should investigate causal mechanisms and moderating factors, such as regulations and technological advancements, private–public partnerships (PPP), etc., through longitudinal and scenario-based analyses via Wavelet method to guide policymakers in fostering environmentally friendly development.

**Acknowledgements** This research was supported by Universitas Airlangga, Surabaya, Indonesia Under The Scheme of International Research Consortium No.: 183/UN3.LPPM/PT.08.22/2024.

**Author contributions** Conceptualization, M.R., N.N.A.; methodology, M.R.; software, S.B.; validation, M.E.H; formal analysis, M.R., N.N.A; investigation, M.E.; resources, M.M.J.; data curation, S.B.; writing—original draft preparation, M.R., N.N.A., S.B., A.A., M.E.; writing—review and editing, M.E.H., M.A.E.; visualization, A.A.; supervision, M.E.H., M.A.E.; funding acquisition, M.A.E. All authors have read and agreed to the published version of the manuscript.

**Data availability** Data will be made available on request.

## Declarations

**Institutional review board statement** Not applicable.

**Informed consent statement** Not applicable.

**Competing interests** The authors declare no competing interests.

## References


1. Ummalla M, Samal A, Goyari P. The impact of public–private investment in energy on environmental degradation: evidence from major investment countries. Environ Sci Pollut Res. 2023;30(44):100114–23.
2. Bekun FV. Race to carbon neutrality in South Africa: what role does environmental technological innovation play? Appl Energy. 2024;354: 122212.
3. Pata UK, Isik C. Determinants of the load capacity factor in China: a novel dynamic ARDL approach for ecological footprint accounting. Resour Policy. 2021;74: 102313.
4. WDI. World Bank Indicators. Available at: https://databank.worldbank.org/source/world-development-indicators. Accessed 12 Apr 2024.
5. BP. Statistical Review of World Energy. 2020. Available at https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf. Accessed 10 Jan 2024.
6. Sikder M, Wang C, Yao X, Huai X, Wu L, KwameYeboah F, et al. The integrated impact of GDP growth, industrialization, energy use, and urbanization on $CO_2$ emissions in developing countries: evidence from the panel ARDL approach. Sci Total Environ. 2022;837:155795.
7. Voumik LC, Ridwan M, Rahman MH, Raihan A. An investigation into the primary causes of carbon dioxide releases in Kenya: does renewable energy matter to reduce carbon emission? Renewable Energy Focus. 2023;47: 100491.
8. Martial AAA, Dechun H, Voumik LC, Islam MJ, Majumder SC. Investigating the influence of tourism, GDP, renewable energy, and electricity consumption on carbon emissions in low-income countries. Energies. 2023;16(12):4608.
9. Jianguo D, Ali K, Alnori F, Ullah S. The nexus of financial development, technological innovation, institutional quality, and environmental quality: evidence from OECD economies. Environ Sci Pollut Res. 2022;29(38):58179–200.
10. Siche R, Pereira L, Agostinho F, Ortega E. Convergence of ecological footprint and emergency analysis as a sustainability indicator of countries: Peru as case study. Commun Nonlinear Sci Numer Simul. 2010;15(10):3182–92.
11. Pata UK. Do renewable energy and health expenditures improve load capacity factor in the USA and Japan? A new approach to environmental issues. Eur J Health Econ. 2021;22(9):1427–39.
12. Shang Y, Razzaq A, Chupradit S, An NB, Abdul-Samad Z. The role of renewable energy consumption and health expenditures in improving load capacity factor in ASEAN countries: exploring new paradigm using advance panel models. Renewable Energy. 2022;191:715–22.
13. Fareed Z, Salem S, Adebayo TS, Pata UK, Shahzad F. Role of export diversification and renewable energy on the load capacity factor in Indonesia: a Fourier quantile causality approach. Front Environ Sci. 2021;9: 770152.
14. Dogan A, Pata UK. The role of ICT, R&D spending and renewable energy consumption on environmental quality: testing the LCC hypothesis for G7 countries. J Clean Prod. 2022;380: 135038.
15. Pata UK, Ertugrul HM. Do the Kyoto Protocol, geopolitical risks, human capital and natural resources affect the sustainability limit? A new environmental approach based on the LCC hypothesis. Resour Policy. 2023;81: 103352.
16. Frankel J, Romer D. Does trade cause growth? Am Econ Rev. 1999;89(3):379–99.
17. Jensen V. The pollution haven hypothesis and the industrial flight hypothesis: some perspectives on theory and empirics. Working Paper 1996.5, Centre for Development and the Environment, University of Oslo. 1996.
18. Ali K, Bakhsh S, Ullah S, Ullah A, Ullah S. Industrial growth and $CO_2$ emissions in Vietnam: the key role of financial development and fossil fuel consumption. Environ Sci Pollut Res. 2021;28(6):7515–27.
19. Zhen Z, Ullah S, Shaowen Z, Irfan M. How do renewable energy consumption, financial development, and technical efficiency change cause ecological sustainability in European Union countries? Energy Environ. 2022;0958305X2211099.
20. Kirikkaleli D, Güngör H, Adebayo TS. Consumption-based carbon emissions, renewable energy consumption, financial development and economic growth in Chile. Bus Strategy Environ. 2022;31(3):1123–37.
21. Paramati SR, Ummalla M, Apergis N. The effect of foreign direct investment and stock market growth on clean energy use across a panel of emerging market economies. Energy Econ. 2016;56:29–41.
22. Altan İM, Alvan A, Aslan L, Aydin Ü, Berk C, Bilik M, et al. Financial systems, central banking and monetary policy during COVID-19 pandemic and after. Rowman & Littlefield; 2021.
23. Bai L, Wei Y, Wei G, Li X, Zhang S. Infectious disease pandemic and permanent volatility of international stock markets: a long-term perspective. Financ Res Lett. 2021;40: 101709.
24. Azeem A, Naseem MA, Hassan NU, Butt I, Aslam MT, Ali S, Jadoon AK. A novel lens of stock market capitalization and environmental degradation. Environ Sci Pollut Res. 2023;30(5):11431–42.
25. Wang Q, Sun J, Li R, Pata UK. Linking trade openness to load capacity factor: the threshold effects of natural resource rent and corruption control. Gondwana Research. 2023.
26. Sadorsky P. The effect of urbanization and industrialization on energy use in emerging economies: implications for sustainable development. Am J Econ Sociol. 2014;73(2):392–409.
27. Li K, Lin BJR, Reviews SE. Impacts of urbanization and industrialization on energy consumption/$CO_2$ emissions: does the level of development matter? Renewable Sustain Energy. 2015;52:1107–22.
28. Pata UK, Balsalobre-Lorente D. Exploring the impact of tourism and energy consumption on the load capacity factor in Turkey: a novel dynamic ARDL approach. Environ Sci Pollut Res. 2022;29(9):13491–503.
29. Ni Z, Yang J, Razzaq A. How do natural resources, digitalization, and institutional governance contribute to ecological sustainability through load capacity factors in highly resource-consuming economies? Resour Policy. 2022;79: 103068.
30. Khan U, Khan AM, Khan MS, Ahmed P, Haque A, Parvin RA. Are the impacts of renewable energy use on load capacity factors homogeneous for developed and developing nations? Evidence from the G7 and E7 nations. Environ Sci Pollut Res. 2023;30(9):24629–40.
31. Xu D, Salem S, Awosusi AA, Abdurakhmanova G, Altuntaş M, Oluwajana D, et al. Load capacity factor and financial globalization in Brazil: the role of renewable energy and urbanization. Front Environ Sci. 2022;9:823185.
32. Awosusi AA, Kutlay K, Altuntaş M, Khodjiev B, Agyekum EB, Shouran M, et al. A roadmap toward achieving sustainable environment: evaluating the impact of technological innovation and globalization on load capacity factor. Int J Environ Res Public Health. 2022;19(6):3288.

33. Saliba CB, Hassanein FR, Athari SA, Dördüncü H, Agyekum EB, Adadi P. The dynamic impact of renewable energy and economic growth on $CO_2$ emissions in China: do remittances and technological innovations matter? Sustainability. 2022;14(21):14629.
34. Özbay RD, Athari SA, Saliba C, Kirikkaleli D. Towards environmental sustainability in China: role of globalization and hydroelectricity consumption. Sustainability. 2022;14(7):4182.
35. Khan MK, Teng JZ, Khan MI, Khan MO. Impact of globalization, economic factors and energy consumption on $CO_2$ emissions in Pakistan. Sci Total Environ. 2019;688:424–36. https://doi.org/10.1016/j.scitotenv.2019.06.065.
36. Baloch MA, Zhang J, Iqbal K, Iqbal Z. The effect of financial development on ecological footprint in BRI countries: evidence from panel data estimation. Environ Sci Pollut Res. 2019;26(6):6199–208. https://doi.org/10.1007/s11356-018-3992-9.
37. Saud S, Chen S, Haseeb A. Impact of financial development and economic growth on environmental quality: an empirical analysis from belt and road initiative (BRI) countries. Environ Sci Pollut Res. 2018;17:2253–69. https://doi.org/10.1007/s11356-018-3688-1.
38. Riti JS, Yang S, Song D, Kamah M. The contribution of energy use and financial development by source in climate change mitigation process: a global empirical perspective. J Clean Prod. 2017;148:882–94. https://doi.org/10.1016/j.jclepro.2017.02.037.
39. Abbasi F, Riaz K. CO2 emissions and financial development in an emerging economy: An augmented VAR approach. Energy Policy. 2016;90:102–14. https://doi.org/10.1016/j.enpol.2015.12.017.
40. Fakher HA, Panahi M, Emami K, Peykarjou K, Zeraatkish SY. Investigating marginal effect of economic growth on environmental quality based on six environmental indicators: does financial development have a determinative role in strengthening or weakening this effect? Environ Sci Pollut Res. 2021;28(38):53679–99. https://doi.org/10.1007/s11356-021-14470-9.
41. Latif N, Faridi MZ. Examining the impact of financial development on load capacity factor (LCF): system GMM analysis for Asian economies. Front Energy Res. 2023;10:1063212.
42. Akhayere E, Kartal MT, Adebayo TS, Kavaz D. Role of energy consumption and trade openness towards environmental sustainability in Turkey. Environ Sci Pollut Res. 2023;30(8):21156–68.
43. Kartal MT, Samour A, Adebayo TS, Depren SK. Do nuclear energy and renewable energy surge environmental quality in the United States? New insights from novel bootstrap Fourier Granger causality in quantiles approach. Prog Nucl Energy. 2023;155: 104509.
44. Caglar AE, Yavuz E. The role of environmental protection expenditures and renewable energy consumption in the context of ecological challenges: insights from the European Union with the novel panel econometric approach. J Environ Manage. 2023;331: 117317.
45. Okezie BN, Nwani C, Nnam HI, Onuoha PI. Testing the income-finance-trade-environment nexus based on the ecological load capacity factor: Frequency-domain causality evidence from Nigeria. Heliyon. 2023;9(9):e19584.
46. Pata UK, Tanriover B. Is the load capacity curve hypothesis valid for the top ten tourism destinations? Sustainability. 2023;15:960.
47. Athari SA. The impact of financial development and technological innovations on renewable energy consumption: do the roles of economic openness and financial stability matter in BRICS economies? Geol J. 2024;59(1):288–300.
48. Gulzar R, Bhat AA, Mir AA, Athari SA, Al-Adwan AS. Green banking practices and environmental performance: navigating sustainability in banks. Environ Sci Pollut Res. 2024;31(15):23211–26.
49. Avcı P, Sarıgül SS, Karataşer B, Çetin M, Aslan A. Analysis of the relationship between tourism, green technological innovation and environmental quality in the top 15 most visited countries: evidence from method of moments quantile regression. Clean Technol Environ Policy. 2024;26:2337.
50. Cetin M, Ecevit E. The impact of financial development on carbon emissions under the structural breaks: empirical evidence from Turkish Economy. Int J Econ Perspect. 2017;11(1).
51. Çetin M, Sarıgül SS, Topcu BA, Alvarado R, Karataser B. Does globalization mitigate environmental degradation in selected emerging economies? Assessment of the role of financial development, economic growth, renewable energy consumption and urbanization. Environ Sci Pollut Res. 2023;30(45):100340–59.
52. Cetin M, Ozturk I, Sumerli Sarigul S, Murshed M, Kilavuz E. Nexus between technological innovation and environmental pollution in selected OECD countries. In: Natural Resources Forum. Oxford: Blackwell Publishing Ltd. 2024.
53. Uysal M, Çayir M. Analysis of the asymmetric relationship between stock markets and environmental quality: an analysis on Turkey. Theor Appl Econ. 2023;30(4):99–118.
54. Paramati SR, Alam MS, Apergis N. The role of stock markets on environmental degradation: a comparative study of developed and emerging market economies across the globe. Emerg Mark Rev. 2018;35:19–30.
55. Al-mulali U, Solarin SA, Ozturk I. Examining the asymmetric effects of stock markets on Malaysia's air pollution: a nonlinear ARDL approach. Environ Sci Pollut Res. 2019;26:34977–82. https://doi.org/10.1007/s11356-019-06710-w.
56. Habiba U, Xinbang C. The impact of financial development on $CO_2$ emissions: new evidence from developed and emerging countries. Environ Sci Pollut Res. 2022;29:31453–66.
57. Mhadhbi M, Gallali MI, Goutte S, Guesmi K. On the asymmetric relationship between stock market development, energy efficiency and environmental quality: a nonlinear analysis. Int Rev Financ Anal. 2021;77: 101840.
58. Alam MS, Apergis N, Paramati SR, Fang J. The impacts of R&D investment and stock markets on clean-energy consumption and $CO_2$ emissions in OECD economies. Int J Financ Econ. 2021;26(4):4979–92.
59. Kuvshinov D, Zimmermann K. The big bang: stock market capitalization in the long run. J Financ Econ. 2022;145(2):527–52.
60. Huilan W, Akadiri SS, Haouas I, Awosusi AA, Odu AT. Impact of trade liberalization and renewable energy on load capacity factor: evidence from novel dual adjustment approach. Energy Environ. 2024;35(2):795–814.
61. Ibrahim RL, Ajide KB. Disaggregated environmental impacts of non-renewable energy and trade openness in selected G-20 countries: the conditioning role of technological innovation. Environ Sci Pollut Res. 2021;28:67496–510.
62. Dam MM, Sarkodie SA. Renewable energy consumption, real income, trade openness, and inverted load capacity factor nexus in Turkiye: revisiting the EKC hypothesis with environmental sustainability. Sustainable Horizons. 2023;8: 100063.
63. Agila ABT, Khalifa WM, SaintAkadiri S, Adebayo TS, Altuntaş M. Determinants of load capacity factor in South Korea: does structural change matter? Environ Sci Pollut Res. 2022;29(46):69932–48.
64. Khan A, Sicen L, Khan B, Salman N. On the influence of demographic structure and industrial growth on environmental quality. J Environ Manage. 2021;288: 112453.

65. Wang W, Rehman MA, Fahad S. The dynamic influence of renewable energy, trade openness, and industrialization on the sustainable environment in G-7 economies. Renewable Energy. 2022;198:484–91.
66. Patel N, Mehta D. The asymmetry effect of industrialization, financial development and globalization on $CO_2$ emissions in India. Int J Thermofluids. 2023;20: 100397.
67. Aslam B, Hu J, Shahab S, Ahmad A, Saleem M, Shah SSA, et al. The nexus of industrialization, GDP per capita and $CO_2$ emission in China. Environ Technol Innov. 2021;23: 101674.
68. Opoku EEO, Aluko OA. Heterogeneous effects of industrialization on the environment: evidence from panel quantile regression. Struct Chang Econ Dyn. 2021;59:174–84.
69. GFN. Global Footprint Network. Accessed on 12 Apr 2024. Available at: https://www.footprintnetwork.org/resources/.
70. WDI. World Bank Indicators. 2022. Accessed 12 Apr 2024. https://databank.worldbank.org/source/world-development-indicators.
71. IMF. International Monetary Fund. 2022. Accessed 12 Apr 2024. Available at: https://www.imf.org/en/Data.
72. GFD. Global Financial Development. Accessed on 12 April 2024. 2022. Available at: https://databank.worldbank.org/source/global-financial-development#.
73. Degirmenci T, Aydin M. Testing the load capacity curve hypothesis with green innovation, green tax, green energy, and technological diffusion: a novel approach to Kyoto protocol. Sustain Dev. 2024;32:4931.
74. Ridwan M, Urbee AJ, Voumik LC, Das MK, Rashid M, Esquivias MA. Investigating the environmental Kuznets curve hypothesis with urbanization, industrialization, and service sector for six South Asian Countries: fresh evidence from Driscoll Kraay standard error. Res Globaliz. 2024;8:100223.
75. Ayad H, Lefilef A. Unveiling new insights into China's marine ecosystem: exploring the fishing grounds load capacity curve. J Clean Prod. 2024;450:141507.
76. Voumik LC, Ridwan M. Impact of FDI, industrialization, and education on the environment in Argentina: ARDL approach. Heliyon. 2023;9(1).
77. Raihan A, Voumik LC, Ridwan M, Ridzuan AR, Jaaffar AH, Yusoff NYM. From growth to green: navigating the complexities of economic development, energy sources, health spending, and carbon emissions in Malaysia. Energy Rep. 2023;10:4318–31.
78. Dickey DA, Fuller WA. Distribution of the estimators for autoregressive time series with a unit root. J Am Stat Assoc. 1979;74(366a):427–31.
79. Phillips PC, Perron P. Testing for a unit root in time series regression. Biometrika. 1988;75(2):335–46.
80. Elliott G, Rothenberg TJ, Stock JH. Efficient tests for an autoregressive unit root. 1992.
81. Pesaran MH, Shin Y, Smith RJ. Bounds testing approaches to the analysis of level relationships. J Appl Economet. 2001;16(3):289–326.
82. Ahmad S, Raihan A, Ridwan M. Role of economy, technology, and renewable energy toward carbon neutrality in China. J Econ Technol. 2024;2:138–54.
83. Majekodunmi TB, Shaari MS, Abidin NZ, Esquivias MA. The environmental influence of national savings in D-8 countries: Empirical evidence using an ARDL model. Environ Sci Pollut Res. 2023;30:94456–73. https://doi.org/10.1007/s11356-023-28865-3
84. Granger CW. Investigating causal relations by econometric models and cross-spectral methods. Econometrica. 1969;1969(37):424–38.
85. Wu Y, Anwar A, Quynh NN, Abbas A, Cong PT. Impact of economic policy uncertainty and renewable energy on environmental quality: testing the LCC hypothesis for fast growing economies. Environ Sci Pollut Res. 2023;31:36405.
86. Pata UK, Kartal MT. Impact of nuclear and renewable energy sources on environment quality: testing the EKC and LCC hypotheses for South Korea. Nucl Eng Technol. 2023;55(2):587–94.
87. Karimi MS, Khezri M, Khan YA, Razzaghi S. Exploring the influence of economic freedom index on fishing grounds footprint in environmental Kuznets curve framework through spatial econometrics technique: evidence from Asia-Pacific countries. Environ Sci Pollut Res. 2022;29(4):6251–66.
88. Yao X, Yasmeen R, Hussain J, Shah WUH. The repercussions of financial development and corruption on energy efficiency and ecological footprint: evidence from BRICS and next 11 countries. Energy. 2021;223: 120063.
89. Annor LDJ, Robaina M, Vieira E. Climbing the green ladder in Sub-Saharan Africa: dynamics of financial development, green energy, and load capacity factor. Environ Syst Decis. 2024;44:607–23.
90. Yang M, She D, Abbas S, Ai F, Adebayo TS. 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? Geol J. 2023;58(10):3915–27.
91. UNIDO. Sustainable development goals; 2022. https://www.unido.org/unido-sdgs. 2022. Accessed 5 May 2023.