Received: 28 July 2022 | Revised: 15 August 2022 | Accepted: 20 August 2022
https://doi.org/10.56946/jeee.v1i2.482
Journal of Environmental and Energy Economics

Research Article

An Econometric Investigation of How the Usage of Non-Renewable Energy Resources Affects the Load Capacity Factor in the United States

Filiz Guneysu Atasoy[1], Murat Atasoy[2], Asif Raihan[3,*], Khayruzzaman[3], Md. Shoaibur Rahman[4], Mohammad Ridwan[5], Tipon Tanchangya[6], Junaid Rahman[6], Md. Zia Uddin Foisal[7], Babla Mohajan[8], Samanta Islam[9], Arindrajit Paul[10], Abdullah Al Jubayed[11]

[1]Wilson Science Center, Information and Data Science, University of the Ozarks, Clarksville, AR 72830, United States.
[2]Wilson Science Center, Department of Environmental Science, University of the Ozarks, Clarksville, AR 72830, United States.
[3]Institute of Climate Change, National University of Malaysia, Bangi 43600, Malaysia.
[4]Department of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur 5200, Bangladesh.
[5]Department of Economics, Noakhali Science and Technology University, Noakhali 3814, Bangladesh.
[6]Department of Finance, University of Chittagong, Chittagong 4331, Bangladesh.
[7]Department of Statistics and Data Science, Jahangirnagar University, Dhaka 1342, Bangladesh.
[8]Department of Land, Environment, Agriculture and Forestry, University of Padua, Padova PD 35122, Italy.
[9]Department of Environmental Science and Engineering, Jatiya Kabi Kazi Nazrul Islam University, Mymensingh 2220, Bangladesh.
[10]Department of Computer Science, University of Colorado Boulder, Boulder, CO 80309, United States.
[11]Department of Economics, Western Kentucky University, KY 42101, United States.

*Corresponding author: Asif Raihan, Email: asifraihan666@gmail.com

Abstract

A substantial body of studies exists regarding the consequences of significant non-renewable energy usage on ecosystem health. Nonetheless, a research deficit exists in examining the nexus within the United States by utilizing the load capacity factor (LCF) as an indicator of environmental sustainability. The current study addresses the identified research gap by employing the autoregressive distributed lag (ARDL) method to examine the influences of non-renewable energy use on the environmental condition of the United States, utilizing data from 1965 to 2022. This analysis delivers a deeper understanding of the long-term impacts of coal, gas, oil, and nuclear utilization on the LCF, considering the United States' significant dependence on energy derived from non-renewable energy resources. The analysis of the ARDL model reveals that a 1% rise in coal, gas, and oil adoption results in a long-term reduction of LCF of 0.14%, 0.12%, and 0.16%, respectively, and a short-term reduction of 0.12%, 0.08%, and 0.10%. However, a 1% increase in nuclear energy usage would enhance LCF by 0.02% in the short term and 0.13% in the long term. This study advocates for the increased adoption of nuclear energy through the gradual diminishment of coal, oil, and gas usage to enhance the sustainability of natural health in the United States while taking into account the social and economic ramifications of transitioning from fossil fuels.

Keywords: Environmental sustainability, load capacity factor, coal, gas, oil, nuclear energy.

Introduction

The global need for energy resources has markedly increased due to industrialization since the mid-19th century [1]. Increasing power adoption has enhanced both financial growth and social fairness [2], yet it significantly affects the environment based on the energy sources utilized. In 2015, nations globally dedicated to restricting temperature rise to 1.5◦C prior to industrialization acknowledged the imperative to diminish emissions of greenhouse gases (GHG) to protect the planet for upcoming times through a shift to clean powers [3]. Renewable energy (RE) sources, distinguished by their clean and ecologically friendly characteristics, present a viable approach for alleviating negative environmental impacts [4].

Nonetheless, the USA, as the second biggest electricity user and GHG emitter globally, encounters significant obstacles in accomplishing this shift [5]. The USA officials intend to reduce GHG output by 50% (relative to 2005 levels) by 2030 and attain net-zero emissions by 2050. Notwithstanding a modest rise in green power usage, the nation predominantly depends on non-renewable energy (NRE) assets to satisfy its electricity requirements. NRE resources—coal, gas, oil, and atomic power (notably, nuclear energy is classified as non-renewable due to the finite nature of uranium used in power plants, despite the renewable energy produced through nuclear processes)—constituted approximately 90% of overall U.S. energy utilization, while sustainable electricity comprised merely 9%. The substantial energy use of non-renewable energy resources markedly exacerbates environmental degradation by emitting GHGs, particularly carbon dioxide (CO_2), which are considered the principal factors in temperature rise and climate change [6]. Consequently, there is a clear necessity for environment friendly and contemporary RE resources to ensure sustainability for the environment in the United States.

The transition from unsustainable energy to green power adoption is undeniably a protracted process, necessitating the implementation of distinct structures and modern innovations to minimize historical reliance on fossil fuels. The detrimental effects of non-renewable fossil fuels, including coal, gas, and oil, on human well-being and the natural environment vary significantly among them [7]. Numerous investigations have assessed the implication of clean and NRE supplies on pollutants in the environment, frequently utilizing CO_2 emissions as a primary metric [8-10].

Nonetheless, a thorough assessment of a nation's long-term environmental sustainability necessitates the consideration of air, water, and land pollution. A fresh study has proposed the ecological footprint (EFP) as an indicator of biodiversity loss [11-13]; however, it exclusively considers pollutants stemming from human consumption and waste absorption, neglecting the supply side, namely biocapacity. Consequently, the LCF, denoting the ratio of biocapacity to EFP, serves as the most effective indicator of environmental sustainability [14]. The LCF denotes a country's adherence to its ecological capacity, with a ratio below one signifying unsustainability [15].

Figure 1 illustrates the annual patterns of EFP and biocapacity in the United States. The LCF of the USA has constantly prevailed at less than 0.5 from 1970 to 2022, signifying an inadequate role in achieving ecological responsibility and insufficient material supply to sustain current utilization and output levels [16]. The United States experienced a regional biocapacity deficit, indicating that its EFP exceeds twice its national biocapacity.

The United States depends on substantial consumption of energy for GDP growth and possesses a varied electricity portfolio. Carbon constitutes the primary element of the EFP; therefore, the United States must diminish carbon-related power alternatives within its energy portfolio to mitigate biocapacity loss. In the USA, there is a deficiency of research assessing the consequences of a non-green supply of energy utilization on the LCF. This paper tries to assess the implications of unsustainable power (coal, gas, and oil) intake on the sustainability of the environment, as indicated by the LCF, utilizing the ARDL methodology. This research employed a time series dataset spanning 58 years (1965-2022). This research offers essential information for formulating targeted policies to eliminate the most harmful energy sources and enhance the sustainability of the environment in the United States.

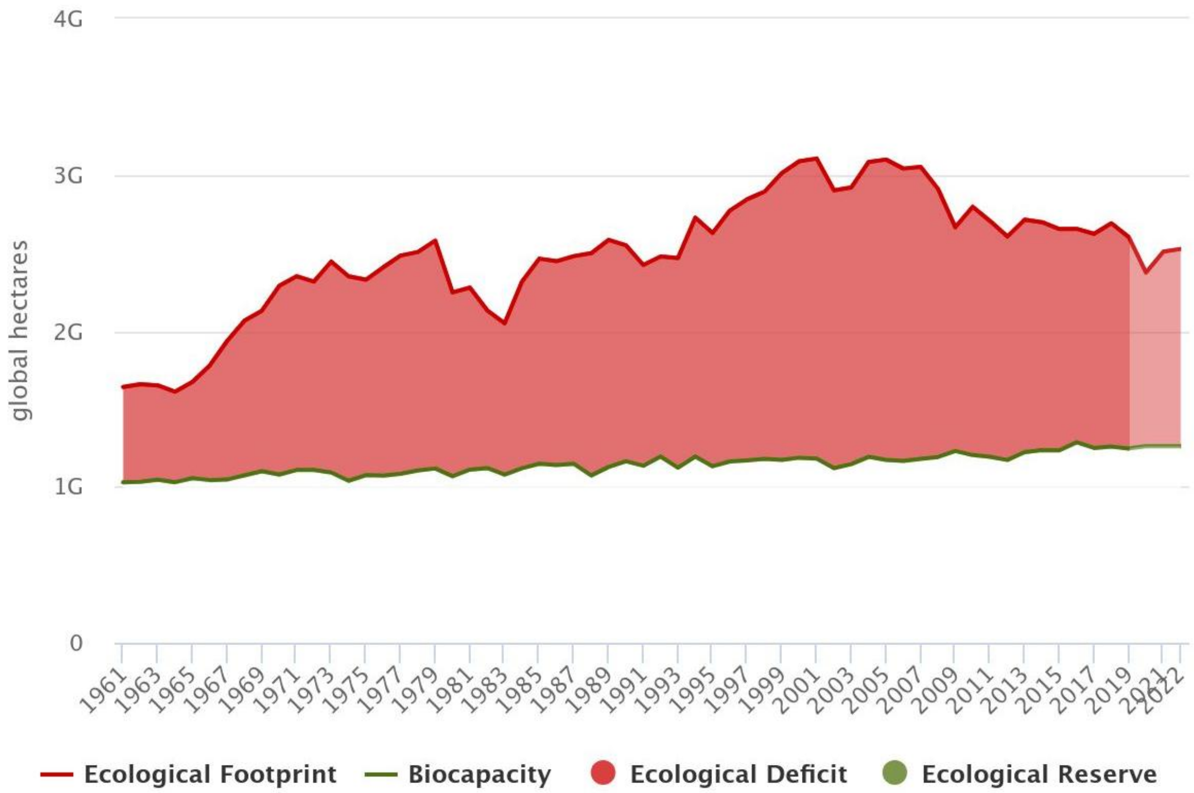

Figure 1. Annual trends of ecological footprint and biocapacity in the United States.

Literature Review

Environmental sustainability has garnered considerable focus in scholarly studies in the past few years. This section consolidates recent results regarding the correlation between many sources of NRE use and environmental sustainability. Coal continues to be a significant energy supply for economic advancement in numerous locations, although being the foremost producer of CO_2 emissions in the energy industry [17]. Alhassan et al. [18] deployed the implication of coal consumption on ecosystem health, adopting CO_2 emissions as a metric, and employed a generalized method of moments (GMM) to simulate prominent coal-consuming industrialized and emerging countries. They indicated a robust correlation between coal usage and environmental degradation, with industrialized nations exhibiting somewhat greater impacts than emerging nations. Adebayo [19], employing the wavelet regional multiple correlation method, determined that heightened coal consumption in China considerably deteriorated the natural world by elevating CO_2 outputs in both the immediate and distant future.

Conversely, the increasing dependence on gas, especially for power production, stems from advancements in extraction techniques and international initiatives to mitigate GHGs from carbon-heavy resources, such as coal [7]. Etokakpan et al. [20] examined the correlation amid individual gas usage and CO_2 pollution in China adopting the ARDL model, demonstrating an encouraging association between gas utilization and CO_2 releases. Adebayo et al. [21] employed the ARDL approach to investigate the biodiversity consequences of gas applications, determining that increased gas usage adversely impacts the natural world.

Alam and Paramati [22] employed a vector error correction model (VECM) to illustrate that the execution of oil significantly influences CO_2 outputs in 18 prominent oil-consuming emerging nations. Saboori et al. [23] corroborated this observation within South Korea, identifying an obvious relationship involving the adoption of oil and CO_2 pollution, but Zakari et al. [24] determined that in African nations, local oil use adversely affects the ecosystem in the immediate time.

Nuclear power is frequently regarded as a viable remedy for environmental degradation, with current research examining its ecological effects. Ullah and Lin [25], employing the dynamic ARDL approach, determined that nuclear power use in Pakistan enhanced ecosystem health by improving the LCF. Apergis and Litinas [26] identified a substantial inverse correlation between atomic energy consumption and CO_2 releases across 19 chosen industrialized and emerging nations. Baek and Pride [27] showed that nuclear energy usage markedly enhances natural health by diminishing the release of CO_2 in the six foremost nuclear-power-producing nations. Mathew [28] further established that the rising share of nuclear energy use in 18 principal atomic energy-generating regions results in sustained decreases in CO_2 emissions.

Although the majority of studies suggest that nuclear electricity usage can alleviate ecological damage, additional research presents opposing conclusions. Saidi and Omri [29] noted that escalating worldwide investment in nuclear power plants correlates with heightened emissions of CO_2 in South Korea as well as the Netherlands. Bandyopadhyay et al. [30] similarly determined that atomic energy adoption does not substantially aid in maintaining a healthy environment in France, Germany, and China across many quantiles.

Finally, the majority of the scholarly work emphasizes the advantages of atomic power in mitigating CO_2 output; however, certain studies offer contradictory findings. Moreover, scant research has utilized the LCF as a substitute for environment sustainability, with less investigation into the diverse impacts of non-renewable energy (NRE) supplies on the LCF [31], particularly, in the context of the USA. To combat this literature deficiency, this paper evaluates the effects of coal, gas, and oil use on LCF in the USA.

Methodology

Data and model

This study incorporated LCF as a proxy for the United States' ecosystem health. This study calculated the LCF (global hectares) by dividing biocapacity by the EFP, utilizing information from the Global Footprint Network (GFN) database [16]. The statistics for coal, gas, oil, and nuclear energy utilization were collected from the Statistical Review of World Energy [32], with all quantities quantified in Exajoules. These variables encompass yearly data from 1965 to 2022. Figure 2 illustrates the yearly pattern of LCF in the United States. Despite the LCF exhibiting a declining tendency, it has seen an increase in volatility post-2005. Furthermore, Figure 3 illustrates the yearly statistics on the use of coal, gas, oil, and nuclear energy in the United States. Despite a declining tendency in coal consumption over the past two decades, the consumption of oil, gas, and nuclear energy exhibits a rising trajectory with oscillations.

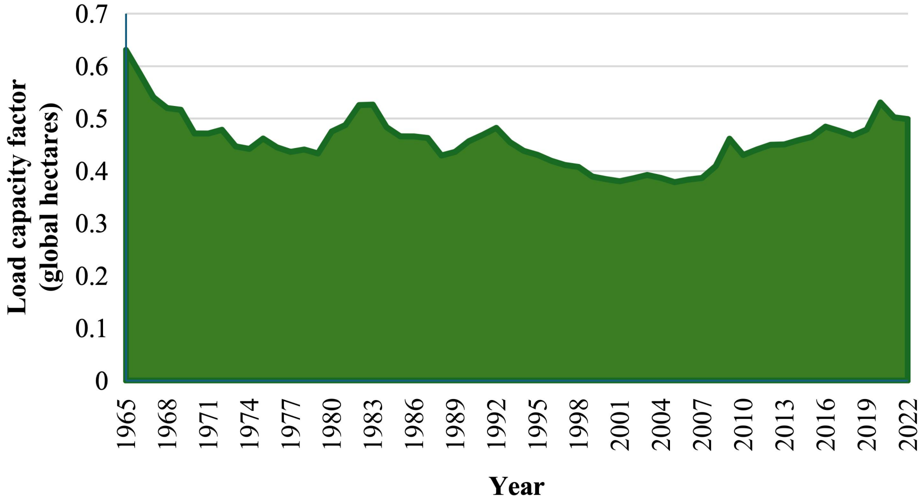

Figure 2. Annual trend of load capacity factor in the United States.

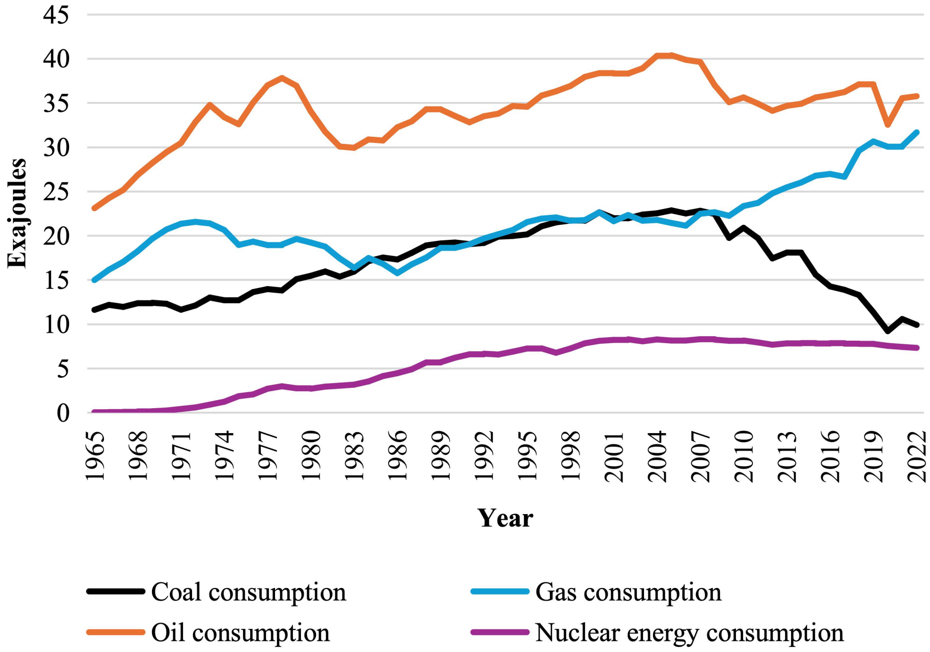

Figure 3. Annual trends of coal, gas, oil, and nuclear energy usage in the United States.

The ecological sustainability-related function utilized in this research can be articulated as follows:

$$L = f(C, G, O, N) \quad (1)$$

Where L represents the load capacity factor, C represents coal consumption, G represents gas consumption, O represents oil consumption, and N represents nuclear energy consumption.
Equation (1) can be alternatively represented in the econometric model at time "t" as follows:

$$L_t = \tau_0 + \tau_1 C_t + \tau_2 G_t + \tau_3 O_t + \tau_4 N_t + \varepsilon_t \quad (2)$$

Here, τ_0 and ε_t are the intercept and error terms. Besides, τ_1, τ_2, τ_3, and τ_4 are the coefficients.

Econometric strategies

This research used the ARDL methodology [33] to investigate the impacts of NRE resources on the LCF. Two prerequisites must be met before executing the ARDL simulation on a time series set of data. The endogenous factor may exhibit non-stationarity at level I(0) but must achieve stationarity at level I(1). Secondly, a long-term connection must exist across the examined parameters. Three statistical assessments were incorporated to check the stationarity of the parameters: the augmented Dickey-Fuller (ADF) test [34], the Dickey-Fuller generalized least squares (DF-GLS) test [35], and the Phillips-Perron (P-P) test [36]. These examinations are essential to mitigate erroneous regression influences arising from non-stationary qualities, thus enhancing the model's stability and resilience.

Upon verifying that the variables exhibit stationarity at the initial difference, the cointegration among the variables is subsequently assessed utilizing the ARDL bounds test [33]. Upon verifying the stationarity and cointegration assumptions, it is necessary to analyze the ARDL simulation for both the time frame impacts of the variables. The ARDL simulation effectively captures temporal fluctuations and provides estimates for both long-run and short-run coefficients, facilitating the examination of the distinct effects of the chosen variables and their intricate interactions, hence allowing for a comprehensive examination of their consequences [33]. The ARDL limit testing, utilized to explore the sustained associations across the chosen variables, is delineated as follows:

$$\Delta L_t = \tau_0 + \tau_1 L_{t-1} + \tau_2 C_{t-1} + \tau_3 G_{t-1} + \tau_4 O_{t-1} + \tau_5 N_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta L_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta C_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta G_{t-i} + \sum_{i=1}^{q} \gamma_4 \Delta O_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta N_{t-i} + \varepsilon_t \tag{3}$$

Here, the first-difference operator (Δ) is used to describe temporal variations in the parameters and the optimal lag length is signed as "q".

The null hypothesis (H0) under the ARDL bounds posits the deficiency of cointegration across the factors, whereas the alternative hypothesis (H1) asserts the existence of cointegration amongst all of the factors. After identifying the long-term equilibrium linkages among the study parameters, a bounds test is conducted prior to utilizing the ARDL framework to ascertain the short and long-run coefficients. The integration of the error correction term (ECT) in the equation of the ARDL model employed for analyzing short-run dynamics can be expressed as follows:

$$\Delta L_t = \tau_0 + \tau_1 L_{t-1} + \tau_2 C_{t-1} + \tau_3 G_{t-1} + \tau_4 O_{t-1} + \tau_5 N_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta L_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta C_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta G_{t-i} + \sum_{i=1}^{q} \gamma_4 \Delta O_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta N_{t-i} + \theta ECT_{t-1} + \varepsilon_t \tag{4}$$

Here, θ represents the coefficient of the ECT. Ultimately, several diagnostic assessments were performed to figure out the stability of the ARDL method and the reliability of the statistical findings. For instance, the diagnostic assessments evaluate normality, heteroskedasticity, and correlation inside the model.

Results and discussion

Before initiating any regression analysis, it is essential to thoroughly investigate the underlying properties of the parameters and their relationships. Table 1 illustrates the results of summary calculations within factors, in tandem with the values of statistics derived from multiple normality assessments. Skewness values adjacent to zero suggest that all variables show a normal distribution. Furthermore, the outcomes reveal that all series demonstrate a platykurtic distribution, evidenced by their kurtosis values falling beneath 3. Moreover, the reduced Jarque-Bera statistics and probability values beyond 0.1 suggest that all factors demonstrate a normal distribution.

Table 1. Summary statistics of the variables.

Variables	LCF	Coal	Gas	Oil	Nuclear
Mean	0.46	16.88	21.46	34.21	5.31
Median	0.46	17.36	21.36	34.71	6.71
Maximum	0.63	22.85	31.67	40.38	8.29
Minimum	0.38	9.20	14.97	23.09	0.04
Std. Dev.	0.01	0.53	0.51	0.50	0.29
Skewness	0.82	-0.08	0.88	-0.92	-0.64
Kurtosis	1.65	1.32	0.45	1.03	1.18
Jarque-Bera	2.11	1.96	1.66	1.35	1.43
Probability	0.19	0.27	0.44	0.39	0.25
Observations	58	58	58	58	58

Note: LCF = Load capacity factor.

The results of the unit root testing are displayed in Table 2. It can be observed that the factors are non-stationary at the I(0) but stationary at the first difference, as the test statistics for ADF, DF-GLS, and P-P at I(1) are significant. Consequently, all variables satisfy the requisite conditions for the application of the ARDL model, thereby validating their integration of order I (1).

Table 2. Results of unit root tests.

Variables		LCF	Coal	Gas	Oil	Nuclear
ADF	I(0)	-0.21	-0.88	-0.21	-0.98	-0.71
	I(1)	-6.56***	-6.71***	-6.16***	-5.88***	-5.69***
DF-GLS	I(0)	-0.25	-1.46	-0.27	-1.35	-0.84
	I(1)	-5.67***	-6.17***	-5.94***	-5.63***	-4.94***
P-P	I(0)	-0.27	-0.72	-0.23	-0.97	-0.69
	I(1)	-6.57***	-6.80***	-6.22***	-5.87***	-5.65***

Note: LCF = Load capacity factor, *** indicates significance at a 1% level.

Following the confirmation of data stationarity by unit root examinations, this work adopted the ARDL bounds examination to analyze the long-term relationship among the variables. Table 3 presents the findings from the application of ARDL bounds testing methods for cointegration. The calculated F-statistic exceeds the upper critical constraint, indicating the existence of long-term cointegration across the parameters.

Table 3. Results of ARDL bounds test.

Test statistic	Estimate	Significance levels	I(0)	I(1)
F-statistic	9.87	10%	2.37	3.20
K	4	5%	2.79	3.67
		2.5%	3.15	4.08
		1%	3.65	4.66

Table 4 delivers the conclusions of the ARDL simulation. The ARDL method's findings indicate that the usage of coal, gas, and oil has a substantial destructive correlation with the ecosystem level in both the short and long time. A 1% boost in coal-based electricity usage causes a 0.12% reduction in the LCF in the near run and a 0.14% reduction over time. Additionally, a 1% surge in gas consumption causes a

0.08% and 0.12% decline in the LCF in the short and long term, accordingly. Furthermore, oil utilization adversely impacts the LCF, resulting in a reduction of 0.10% in the short period and 0.16% over time. Nuclear energy use contributes positively to the long-term sustainability of biodiversity. A 1% spike in nuclear power utilization would elevate the LCF by 0.02% in the short term and 0.13% in the longer phase.

Table 4. Results of ARDL long- and short-run analysis.

Variables	Long-run			Short-run		
	Coefficient	t-statistic	p-value	Coefficient	t-statistic	p-value
Coal	-0.14***	-4.71	0.00	-0.12***	-4.12	0.00
Gas	-0.12***	-3.89	0.00	-0.08***	-3.17	0.00
Oil	-0.16***	-3.56	0.00	-0.10***	-3.41	0.00
Nuclear	0.13***	4.20	0.00	0.02***	4.07	0.00
C	11.11	1.49	0.10	-	-	-
ECT (-1)	-	-	-	-0.56***	-3.96	0.00
R^2	0.97					
Adjusted R^2	0.96					

Note: ECT = Error correction term, *** indicates significance at a 1% level.

The value of ECT is -0.56 and significant at 1% thresholds, corroborating the evidence of persistent integration within the adoption of coal, gas, oil, and nuclear electricity with the LCF. It illustrates that variations in these factors are linked with about 56% of long-term changes in the LCF. Besides, the long-run evaluation R^2 and adjusted R^2 values are 0.97 and 0.96, respectively, revealing that the estimated regression model matches the information excellently.

Furthermore, Table 5 presents the ARDL diagnostic assessment conclusions. The lower value of the Jarque-Bera coefficient and the insignificant p-value indicate that the residuals have a normal distribution. The Breusch-Godfrey LM examination result indicates no significant autocorrelation existed in the model, as the p-value is not significant. In the case of the Breusch-Pagan-Godfrey test, the p-value obtained is not significant, and this indicates no heteroscedasticity issue in the model. In addition, the Ramsey RESET test was conducted to check if the model was properly specified. The insignificant p-value from the test demonstrates that the model is appropriately specified.

Table 5. Diagnostic test results.

Diagnostic tests	Coefficient	p-value	Decision
Jarque-Bera	0.47	0.82	Normal distribution residuals
Breusch-Godfrey LM	0.74	0.59	No autocorrelation
Breusch-Pagan-Godfrey	0.87	0.77	No heteroscedasticity
Ramsey RESET	0.63	0.69	The model is properly specified

The findings of the ARDL simulation indicate that the usage of coal, gas, and oil adversely affects the sustainability of the environment in the United States, both in the near future and over the course of time. Our findings are consistent with studies conducted from various international viewpoints. Raihan et al. [37] calculated an ARDL simulation and determined that energy use from fossil fuels considerably exacerbates biodiversity loss. Bello et al. [38] examined the ASEAN countries and determined that non-renewable energy usage inflicts significant ecosystem damage, necessitating immediate governmental measures to mitigate pollutants and promote a green environment. Apergis et al. [39] employed the ARDL method for the United States and discovered that while aggregated non-renewable energy sources adversely affect the quality of the environment, expenditures in more ecologically sound alternatives are essential to mitigate these unfavorable consequences and enhance environmental sustainability.

Acheampong [40] discerned a comparable pattern connecting fossil fuel intake and degradation of the environment in his analysis of 116 countries.

Conversely, our outcomes demonstrate that nuclear energy use positively influences the sustainability of the environment, as it generates no emissions during power production. This is consistent with the findings of Lin and Ullah [41], who explored that nuclear power causes a cut of CO_2 releases. Kadioglu and Gurbuz [42] demonstrated the potential of nuclear energy in a green economy, asserting its comparative benefit in long-term sustainability compared to fossil fuels. Khan et al. [43] similarly identified enduring environmental benefits of atomic energy in contrast to fossil fuels, acknowledging its capacity to substantially improve the sustainability of the environment over time. Their outcomes correspond with those of Kanat et al. [44], ensuring that natural health deteriorates with heightened use of coal, gas, and oil, whereas nuclear energy usage is beneficial to environmental quality. Nonetheless, atomic power has certain obstacles. A principal worry is waste management, particularly for emerging technologies such as small modular reactors (SMRs), which produce trash necessitating sustained removal remedies, possibly constraining their ecological advantages [45]. The monetary feasibility of SMRs is also under doubt because of their substantial development expenses and unpredictable financial yields [46]. Moreover, political and institutional obstacles among regions hinder nuclear energy's contribution to pollutant mitigation, given that each state possesses its own regulatory structure and differing levels of public approval [47]. The government of the United States has sought to tackle these difficulties by providing funds for new reactor designs and optimizing systematic ways to lower costs and expedite renovation. Additionally, the Department of Energy (DOE) is enhancing the security of atomic advances in technology, advancing garbage handling systems, and assuring the financial feasibility of atomic power through projects like the Civil Nuclear Credit.

Notwithstanding these endeavors, the shift to greener electricity sources in the United States encounters considerable obstacles. Regions that have adopted renewable energy, particularly through investments in wind and solar, often express support; conversely, states dependent on fossil fuels, such as West Virginia, are apprehensive about potential work reductions and the wider monetary ramifications of this transition. A significant political gap exists, with Democrats typically advocating for the shift to clean energy, but numerous Republicans exhibit doubt over the consequences of economic and energy dependability. Local resistance to clean energy initiatives, notably wind farms, frequently emerges from apprehensions regarding environmental consequences and property valuations. Carley and Konisky [48] emphasize that a "just" shifting approach, which encompasses assistance for impacted laborers and societies, is essential for securing broad support for energy transitions.

Nuclear energy is an essential and sustainable low-carbon energy alternative that might significantly diminish world dependence on fossil fuels. It provides a dependable resolution to the persistent challenges of global warming, and it is essential for assisting the United States in achieving its objectives of SDG- 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). Hao et al. [49] contend that attaining a stabilized integration of renewable energy sources and nuclear power constitutes the most efficacious approach for improving the natural world and meeting net-zero emission objectives. The outcomes of the current study demonstrate that diminishing the application of coal, gas, and oil markedly improves the LCF. The findings together emphasize the necessity of shifting from natural gas to atomic energy to attain improved ecological results, so advocating for policy reforms that diminish fossil fuel reliance and enhance nuclear energy utilization for a green future. The outcomes provide policymakers and stakeholders with a robust framework for their decision-making.

The results of our analysis underscore the critical policy significance of decreasing non-clean power usage and augmenting atomic electricity utilization to enhance the condition of the environment. Nuclear energy exhibits an increasing capacity to alleviate the environmental damage resulting from fossil fuel consumption. As nuclear energy expands, it is imperative to establish rigorous regulatory frameworks to assure safety, openness, and public trust, which is vital for its wider acceptance. Scenario-based energy modeling, highlighted by researchers such as Gillingham and Stock [50], is a crucial instrument for lawmakers to evaluate the sustained effects of diverse power strategies. In the United States, these models highlight the pressing necessity for prompt legislative measures, including carbon pricing, subsidies for renewable energies, and increased funds for nuclear facilities. These instruments are broadly acknowledged as efficient in expediting the shift to cleaner sources of energy and fulfilling the United States' decarbonization objectives under Sustainable Development Goals 7 and 13.

Conclusions and policy recommendations

The United States, which ranks among the foremost global energy users and GHG emitters, encounters substantial obstacles in shifting from non-renewable power supplies to greener options. The investigation attempts to measure the implication of non-renewable energy (NRE) intake on environmental conditions, utilizing the LCF as a metric and considering the persistent emphasis on NRE alternatives and their detrimental environmental repercussions. The current investigation used the ARDL methodology to explore the impacts of coal, gas, oil, and nuclear energy usage from 1965 to 2022. The findings indicate that all energy supplies that are not renewable, such as coal, gas, and oil, substantially diminish sustainability for the environment in the immediate and distant future. Furthermore, the application of atomic power enhances environmental sustainability over time.

This article advocates for the United States energy policies to prioritize the gradual elimination of coal owing to its significant adverse environmental effects. This can be accomplished by enforcing more stringent pollution restrictions, encouraging the decommissioning of coal-fired electricity facilities, and advocating for sustainable energy resources such as solar and wind. Despite being cleaner than coal, gas nevertheless adversely impacts sustainability. Consequently, a systematic decrease in its utilization is important, which can be facilitated by enhancing energy efficiency, augmenting the adoption of clean power, and updating the grid to more effectively accommodate green alternatives. The substantial destructive consequences of oil on natural health necessitate laws designed to curtail its consumption. This may encompass the promotion of electric vehicles, enhancement of transit systems, and facilitation of biofuel development.

The favorable consequence of nuclear power on the ecosystem level indicates that enhancing nuclear capacity ought to be a primary governmental priority. Simultaneously, endeavors should be amplified to broaden the utilization of environment-friendly energy sources such as wind and solar, along with hydroelectricity. The principal shortcomings of this study are the absence of a study of the ecological repercussions of nuclear disposal and the exclusion of social and economic expenses, such as employment displacement and rehabilitation, related to the shift from fossil fuels. These elements are essential for assessing the continued prosperity and conservation of power legislation modifications. The influence of a comprehensive disaggregated sustainable electricity utilization source on the ecosystem in the United States can be assessed using the same methodology. In this instance, the less concentrated usage of renewable energies, especially geothermal and hydroelectric power, may be considered.

Funding: Not applicable.
Acknowledgment: Not applicable.
Conflict of Interest: The authors declare no conflict of interest.
Authors' contributions: Asif Raihan assisted in the study's conception and design. Material preparation, data collection, and analysis were done by Asif Raihan, Khayruzzaman, Mohammad Ridwan, Filiz Guneysu Atasoy, Murat Atasoy, Md. Shoaibur Rahman, Md. Zia Uddin Foisal, Babla Mohajan, Tipon Tanchangya, Junaid Rahman, Samanta Islam, Arindrajit Paul, and Abdullah Al Jubayed. All authors read and approved of the final manuscript.
Data availability statement: Data supporting this manuscript will be provided upon reasonable request from the corresponding author.

References

1. Moe, E. (2010). Energy, industry and politics: Energy, vested interests, and long-term economic growth and development. Energy, 35(4), 1730-1740.

2. He, J., Zhuang, T., & Xie, X. (2014). Energy consumption, economic development and environmental improvement in China. Energy & Environment, 25(8), 1345-1357.
3. Raihan, A., Begum, R. A., Mohd Said, M. N., & Abdullah, S. M. S. (2019). A review of emission reduction potential and cost savings through forest carbon sequestration. Asian Journal of Water, Environment and Pollution, 16(3), 1-7.
4. Begum, R. A., Raihan, A., & Said, M. N. M. (2020). Dynamic impacts of economic growth and forested area on carbon dioxide emissions in Malaysia. Sustainability, 12(22), 9375.
5. Sovacool, B. K., Hook, A., Sareen, S., & Geels, F. W. (2021). Global sustainability, innovation and governance dynamics of national smart electricity meter transitions. Global Environmental Change, 68, 102272.
6. Raihan, A., & Said, M. N. M. (2022). Cost–benefit analysis of climate change mitigation measures in the forestry sector of Peninsular Malaysia. Earth Systems and Environment, 6(2), 405-419.
7. Mac Kinnon, M. A., Brouwer, J., & Samuelsen, S. (2018). The role of natural gas and its infrastructure in mitigating greenhouse gas emissions, improving regional air quality, and renewable resource integration. Progress in Energy and Combustion science, 64, 62-92.
8. Dogan, E., & Seker, F. (2016). Determinants of CO_2 emissions in the European Union: the role of renewable and non-renewable energy. Renewable Energy, 94, 429-439.
9. Bulut, U. (2017). The impacts of non-renewable and renewable energy on CO_2 emissions in Turkey. Environmental Science and Pollution Research, 24, 15416-15426.
10. Chen, Y., Wang, Z., & Zhong, Z. (2019). CO_2 emissions, economic growth, renewable and non-renewable energy production and foreign trade in China. Renewable energy, 131, 208-216.
11. Adekoya, O. B., Oliyide, J. A., & Fasanya, I. O. (2022). Renewable and non-renewable energy consumption–Ecological footprint nexus in net-oil exporting and net-oil importing countries: Policy implications for a sustainable environment. Renewable Energy, 189, 524-534.
12. Kongbuamai, N., Bui, Q., Yousaf, H. M. A. U., & Liu, Y. (2020). The impact of tourism and natural resources on the ecological footprint: a case study of ASEAN countries. Environmental Science and Pollution Research, 27, 19251-19264.
13. Li, R., Wang, X., & Wang, Q. (2022). Does renewable energy reduce ecological footprint at the expense of economic growth? An empirical analysis of 120 countries. Journal of Cleaner Production, 346, 131207.
14. Pata, U. K. (2021). Do renewable energy and health expenditures improve load capacity factor in the USA and Japan? A new approach to environmental issues. The European Journal of Health Economics, 22(9), 1427-1439.
15. Pata, U. K., & Isik, C. (2021). Determinants of the load capacity factor in China: a novel dynamic ARDL approach for ecological footprint accounting. Resources Policy, 74, 102313.
16. GFN. (2022). Global Footprint Network. Available online: https://data.footprintnetwork.org/#/countryTrends?cn=231&type=BCpc,EFCpc (accessed 7 May 2022).
17. Chen, H., Liu, K., Shi, T., & Wang, L. (2022). Coal consumption and economic growth: a Chinese city-level study. Energy Economics, 109, 105940.
18. Alhassan, M., Andrew, I., Auta, M., Umaru, M., Garba, M. U., Isah, A. G., & Alhassan, B. (2018). Comparative studies of CO_2 capture using acid and base modified activated carbon from sugarcane bagasse. Biofuels, 9(6), 719-728.
19. Adebayo, T. S. (2021). Do CO_2 emissions, energy consumption and globalization promote economic growth? Empirical evidence from Japan. Environmental Science and Pollution Research, 28(26), 34714-34729.
20. Etokakpan, M. U., Akadiri, S. S., & Alola, A. A. (2021). Natural gas consumption-economic output and environmental sustainability target in China: an N-shaped hypothesis inference. Environmental Science and Pollution Research, 28, 37741-37753.

21. Adebayo, T. S., Udemba, E. N., Ahmed, Z., & Kirikkaleli, D. (2021). Determinants of consumption-based carbon emissions in Chile: an application of non-linear ARDL. Environmental Science and Pollution Research, 28(32), 43908-43922.
22. Alam, M. S., & Paramati, S. R. (2015). Do oil consumption and economic growth intensify environmental degradation? Evidence from developing economies. Applied Economics, 47(48), 5186-5203.
23. Saboori, B., Rasoulinezhad, E., & Sung, J. (2017). The nexus of oil consumption, CO_2 emissions and economic growth in China, Japan and South Korea. Environmental Science and Pollution Research, 24(8), 7436-7455.
24. Zakari, A., Li, G., Khan, I., Jindal, A., Tawiah, V., & Alvarado, R. (2022). Are abundant energy resources and Chinese business a solution to environmental prosperity in Africa?. Energy Policy, 163, 112829.
25. Ullah, S., Ozturk, I., Usman, A., Majeed, M. T., & Akhtar, P. (2020). On the asymmetric effects of premature deindustrialization on CO_2 emissions: evidence from Pakistan. Environmental Science and Pollution Research, 27, 13692-13702.
26. Apergis, N., Payne, J. E., Menyah, K., & Wolde-Rufael, Y. (2010). On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth. Ecological Economics, 69(11), 2255-2260.
27. Baek, J., & Pride, D. (2014). On the income–nuclear energy–CO_2 emissions nexus revisited. Energy Economics, 43, 6-10.
28. Mathew, M. D. (2022). Nuclear energy: A pathway towards mitigation of global warming. Progress in Nuclear Energy, 143, 104080.
29. Saidi, K., & Omri, A. (2020). Reducing CO_2 emissions in OECD countries: do renewable and nuclear energy matter?. Progress in Nuclear Energy, 126, 103425.
30. Bandyopadhyay, A., & Rej, S. (2021). Can nuclear energy fuel an environmentally sustainable economic growth? Revisiting the EKC hypothesis for India. Environmental Science and Pollution Research, 28(44), 63065-63086.
31. Xu, D., Salem, S., Awosusi, A. A., Abdurakhmanova, G., Altuntaş, M., Oluwajana, D., ... & Ojekemi, O. (2022). Load capacity factor and financial globalization in Brazil: the role of renewable energy and urbanization. Frontiers in Environmental Science, 9, 823185.
32. Energy Institute. (2022). Statistical Review of World Energy. Available online: https://www.energyinst.org/statistical-review (accessed on 7 May 2022).
33. Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. Journal of Applied Econometrics, 16(3), 289-326.
34. Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. Journal of the American Statistical Association, 74(366a), 427-431.
35. Elliott, G., Rothenberg, T. J., & Stock, J. H. (1996). Efficient Tests for an Autoregressive Unit Root. Econometrica, 64(4), 813-836.
36. Phillips, P. C., & Perron, P. (1988). Testing for a Unit Root in Time Series Regression. Biometrika, 75(2), 335-346.
37. Raihan, A., Begum, R. A., Said, M. N. M., & Pereira, J. J. (2021). Assessment of carbon stock in forest biomass and emission reduction potential in Malaysia. Forests, 12(10), 1294.
38. Bello, M. O., Solarin, S. A., & Yen, Y. Y. (2018). Hydropower and potential for interfuel substitution: The case of electricity sector in Malaysia. Energy, 151, 966-983.
39. Apergis, N., Jebli, M. B., & Youssef, S. B. (2018). Does renewable energy consumption and health expenditures decrease carbon dioxide emissions? Evidence for sub-Saharan Africa countries. Renewable energy, 127, 1011-1016.
40. Acheampong, A. O. (2018). Economic growth, CO_2 emissions and energy consumption: what causes what and where?. Energy Economics, 74, 677-692.

41. Lin, X., Ullah, M. H. E., Wu, X., Xu, F., Shan, S. K., Lei, L. M., ... & Liu, J. (2022). Cerebro-cardiovascular risk, target organ damage, and treatment outcomes in primary aldosteronism. Frontiers in cardiovascular medicine, 8, 798364.
42. Kadioglu, E., Kilic, S., & Yilmaz, E. A. (2017). Testing the relationship between free cash flow and company performance in Borsa Istanbul. International Business Research, 10(5), 148-158.
43. Khan, I., Tan, D., Hassan, S. T., & Bilal. (2022). Role of alternative and nuclear energy in stimulating environmental sustainability: impact of government expenditures. Environmental Science and Pollution Research, 29(25), 37894-37905.
44. Kanat, O., Yan, Z., Asghar, M. M., Ahmed, Z., Mahmood, H., Kirikkaleli, D., & Murshed, M. (2022). Do natural gas, oil, and coal consumption ameliorate environmental quality? Empirical evidence from Russia. Environmental Science and Pollution Research, 29(3), 4540-4556.
45. Staffell, I., Scamman, D., Abad, A. V., Balcombe, P., Dodds, P. E., Ekins, P., ... & Ward, K. R. (2019). The role of hydrogen and fuel cells in the global energy system. Energy & Environmental Science, 12(2), 463-491.
46. Storm, S. (2018). Financialization and economic development: a debate on the social efficiency of modern finance. Development and Change, 49(2), 302-329.
47. Huang, G. C. L., & Chen, R. Y. (2021). Injustices in phasing out nuclear power?: Exploring limited public participation and transparency in Taiwan's transition away from nuclear energy. Energy Research & Social Science, 71, 101808.
48. Carley, S., & Konisky, D. M. (2020). The justice and equity implications of the clean energy transition. Nature Energy, 5(8), 569-577.
49. Hao, Y., Guo, Y., Tian, B., & Shao, Y. (2019). What affects college students' acceptance of nuclear energy? Evidence from China. Journal of Cleaner Production, 222, 746-759.
50. Gillingham, K., & Stock, J. H. (2018). The cost of reducing greenhouse gas emissions. Journal of Economic Perspectives, 32(4), 53-72.