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Research Article

The role of green energy, globalization, urbanization, and economic growth toward environmental sustainability in the United States

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Abstract
The subject of global climate change is of great concern due to the accumulation of greenhouse gases (GHGs) in the atmosphere, primarily carbon dioxide (CO_2). The United States ranks as the second-largest contributor to CO_2 emissions globally, accounting for almost 15% of the total global emissions. The primary contributor to the United States' emissions is the combustion of fossil fuels to generate power, provide heat, and facilitate transportation. Nevertheless, the United States intends to decrease emissions by substituting fossil fuels with ecologically sustainable green energy sources. This study aims to analyze the effects of green energy consumption, economic growth, globalization, and urbanization on CO_2 emissions in the United States. It utilizes annual time series data from 1970 to 2022. The Autoregressive Distributed Lag (ARDL) predictions indicate that a 1% increase in green energy and globalization would result in a reduction in CO_2 emissions by 0.44% and 0.61% in the short term, and by 0.76% and 1.45% in the long term. Nevertheless, there is a direct correlation between a 1% rise in economic growth and urbanization and a corresponding increase in CO_2 emissions. Specifically, in the short-term, CO_2 emissions increase by 0.59% and 0.56%, while in the long-term, the increase is 0.29% and 0.20%. The findings validate the urgent need for a higher proportion of renewable energy in the energy mix. To achieve this, it would be necessary to promptly increase the renewable portfolio standards besides implementing additional aggressive cleaner energy goals. Furthermore, it is imperative to advocate for the promotion of sustainable trade performance besides fostering global partnerships with different nations to facilitate the development of collaborative research initiatives, sharing of specialized knowledge, and stimulation of innovation in the fields of green energy and sustainable practices.

Keywords: Climate change, green energy, globalization, urbanization, economic growth, environmental sustainability

Introduction

Climate change is a prominent issue in the global economy [1]. Burning fossil fuels is the primary factor behind global warming, which is the main driver of climate change [2]. Fossil fuels emit CO_2 into the atmosphere, leading to the retention of heat and subsequent global warming [3]. This global warming phenomenon will have catastrophic effects on the planet, resulting in an increase in severe weather occurrences, a rise in sea levels, and the eradication of numerous species [4]. Hence, businesses and policymakers must implement measures aimed at mitigating CO_2 emissions to avert these disastrous ramifications. This can be achieved by transitioning to a cleaner energy infrastructure and enhancing the efficiency of energy [5].

Gaining insight into the factors that influence CO_2 emissions is crucial for formulating efficient strategies to mitigate them. Nevertheless, the factors driving CO_2 emissions differ from one country to another due to the distinctive characteristics of each economy that impact its amount of CO_2 emissions. The drivers encompass factors such as economy, energy use, ecological restrictions, globalization, growth of population, and technology [6]. Policymakers can optimize the effectiveness of guidelines aimed at reducing CO_2 emissions and mitigating climate change by comprehending these elements.

The Environmental Kuznets Curve (EKC) hypothesis suggests that there is a considerable impact of economic performance on emissions of CO_2 [7]. Yet, this liaison varies across several nations. CO_2 emissions exhibit an early positive correlation with economic growth but eventually decline once GDP is above a certain threshold [8]. There is a correlation between economic expansion and a reduction in emissions in certain countries [9]. The process of economic expansion can lead to a decrease in emissions by promoting technological advancements and facilitating a shift from fossil fuels to energy sources that have a lower carbon footprint. Implementing these modifications can effectively sustain or enhance production levels while simultaneously decreasing emissions, so disassociating economic expansion from greenhouse gas discharges. However, there is a correlation between economic progress and higher levels of CO_2 emissions in certain countries [10]. While several advanced economies have successfully disconnected their GDP growth from CO_2 emissions, many emerging and developing nations have yet to achieve this. This is attributed to the abundance of resources allocated for environmentally friendly investments, the accessibility of advanced technologies, and the proportion of the industrial sector in the overall economy. In general, there is a combination of evidence supporting and contradicting the EKC hypothesis [11].

Moreover, urban inhabitants can impact emissions through numerous means. The primary concern is the notion of industrial development, which frequently relies on fossil fuels for its energy needs [12]. Metropolitan areas house several industries that serve as major contributors to CO_2 emissions [13]. The second problem pertains to energy consumption, as urban areas consume a greater amount of energy per person compared to rural regions. This is due to the higher need for energy-concentrated services and goods, for instance, heating, cooling, and transport, in cities [14]. Moreover, Transportation is a substantial contributor to carbon emissions, particularly in urban regions where there is a greater dependence on cars compared to rural areas [15]. In addition, one of the main concerns is environmental pollution, as urban areas generate a significant amount of garbage, leading to the release of CO_2 and methane gases [16].

However, green energy use is the ultimate determinant of carbon emissions. Nations often utilize a diverse range of energy sources [17]. The consumption of crude oil and natural gas alongside coal contributes to the release of carbon emissions [18]. Hydropower and nuclear power besides renewable energies are environmentally friendly resources that produce minimal amounts of CO_2 emissions [19]. Moreover, globalization can have a substantial impact on CO_2 emissions [20]. Globalization facilitates the transmission of cleaner technologies from more developed economies to less developed nations. Technology can mitigate CO_2 emissions by facilitating energy efficiency and curbing energy use [21]. Globalization can effectively reduce CO_2 emissions by promoting the consumption of energy-efficient products. Globalization can contribute to increased energy consumption, but it also has a significant impact on reducing carbon emissions by promoting the use of renewable energy sources [22]. Globalization also transitions from manufacturing to services. Given that services often have lower energy intensity compared to production, this can contribute to a reduction in CO_2 emissions [23]. In light of these concerns, it is crucial to investigate the environmental impacts of globalization.

Over the past ten years, the United States has held the position of being the largest economy globally, ranking second in terms of CO_2 emissions, only behind China. The United States released around 5.1 billion metric tons of CO_2 into the atmosphere in 2022, accounting for almost 15% of the total global emissions. The primary contributor to emissions in the United States is the combustion of fossil fuels to generate power, provide heat, and facilitate transportation. The United States intends to decrease emissions by substituting fossil fuels with environmentally sustainable green energy sources. However, there is a research gap investigating the influence of green energy, globalization, economic growth, and urbanization in the United States by utilizing the latest time series data. Therefore, this article examines the effects of green energy, globalization, urbanization, and economic growth on CO_2 emissions in the United States.

This study contributes to the existing literature by determining that the promotion of energy switches plus globalization are crucial policy instruments for mitigating climate change in the United States. A wide range of datasets throughout 1970-2022 were analyzed, considering the current circumstances. Moreover, the investigation utilized the ARDL simulation to explore the influences of the variables on carbon emissions, both in the short and long term. In addition, several unit root tests and diagnostic tests were applied to confirm the accuracy of the findings. Finally, the study outcomes lead to appropriate policy recommendations for emission reduction and environmental sustainability.

The subsequent parts of the article are organized in the following way. After the “Introduction” section of the paper, there is a Literature Review section where relevant study works have been discussed. The next section stands for "Methodology" which describes the data, econometric model generation, and estimation strategies. The section that comes after is "Results and Discussion" which presents and discusses the study outcomes. In the last section of the study, the conclusions and policy suggestions are offered.

Methodology

Data and model specifications

The analysis utilizes data spanning 1970-2022 to examine the interrelationship among green energy, globalization, urbanization, economic growth, and carbon emissions in the context of the United States. The carbon emissions and green energy data were obtained from the Our World in Data (OWD) source. Furthermore, the information regarding economic growth and urbanization was obtained from the World Development Indicators (WDI). In addition, the data on globalization was obtained from the KOF Globalization Index. Figure 1 displays the yearly patterns of these variables.

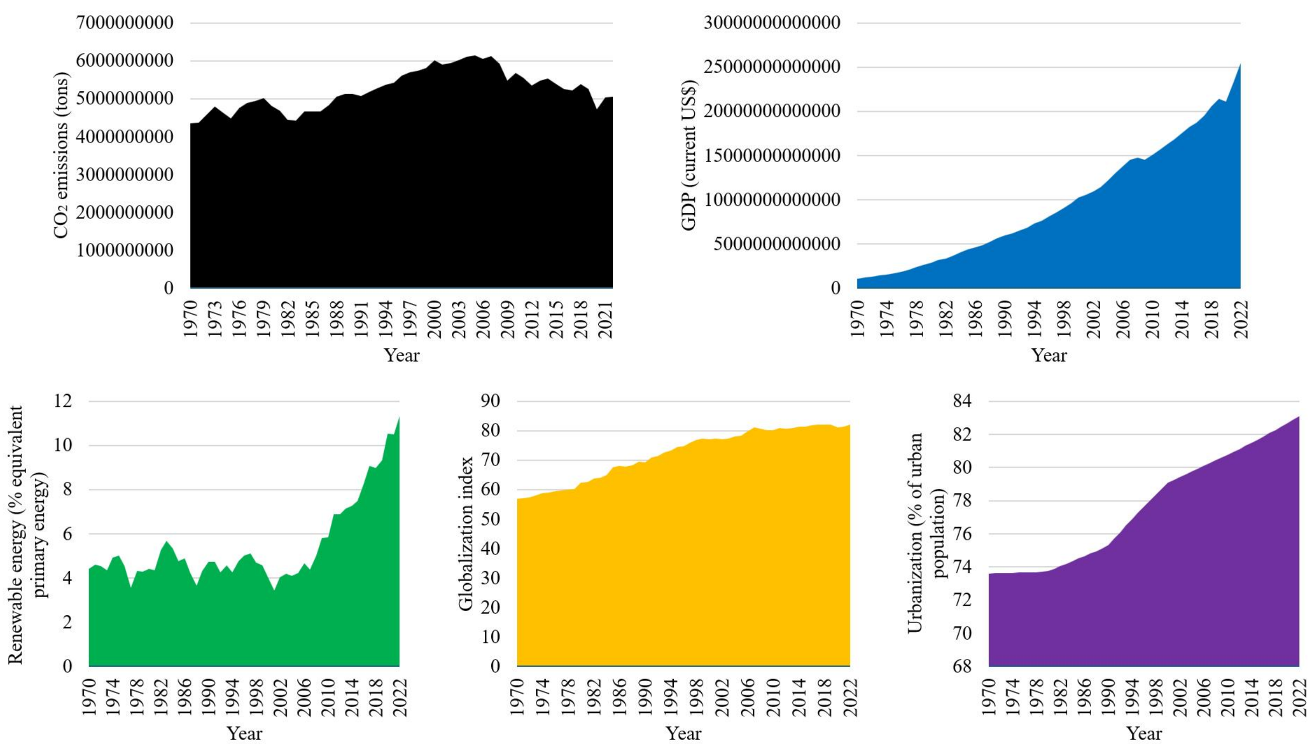

Figure 1. Annual trends of the variables.

The CO_2 emissions model at time "t" is presented according to the factors that have been specified above.

$$C_t = f(GE_t, Y_t, GL_t, U_t) \quad (1)$$

Where C_t, GE_t, Y_t, GL_t, and U_t are the CO_2 emissions, green energy consumption, economic growth, globalization, and urbanization at time t.

The logarithmic transformation of variables with large variances is illustrated below:

$$LC_t = \alpha_0 + \alpha_1 LGE_t + \alpha_2 LY_t + \alpha_3 LGL_t + \alpha_4 LU_t + \varepsilon_t \quad (2)$$

Econometric strategies

Before determining the enduring association in the current analysis, it is crucial to evaluate the unit root of the selected variables to understand their stationary features. This probe utilizes the Augmented Dickey-Fuller (ADF) [24], Dickey-Fuller generalized least squares (DF-GLS) [25], and Phillips-Perron (P-P) [26] tests to examine the amalgamation of the series.

Furthermore, the paper utilizes the ARDL limits test developed by Pesaran et al. [27] to examine the subtleties of both long- and short-term interactions relating emissions of CO_2 with the chosen descriptive factors, taking into account the stationary features of these variables. The main rationale behind using the ARDL model is that it offers distinct advantages compared to conventional tests. The ARDL limits test is less restraining as it permits a heterogeneous sequence of amalgamation midst the study variables. Furthermore, the ARDL limits cointegration method tackles the problem of endogeneity by using previous values of the dependent variable as predictors in the cointegration equation. Furthermore, the ARDL is specifically designed to handle tiny sample quantities, which sets it apart from other approaches. Furthermore, unlike traditional models that have a predetermined lag span, the ARDL method effectively identifies the ideal lag interval designed for the model, hence preventing poor choice of models. Ultimately, the ARDL bounds test is used to verify the dependability of the coefficients by conducting diagnostic assessments for heteroscedasticity and serial correlation besides the model's stability. The ARDL limits check calculation, which examines the long-run liaison, is expressed as Equation (3).

$$\Delta LC_t = \alpha_0 + \alpha_1 LC_{t-1} + \alpha_2 LGE_t + \alpha_3 LY_t + \alpha_4 LGL_t + \alpha_5 LU_t + \sum_{i=1}^{q} \beta_1 \Delta LC_{t-i} + \sum_{i=1}^{q} \beta_2 \Delta LGE_{t-i} + \sum_{i=1}^{q} \beta_3 \Delta LY_{t-i} + \sum_{i=1}^{q} \beta_4 \Delta LGL_{t-i} + \sum_{i=1}^{q} \beta_5 \Delta LU_{t-i} + \varepsilon_t \quad (3)$$

In addition to predicting the long-run coefficients, this work evaluated the short-run coefficients via the error correction model (ECM) presented in Equation (4).

$$\Delta LC_t = \alpha_0 + \alpha_1 LC_{t-1} + \alpha_2 LGE_t + \alpha_3 LY_t + \alpha_4 LGL_t + \alpha_5 LU_t + \sum_{i=1}^{q} \beta_1 \Delta LC_{t-i} + \sum_{i=1}^{q} \beta_2 \Delta LGE_{t-i} + \sum_{i=1}^{q} \beta_3 \Delta LY_{t-i} + \sum_{i=1}^{q} \beta_4 \Delta LGL_{t-i} + \sum_{i=1}^{q} \beta_5 \Delta LU_{t-i} + \theta ECM_{t-1} + \varepsilon_t \quad (4)$$

In Equations (3) and (4), the variable q represents the ideal length of the lag variables, while Δ representing the initial difference of the selected variables. In addition, α0 represents the intercept, while ε_t denotes the error term.

Results and Discussion

Table 1 displays the descriptive statistical findings for the variables. The results suggest that all variables, except for LGE and LU, display a negative skewness. The skewness values, which are close to zero, imply that the majority of those elements conform to a normal distribution. All of the series exhibit platykurtic traits, with kurtosis values below 3. The Jarque-Bera probability test can verify if each of the variables follows a normal distribution.

Table 1. Descriptive statistics of the study variables.

Variables	LC	LGE	LY	LGL	LU
Mean	22.37	1.65	29.56	4.27	4.35
Median	22.37	1.55	29.71	4.31	4.35
Maximum	22.53	2.42	30.86	4.40	4.41
Minimum	22.19	1.23	27.70	4.03	4.29
Skewness	-0.01	0.29	-0.50	-0.54	0.08
Kurtosis	1.94	1.14	2.12	1.83	1.45
Jarque-Bera	2.43	1.19	2.94	1.73	1.37

Probability	0.29	0.25	0.18	0.56	0.68

Moreover, Table 2 presents the correlation analysis among the variables. The correlation matrix indicates that there is a positive link among all the variables, except for the negative correlation between LGE and LC.

Table 2. Correlation analysis between the variables.

	LC	LGE	LY	LGL	LU
LC	1.00				
LGE	-0.06	1.00			
LY	0.70	0.58	1.00		
LGL	0.76	0.51	0.98	1.00	
LU	0.66	0.66	0.95	0.94	1.00

Before examining data, it is important to determine its stationary qualities using appropriate unit-root checks. Not considering unit roots has significant consequences for choosing models, accurately predicting outcomes, and establishing the validity of linkages in both the short term and the long term. The outcomes of unit root testing utilizing ADF, DF-GLS, and P-P tests are presented in Table 3. The results suggest that the variables were initially non-stationary, but they became stationary after their first differences were examined in all three unit root tests. The outcomes of the unit root tests prompt to carrying out of the study within the ARDL framework.

Table 3. Results of unit root tests to check data stationarity.

Variables	ADF		DF-GLS		P-P	
	Log levels	Log first difference	Log levels	Log first difference	Log levels	Log first difference
LC	-1.90	-6.81 a	-1.01	-6.87 a	-1.89	-6.81 a
LGE	-0.20	-7.16 a	0.28	-7.02 a	0.47	-7.17 a
LY	-6.58 a	-3.65 a	0.73	-3.40 a	-6.15 a	-3.48 a
LGL	-2.51	-6.46 a	0.58	-6.51 a	-2.55	-6.48 a
LU	-0.46	-4.03 a	-1.13	-3.97 a	0.80	-3.79 a

[a] $P<0.01$

The study employed the ARDL-bound testing approach to examine the long-run cointegration among the variables comprehensively and simply. Table 4 presents the results of ARDL bound testing. The outcome suggests the existence of co-integration, which shows a lasting relationship between variables. This is corroborated by the F statistic (30.14) for this model, which surpasses the upper critical levels.

Table 4. Results of ARDL bounds test.

Test statistic	Value	Significance at	I(0)	I(1)
F-statistic	30.14	10%	2.20	3.09
K	4	5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37

Table 5 displays the long-term with short-term estimates from the ARDL. The figures offer compelling proof of the substantial influence of green energy on the CO_2 emissions of the United States. Specifically, there is an inverse correlation between the consumption of green energy with the emissions of CO_2 in the short term and long term. The outcomes validate that the adoption of green energy has significant potential to reduce CO_2 emissions and alleviate the negative impacts of climate change on the United States economy. The results indicate that a 1% increase in green energy would result in a reduction in CO_2 emissions by 0.44% in the short term, and by 0.76% in the long term. The finding is supported by the previous studies [28-33]. Although there are initial obstacles such as increased expenses and the need for infrastructure, the advantages of adopting green energy sources in terms of the environment are far more than the negative impacts [34-36].

Moreover, the coefficients of the GDP exhibit a positive value. The results indicate that a 1% increase in GDP would result in intensified emissions of CO_2 by 0.59% in the short run and 0.29% in the long run. Therefore, economic advancement continues to sustain the environmental norms of the United States by causing a rise in CO_2 emissions. Furthermore, this suggests that although the United States is the most advanced economy, it has not yet achieved the level of economic development necessary to support ecological superiority, as projected via the EKC assumption. The main factor behind the outcomes is the USA's status as a vastly industrial nation that heavily depends on fossil energy. This dependency poses a challenge when attempting to shift towards renewable energies starved of sacrificing interim financial objectives. The finding is supported by the previous studies [37-40].

Moreover, climate change and environmental policy have caused significant division within the realm of United States politics. Various administrations have demonstrated different degrees of dedication to tackling climate change, leading to divergent policies and regulatory frameworks. The absence of consistent and enduring legislative measures has hindered the efficacy of efforts to reduce CO_2 emissions. Similarly to additional nations, the US needs to allocate a substantial amount of its reserves to build the essential foundation needed for the shift toward green energy. This is a significant barrier that hinders the adoption of renewable power technology and restricts the potential for lowering emissions of CO_2. Energy diversification, which refers to the shift towards green energy sources, has the potential to reduce CO_2 emissions. A green and low-carbon economy is crucial to achieve environmental sustainability.

Table 5. ARDL long- and short-run results.

Variables	Long-run			Short-run		
	Coefficient	t-Statistic	p-value	Coefficient	t-Statistic	p-value
LGE	-0.76	-5.20	0.00	-0.44	-5.21	0.00
LY	0.29	4.73	0.00	0.59	5.78	0.00
LGL	-1.45	-3.57	0.00	-0.61	-3.82	0.00
LU	0.20	4.98	0.00	0.56	4.61	0.00
C	18.72	1.70	0.06	-	-	-
ECM (-1)	-	-	-	-0.57	-4.22	0.00
R^2	0.98					
Adjusted R^2	0.98					

The empirical findings provide additional evidence that globalization has a detrimental and substantial impact on CO_2 emissions. The results indicate that a 1% increase in globalization would result in a reduction in CO_2 emissions by 0.61% in the short term, and by 1.45% in the long term. This research indicates that the United States' decision to open up its economy has had a beneficial impact on its environmental quality by leading to a decrease in CO_2 emissions. The explanation for this phenomenon is in the promotion of market incentives and competition through globalization, which in turn stimulates innovation and the advancement of environmentally friendly technologies. The finding is supported by the previous studies [41-45].

Moreover, globalization has facilitated the relocation of several industrial and manufacturing actions commencing the US to nations that provide minimal labor besides associated expenses. In addition, these outcomes might be ascribed to carbon leakage, which refers to the phenomenon of carbon-intensive economies in the United States relocating to nations with less strict environmental rules. Together, these variables have guaranteed a gradual decrease in the nation's emissions of CO_2. Ultimately, globalization has enabled the dissemination of techniques with knowledge beyond international boundaries. This has enabled countries to embrace further aspiring goals.

Ultimately, the growing urban population has a direct impact on the levels of CO_2 emissions in the United States. The results indicate that a 1% increase in urban population would boost emissions of CO_2 by 0.56% in the short run and 0.20% in the long run. These findings align with the results of earlier investigations [46-48]. Urban environments exhibit elevated energy requirements compared to rural areas as a consequence of heightened population density, increased number of structures, and intensified industrial operations. Consequently, there is an elevated utilization of fossil fuels to generate power, providing heating and cooling, as well as facilitating transportation, which ultimately leads to a rise in CO_2 emissions. In addition, urbanization leads to a rise in trash

production as a result of more people and more commercial activity. Waste management methods such as landfilling, and incineration have the potential to emit GHGs such as methane and CO_2. Insufficient waste management procedures exacerbate CO_2 emissions. Deforestation and alterations in land use led to the depletion of green areas and ecosystems that play a crucial role in absorbing and storing carbon [48]. The process of urbanization exacerbates environmental standards by leading to a rise in CO_2 emissions.
The ECM estimate indicates that the divergence from long-run equilibrium in the present year is corrected at a rate of 57% through multiple channels, as suggested by the significance threshold at the 1% level and the negative trend. In addition, the R^2 and adjusted R^2 values for long-run estimation demonstrate a significant degree of precision for the derived regression model. The independent factors clearly explain 97% of the variation in the dependent variable. In addition, the study conducted diagnostic and stability tests on the current model to verify the reliability of the data. The tests reported in Table 6 provide evidence that there is no serial correlation or heteroscedasticity. Furthermore, these findings indicate that the residuals conform to a normal distribution. The results depicted in Figure 2 demonstrate the results of the stability tests using the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) methods. The tests provide evidence of the model's stability, with a significance level of 5%.

Table 6. Results of diagnostic tests.

Diagnostic tests	Coefficient	p-value	Decision
Jarque-Bera test	0.2582	0.8789	Normal residual distribution
Breusch-Godfrey LM test	0.1751	0.8401	No serial correlation exists
Breusch-Pagan-Godfrey test	1.0375	0.4351	No heteroscedasticity exists
Ramsey RESET test	1.3949	0.1716	The model is properly specified

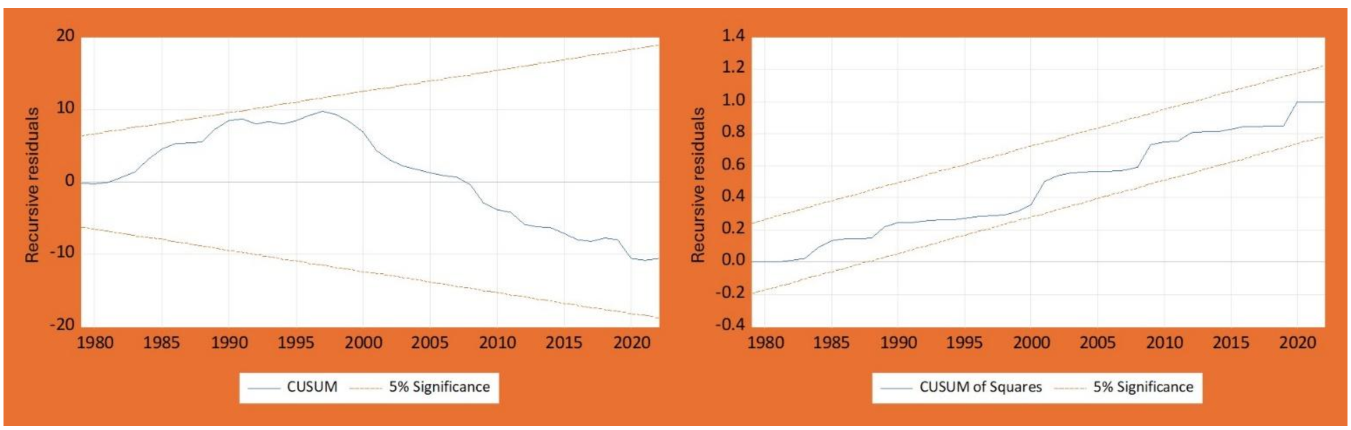

Figure 2. Results of CUSUM and CUSUMSQ tests.

Conclusions and Policy Implications

This study analyzed the fluctuations in CO_2 emissions in the US from 1970 to 2022, with a specific focus on variables such as renewable energy, gross domestic product (GDP), globalization, and urbanization. The results demonstrate that the use of renewable energy sources and the process of urban development have a substantial influence on the state of the environment, specifically by decreasing the release of CO_2 into the atmosphere. The ARDL outcomes indicate that a 1% increase in green energy and globalization would result in a reduction in CO_2 emissions by 0.44% and 0.61% in the short term, and by 0.76% and 1.45% in the long term. Nevertheless, the expansion of the economy and the process of urbanization persistently contribute to the escalation of CO_2 emissions. Specifically, the study found that a 1% rise in economic growth and urbanization would lead to an increase of CO_2 emissions by 0.59% and 0.56% in the short term, while 0.29% and 0.20% in the long term.
The findings have the potential to greatly impact the future direction of the United States' environmental policies. The findings validate the urgent need for a larger proportion of renewable energy in the energy mix. To achieve this, it would be necessary to promptly increase the renewable portfolio standards and implement more aggressive

goals for green energy. Companies will have increased prospects to transition to sustainable energy sources. In addition, it is crucial to create additional financial incentives and tax credits specifically tailored to support the advancement and implementation of environmentally friendly energy projects. This will enhance their economic feasibility and appeal to potential investors. Furthermore, through allocating resources to research and development, the government may cultivate originality and propel progress in environmentally friendly energy, enhancing its effectiveness, affordability, and availability. Additional funds should be allocated to assist both fundamental and practical research, as well as collaborations between public and private sectors. This will expedite the advancement of state-of-the-art knowledge afterwards their seamless amalgamation with the current energy framework. Policymakers have the option to enforce a carbon tax as a means of valuing CO_2 emissions plus motivating industries and individuals to decrease their carbon output.

In addition, the US could enhance the current global agreements that seek to decrease global emissions, for instance, the 2015 Paris Accord. Furthermore, it is imperative to advocate for the promotion of trade activities that are sustainable and foster worldwide alliances with other nations to facilitate the development of collaborative research initiatives, sharing of specialized knowledge, and stimulation of innovation in the fields of cleaner energy besides sustainable activities. Ultimately, the conclusions are restricted to the sustainability besides ecological consequences of the present patterns of progress afterwards urban expansion in the US. The results require a rigorous application of sustainable infrastructure programs and tight execution of tough emission restrictions. Furthermore, it is crucial to advocate for sustainable urban development strategies besides planning that spotlight the creation of compacted metropolises, the integration of different land uses, and the implementation of efficient transportation networks. Subsequent research can prioritize examining additional emerging and advanced economies to comprehend the factors that influence carbon emissions.

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Data availability statement: The data on CO_2 emissions and green energy were obtained from the Our World in Data (OWD) source. The data on economic growth and urbanization was obtained from the World Development Indicators (WDI). The data on globalization was obtained from the KOF Globalization Index.

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