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Analyses of Topical Policy Issues

The impact of green quality of the energy consumption on carbon emissions in the United States

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ABSTRACT

This paper investigates the impact of energy consumption's Green Quality Index (GQI) on carbon dioxide (CO_2) emissions in the United States from 1970 to 2021. At this point, the estimated models control for the effects of gross domestic product (GDP) per capita, urban population, and globalization on CO_2 emissions. The Autoregressive Distributed Lag estimations demonstrate that GQI and globalization reduce CO_2 emissions in the short- and long run. However, GDP per capita and urban population are positively related to CO_2 emissions in the short- and long-run. Different estimation techniques confirm the long-run baseline findings. Potential policy implications for reducing CO_2 emissions in the United States are also provided.

1. Introduction

Climate change is one of the leading problems in the global economy. The leading cause of climate change is global warming, caused by burning fossil fuels (Miralles-Quirós and Miralles-Quirós, 2022). Fossil fuels release carbon dioxide (CO2) into the atmosphere, which traps heat and causes the planet to warm (Mathew, 2022; Millar et al., 2017). This warming will devastate the earth, leading to more extreme weather events, rising sea levels, and the extinction of many species (Shivanna, 2022). Therefore, businesses and policymakers must take action to reduce CO_2 emissions to avoid these catastrophic consequences. This can be done by switching to renewable energy facilities and improving energy efficiency (Ahmed et al., 2022).

Understanding the determinants of CO_2 emissions is essential for developing effective policies to reduce them. However, the drives of CO_2 emissions vary from country to country since each economy has unique characteristics that affect its CO_2 emissions level (Disli et al., 2016). These determinants include economic growth, energy consumption, environmental regulations, globalization, population growth, and technological change (Adams et al., 2020; Bouri et al., 2023; Chen et al., 2020; Dogan and Seker, 2016; Dong et al., 2022; Gozgor, 2018; Khan et al., 2021; Lee and Wang, 2022; Li et al., 2023; Ma et al., 2023; Sharma, 2011; Su et al., 2023; Sun et al., 2023; Syed and Bouri, 2022; Yuping et al., 2021). By understanding these factors, policymakers can design guidelines that will be most effective in decreasing CO_2 emissions

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and mitigating the effects of climate change. The Environmental Kuznets Curve (EKC) hypothesis of Grossman and Krueger (1991, 1995) indicates that economic performance significantly affects CO_2 emissions; however, this relationship differs in different countries.[1] CO_2 emissions initially increase as GDP per capita increases but eventually reduce once GDP per capita income reaches a higher level. In some countries, economic growth is associated with a decrease in emissions. Still, economic development is related to increased CO_2 emissions in some countries. Overall, mixed evidence has been obtained for the EKC hypothesis (Shahbaz et al., 2019b).

On the other hand, the urban population can affect carbon emissions in several ways. The first issue is the concept of industrialization, which often uses fossil fuels to power its operations (Wu et al., 2021). Big cities are home to many industries, which are also significant sources of CO_2 emissions (Sovacool and Brown, 2010). The second issue concerns energy consumption since large cities consume more per capita energy than rural areas since cities have more demand for energy-intensive goods and services, such as cooling, heating, and transportation (Zhao and Zhang, 2018). Transportation is a significant carbon emission source since cities rely more on cars than rural areas (Glaeser and Kahn, 2010). The third issue is environmental pollution, as cities produce a lot of waste, which can drive carbon dioxide and methane emissions (Singh et al., 2018).

Furthermore, globalization can also significantly affect CO_2 emissions. Specifically, globalization can transfer cleaner technologies from advanced to developing economies. Technology can help to reduce CO_2 emissions by promoting energy efficiency and reducing energy consumption (Chen and Lee, 2020; Churchill et al., 2019). Indeed, globalization can decrease CO_2 emissions by consuming less energy-needed products (Shahbaz et al., 2018). Globalization may promote energy consumption, but the carbon emissions-decreasing effects are more prominent as it also supports renewable energy consumption (Lu et al., 2022). Globalization also shifts from manufacturing to services. Since services tend to be less energy-intensive than manufacturing, this can help reduce CO_2 emissions (Avenyo and Tregenna, 2022). Following these issues, we include the KOF globalization index.

The final factor in determining carbon emissions is the energy consumption mix. Countries typically consume a variety of energy sources. At this stage, coal, crude oil, and natural gas consumption promote carbon emissions (Smith et al., 2021). However, hydroelectricity, nuclear, and renewable energy are clean sources of almost zero CO_2 emissions (Azam et al., 2021). At this point, this paper examines the determinants of carbon emissions from 1970 to 2021 in the United States.

Previous studies have used different indicators to analyze the impact of energy consumption on carbon emissions. This paper considers a new measure of energy consumption, GQI, proposed by Lau et al. (2023). The GQI considers carbon emissions from electricity generation from various energy sources with data from the United States Energy Information Administration (EIA) from 1970 to 2021. The GQI is a valuable tool for assessing the role of a country's energy mix in determining its CO_2 emissions (Lau et al., 2023).

During the last decade, the United States has been the world's largest economy, with the second-highest CO_2 emitter after China (Wu et al., 2022). Given these backdrops, in this paper, we analyze the impact of the GQI on carbon emissions from 1970 to 2021 in the United States. The novelty of this paper is that it is the first paper to use the GQI for a single country case (the United States) by utilizing time-series analyses with a large time-series (1970–2021). Following previous articles, the empirical models also control for the impacts of GDP per capita, globalization, and urban population on carbon emissions. The Autoregressive Distributed Lag (ARDL) estimations indicate that the GQI and globalization suppress carbon emissions in the short and long run. However, per capita income and urban population increase CO_2 emissions levels in the short- and long run. The Fully Modified Ordinary Least Squares (FMOLS) estimations also confirm the validity of these findings in the long run. We observe that promoting energy transition and globalization are essential policy tools to mitigate climate change in the United States.

The remaining parts of the study are organized as follows. Section 2 provides a literature review on the determinants of carbon emissions, particularly in the United States. Section 3 discusses data details, model specifications, and econometric techniques. Section 4 presents the empirical findings with various robustness checks. Section 5 provides the concluding remarks.

2. Literature review

Many papers have investigated the factors influencing carbon emissions in different economies, and the energy transition can be a significant driver of environmental degradation. Several articles have also analyzed the determinants of carbon emissions in the United States. For instance, Thoma (2004) considered the monthly data on electricity usage from 1973 to 2000 in the United States. The author found that the impact of electricity usage on industrial output is asymmetric and significant. Shahiduzzaman and Layton (2015) also examined the asymmetric relationship between business cycles (change in economic growth) and carbon emissions. The authors used the yearly data from 1949 to 2013 and monthly data from January 1973 to October 2013 in the United States. They found that CO_2 emissions decline more rapidly during recessions than during expansions. Congregado et al. (2016) focused on data from 1973Q1 to 2015Q2 in the United States. They found that the industry has different dynamics in the carbon emissions-growth relationship compared to the output in other sectors. Gozgor et al. (2019) also investigated the interdependence carbon emissions-growth relationship in

[1] This hypothesis is based on the idea that economic development initially leads to increased pollution as countries rely on more energy-intensive industries. However, as countries become more developed, they adopt cleaner technologies and policies, reducing pollution (Al-Mulali et al., 2015).

the United States from January 1973 to January 2017. The dependence structure between CO_2 emissions and economic performance is significant with a regime-switching nature. Specifically, the recession era from January 1973 to December 1982 is the high dependence regime. From January 1983 to January 2017, a low dependence structure was observed. Shahbaz et al. (2019a) analyzed the effects of globalization, energy consumption, and economic growth (change in per capita GDP) on carbon emissions in the United States. The authors considered data from 1965 to 2016 and observed that energy consumption and foreign direct investments increase CO_2 emissions. Economic growth demonstrated mixed effects, and trade openness is negatively related to carbon emissions.

A significant increase in empirical papers focusing on the determinants of CO_2 emissions has been observed since 2020. For instance, Wang et al. (2020) analyzed the drivers of carbon emissions using the aggregate and sectoral emissions data from 1997 to 2016 in the United States. The authors demonstrated that income and population are the main factors to promote carbon emissions. Technology is negatively related to carbon emissions; however, energy consumption structure has an insignificant effect. Xin et al. (2021) focused on the drivers of carbon emissions from 1990Q1 to 2016Q4 in the United States. The authors found that technology and renewable energy consumption negatively affect CO_2 emissions. However, economic growth (measured by the change in GDP) and globalization (measured by trade openness) increase CO_2 emissions. In a further study, Xin et al. (2022) examined the drivers of CO_2 emissions from 1990Q1 to 2018Q4. The authors observed that international collaboration, renewable energy consumption, and technology are negatively associated with carbon emissions in the United States. However, economic growth and trade openness increase CO_2 emissions. Liguo et al. (2022) also investigated the determinants of CO_2 emissions from 1990Q1 to 2018Q4. International collaboration, renewable energy consumption, and technology decrease CO_2 emissions. Economic growth, expansionary monetary policy, and trade openness positively affect carbon emissions in the United States.

In addition, Jebabli et al. (2023) investigated the asymmetric relationship with time-varying dependence structure in the growth-carbon emissions nexus using the data in G7 economies from 1820Q1 to 2021Q4. In the United States and Canada, CO_2 emissions are the net transmitter. However, CO_2 emissions are the net receiver in France, Germany, Italy, Japan, and the United Kingdom. Razzaq et al. (2023) also analyzed the determinants of CO_2 emissions from 1990Q1 to 2018Q4. The authors found that climate-related technologies and recycling decrease carbon emissions in the United States. International trade has mixed effects. Gangopadhyay et al. (2023) examined the United States' carbon emissions from 1970 to 2019. The authors found that renewable energy consumption has an inverse impact on CO_2 emissions. Globalization promotes CO_2 emissions. Economic growth increases CO_2 emissions only at the lower quantiles. Liao et al. (2023) analyzed the moderating impacts of industrialization and green innovation for the asymmetric effects of the energy transition on ecological footprints. The authors indicate that the clean energy transition process and green innovation decrease environmental degradation. However, economic growth, foreign direct investments, and industrialization increase ecological footprints. The moderating effects of industrialization and green innovation suggest that green innovation policies can help mitigate industrial processes' negative environmental impacts.

Previous studies have shown that energy transition's effects on environmental degradation are generally positive. Still, in some cases, it can be adverse or insignificant. Unlike previous papers, this study uses a new measure of energy transition (GQI). It analyzes its impact on carbon emissions in the United States from 1970 to 2021. The results show that the GQI decreases CO_2 emissions.

3. Data, model specifications, and econometric methodology

3.1. Data and model specifications

This paper utilizes the ARDL model to understand the relationship between CO_2 emissions, GQI, economic growth, globalization index, and urban population. The empirical analyses use the data from 1970 to 2021 to understand the case of the United States in greater detail. The carbon emissions data are downloaded from the British Petroleum (BP) (2022). Since the energy sector is the most significant contributor to CO_2 emissions globally, we use CO_2 emissions from the energy sector as a proxy for overall emissions of the United States (British Petroleum (BP), 2022). Besides, the GQI is calculated by CO_2 emissions estimations from the United States' electricity generation (produced per kilowatt-hour). The US EIA provided the data for CO_2 emissions for electricity production from coal, crude oil, and natural gas. Lau et al. (2023) use this data to calculate the GQI for various countries, including the United States, from 1970 to 2021. We obtained the GQI data from Lau et al. (2023) and refer to the corresponding paper for details.

Regarding control variables, the first variable is real GDP per capita (GDPC) (measured by constant 2015 US$ prices) to capture the income effects in carbon dioxide modeling. The second variable is globalization (GI), measured by the Globalization Index proposed by Gygli et al. (2019). The third variable is urban population (URP) (percentage of total population). The related per capita GDP and population data are obtained from the World Bank (2023). A detailed summary of all the variables and their sources is in Table 1.

The annual trends of these variables are drawn in Fig. 1.

Based on the specification of the above variables, the CO_2 emissions model is presented as follows:

$$\mathrm{CO2}_t = f\,(GQI_t, GDPC_t, GI_t, URP_t) \tag{1}$$

Table 1
Variables with description.

Variable Type	Label	Specification of the Variable	Data Source
Dependent Variable	CO_2	Million Tonnes of Carbon-dioxide Emissions from the Energy Sector	British Petroleum (BP) (2022)
Main Variable of Interest	GQI	Green Quality Index	Lau et al. (2023)
Control Variables	GDPC	Real GDP per Capita (Constant 2015 US$)	World Bank (2023)
	GI	KOF Globalization Index (Index from 1 to 100)	Gygli et al. (2019)
	URP	Urban Population (Percentage of the Total Population)	World Bank (2023)

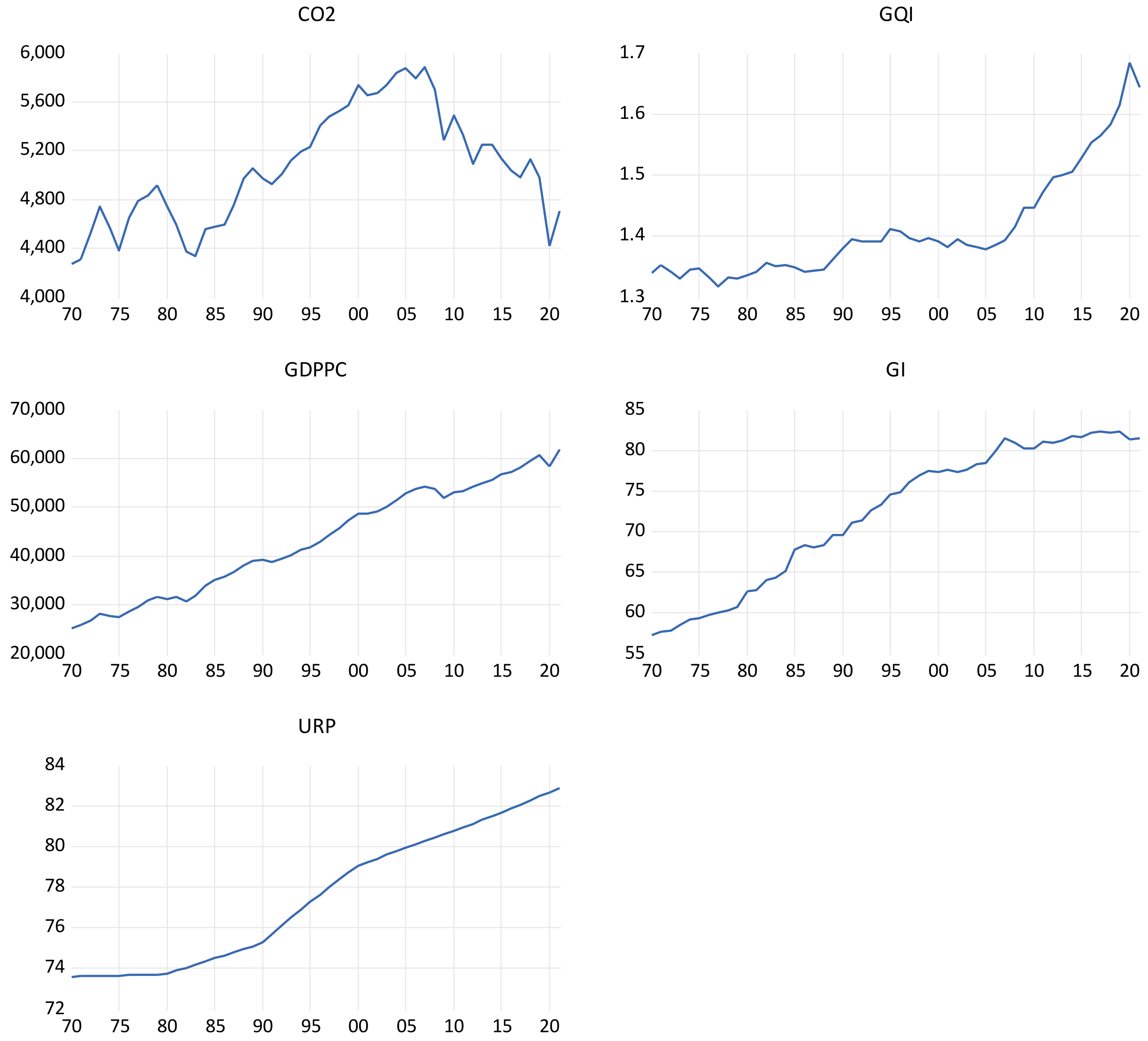

Fig. 1. Annual trends of the study variables.
Note: Data sources are provided in Table 1.

Due to the large variances of some variables, the logarithmic transformation of these variables is presented below as follows:

$$logCO_{2t} = \alpha_0 + \alpha_1 GQI_t + \alpha_2 logGDPC_t + \alpha_3 logGI_t + \alpha_4 URP_t + \varepsilon_t \quad (2)$$

where $\log CO_{2t}$ is the natural log CO_2 emissions, GQI_t is the green quality index, $\log GDPC_t$ is the log GDP per capita, $\log GI_t$ is the log of the KOF index of globalization, and URP_t indicates the percentage of the urban population. ε_t is the error term. Subscript t refers to the year t.

3.2. Econometric methodology

Before establishing the long-term relationship of the present study, it is imperative to examine the unit root of the chosen variables to comprehend their stationary properties. At this stage, we adopt the Augmented Dickey–Fuller (ADF) and the Phillips–Perron (PP) tests to investigate the integration qualities of the series. The primary advantage of the ADF test is that it considers both deterministic and stochastic trends in the data. Furthermore, the ADF test considers the potential auto-correlation issues by selecting the optimal lags.

Given the stationary properties of the variables, the study employs the ARDL bounds cointegration model of Pesaran et al. (2001) to understand the dynamics of short- and long-run relationships between CO_2 emissions and the selected explanatory variables. The ARDL model's primary reason is that it carries certain advantages over the tests of Engle and Granger (1987) and Johansen (1991). First, the ARDL bounds model is less restrictive because it allows for a mixed order of integration among the variables of the cointegration analysis (Shin and Pesaran, 1999). Second, the ARDL bounds cointegration addresses the issue of endogeneity by allowing for lagged values of the dependent variable as regressors in the cointegration equation. Third, unlike the traditional methods, the ARDL is suitable for dealing with small sample sizes. Fourthly, in contrast to the conventional models, which require a pre-determined lag length, the ARDL efficiently determines the optimal lag length for the cointegration model, avoiding suboptimal model selection (Pesaran, 1997). Finally, to confirm the reliability of the coefficients, the ARDL bounds test provides diagnostic tests of serial correlation, heteroscedasticity, and stability of the estimated model (Pesaran et al., 2001).

The ARDL bounds test equation to understand the long-run relationship is presented in Eq. (3), which represents the model shown in Eq. (2):

$$\begin{aligned}\Delta logCO_{2t} &= \alpha_0 + \alpha_1 logCO_{2t-1} + \alpha_2 GQI_{t-1} + \alpha_3 logGDPC_{t-1} + \alpha_4 logGI_{t-1} + \\ &\alpha_5 URP_{t-1} + \sum_{i=1}^{m} \gamma_1 \Delta logCO_{2t-1} + \sum_{i=1}^{m} \gamma_2 \Delta GQI_{t-1} + \sum_{i=1}^{m} \gamma_3 \Delta logGDPC_{t-1} + \\ &\sum_{i=1}^{m} \gamma_4 \Delta logGI_{t-1} + \sum_{i=1}^{m} \gamma_5 \Delta URP_{t-1} + \varepsilon_t\end{aligned} \tag{3}$$

Besides estimating the long-run coefficients, the present study assessed the short-run coefficients using the error-correction model (ECM). Eq. (4) presents the ECM model and is presented as follows:

$$\begin{aligned}\Delta logCO_{2t} &= \alpha_0 + \alpha_1 logCO_{2t-1} + \alpha_2 GQI_{t-1} + \alpha_3 logGDPC_{t-1} + \alpha_4 logGI_{t-1} + \\ &\alpha_5 URP_{t-1} + \sum_{i=1}^{m} \gamma_1 \Delta logCO_{2t-1} + \sum_{i=1}^{m} \gamma_2 \Delta GQI_{t-1} + \sum_{i=1}^{m} \gamma_3 \Delta logGDPC_{t-1} + \\ &\sum_{i=1}^{m} \gamma_4 \Delta logGI_{t-1} + \sum_{i=1}^{m} \gamma_5 \Delta URP_{t-1} + \delta ECT_{t-1} + \varepsilon_t\end{aligned} \tag{4}$$

where in Eqs. (3) and (4), m refers to the optimal ag length of variables and Δ is the first difference of the selected variables. Besides, α_0 is the intercept, δ denotes the lagged error correction term (ECT_{t-1}), and ε_t is the stochastic disturbance term. Besides, it is essential to note that both equations' first and second parts capture long-run relationships among the variables.

4. Empirical findings

4.1. Preliminary test results

Table 2reports a summary statistics for the variables in estimated models presented in Eqs. (1) and (2). As evident, the outcome variable (CO_2) has a mean value of 5056, with a moderate degree of variability indicated by a standard deviation of 465.5. Among the explanatory variables, GDPC has the highest mean value (43,184), followed by URP (77.51), GI (72.26), and GQI (1.411). Since GDP per capita, globalization index, and CO_2 emissions report a higher degree of variability, these variables have undergone a logarithmic transformation.

Table 3 reports the correlation matrix.

As a preliminary step of analyzing the time-series data, it is crucial to understand the stationary properties of the data set through relevant unit-root tests. Failure to account for unit roots has severe implications for model selection, forecasting accuracy, and the validity of short-run and long-run relationships.

Table 2
Statistical summary of the variables.

Variable	CO2	GQI	GDPC	GI	URP
Mean	5,056	1.411	43,184	72.26	77.51
Median	5,021	1.388	42,358	74.70	77.44
Maximum	5,884	1.685	61,855	82.30	82.87
Minimum	4,271	1.318	25,295	57.29	73.60
Std. Dev.	465.5	0.088	11,148	8.599	3.261
Skewness	0.143	1.487	−0.031	−0.418	0.131
Kurtosis	1.978	4.423	1.635	1.691	1.460
Jarque–Bera	2.438	23.54	4.043	5.229	5.286
Probability	0.295	0.000	0.132	0.073	0.071
Observations	52	52	52	52	52

Table 3
Correlation matrix.

Variable	CO2	GQI	GDPC	GI	URP
CO2	1.000				
GQI	0.110	1.000			
GDPC	0.633***	0.813***	1.000		
GI	0.698***	0.734***	0.978***	1.000	
URP	0.597***	0.841***	0.987***	0.958***	1.000

*** $p < 0.01$.

Table 4
Unit root test results.

Variable	ADF		PP	
	Level	d	Level	d
logCO2	−1.026	−6.808***	−1.061	−6.824***
GQI	0.194	−5.169***	0.142	−6.964***
logGDPC	−2.012	−5.348***	−1.792	−6.065***
logGI	0.388	−5.305***	0.400	−7.289***
URP	−3.674**	–-	−2.983	−1.516

** $p < 0.05$.
*** $p < 0.01$.

Table 5
ARDL bounds test results.

F-bounds test null hypothesis: No degrees of relationship.				
Test statistic	Estimate	Significance	I(0)	I(1)
F-statistic	3.737	10%	2.20	3.09
k	4	5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37

The findings of the ADF and the PP tests are reported in Table 4. According to these results, all the variables except the urban population become stationary at the first difference. The urban population, on the other hand, is stationary at the level and does not suffer from the unit-root problem. Overall, these results establish a mixed order of integration for the series under consideration.

4.2. Cointegration test and ARDL estimations

Based on the mixed-order integration of variables, we run the ARDL-based bounds test to comprehend the dynamics of the short- and long-run relations between the variables under consideration. Table 5 shows that the calculated F-statistics (3.737) is significantly higher than the upper bound (I(1)) at the 5% level. This evidence helps us conclude that dependent and explanatory variables are cointegrated.

Table 6 presents the long-run and short-run estimations of the ARDL model. These estimates provide strong evidence of the significant impact of the GQI on the United States CO_2 emissions. More specifically, there is a negative relationship between the GQI and CO_2 emissions in the United States, both in the short- and long run. These findings confirm that adopting a greener energy mix holds immense potential for curbing CO_2 emissions and mitigating climate change's and global warming's adverse effects on the United States economy. Despite the initial challenges of higher cost and infrastructure, the environmental benefits of embracing cleaner energy-mix sources far outweigh the adverse effects.

Table 6
ARDL Long-run and Short-run estimations.

	Variable	Coefficient	Std. Error	t-statistic
Long-run	GQI	−0.710***	0.063	−11.28
	logGDPC	0.561***	0.155	3.617
	logGI	−1.482***	0.335	−4.424
	URP	0.024***	0.004	6.417
	Constant	2.988***	0.201	14.88
Short-run	DGQI	−0.365***	0.079	−4.644
	DlogGDPC	0.969***	0.129	7.520
	DlogGI	−0.703***	0.265	−2.656
	DURP	0.093***	0.031	3.025
	ECT(−1)	−0.777***	1.520	−5127
	R-squared	0.903	Mean dependent var	−7.358
	Adjusted R-squared	0.866	S.D dependent var	0.015
	S.E of regression	0.005	Akaike info criterion	−7.331
	Sum squared residual	0.001	Schwarz-criterion	−6.786

*** $p < 0.01$.

Furthermore, the coefficients of the GDP per capita are positive. Hence, economic progress still perpetuates the environmental standards of the United States through increased CO_2 emissions. More importantly, it indicates that despite being the most developed economy, the United States has not yet reached the stage of economic growth that could foster environmental quality, as predicted by the EKC hypothesis. The primary reason for these results is that the United States is a highly industrialized economy with heavy reliance on fossil fuels, making it challenging to transition to cleaner energy sources without compromising on short-term economic goals. Furthermore, climate change and environmental policies have been divisive in United States politics (Basseches et al., 2022). Different administrations have had varying levels of commitment to addressing climate change, resulting in inconsistent policies and regulatory frameworks. This lack of long-term policy stability has impeded the effectiveness of CO_2 emissions reduction endeavors. Finally, similar to the experiences of other economies, the United States requires a significant portion of its resources to develop the necessary infrastructure to facilitate the transition to cleaner energy (Timmons et al., 2014). This is a considerable obstacle that impedes the implementation of renewable energy technologies and limits the prospects of reducing CO_2 emissions. The transition to cleaner energy sources, so-called energy diversification, can decrease CO_2 emissions (Gozgor and Paramati, 2022).

The empirical results of Table 6 further demonstrate that globalization negatively and significantly affects CO_2 emissions. This evidence means that the opening up of the United States economy has positively affected its environmental quality through reduced CO_2 emissions. This is explained by globalization fostering market incentives and competition, which can drive innovation and the development of cleaner technologies (Gozgor et al., 2020). Furthermore, globalization has allowed many manufacturing and production activities to relocate from the United States to countries with lower labour and related costs. Besides, these results can be attributed to carbon leakage, where the United States carbon-intensive economies have started to relocate to countries with less stringent environmental regulations. Collectively, these factors have ensured a smooth decline in the country's CO_2 emissions. Finally, globalization has facilitated the spread of knowledge and technologies across borders. This has allowed economies to adopt more ambitious targets (Shahbaz et al., 2018).

Finally, the increasing urban population affects CO_2 emissions in the United States. These results are consistent with those of Li and Lin (2015), Martínez-Zarzoso and Maruotti (2011) , and Zhang and Lin (2012). Urban areas have higher energy demands than rural areas due to increased population density, more buildings, and greater industrial activities (Fang et al., 2022). This results in higher consumption of fossil fuels for electricity generation, heating, cooling, and transportation, leading to increased CO_2 emissions. Besides, urbanization increases waste generation due to larger populations and commercial activities. Waste management processes like landfilling and incineration can release greenhouse gases like methane and carbon dioxide. Inefficient waste management practices further contribute to CO_2 emissions. Deforestation and land use changes also result in the loss of green spaces and ecosystems that help absorb and sequester carbon. These factors arising from urbanization worsen the environmental standards through increased CO_2 emissions.

4.3. Diagnostic tests and stability of the model

We also performed the present model's diagnostic and stability tests to ensure the findings' reliability. As a result, the tests presented in Table 7 confirm no serial correlation and heteroscedasticity in the residuals. Besides, these results demonstrate that the residuals follow a normal distribution.

Finally, the findings from Fig. 2 illustrate the outcomes of the cumulative sum (CUSUM) and the cumulative sum of squares (CUSUMSQ) stability tests. These tests demonstrate the model's stability (at the 5% significance).

Table 7
Results of diagnostic tests.

Diagnostic test	Coefficient	p-value	Decision
Serial correlation	1.414	0.261	No serial correlation exists.
Heteroscedasticity	0.385	0.981	No heteroscedasticity exists.
Normality test	2.992	0.224	Residuals are normally distributed.

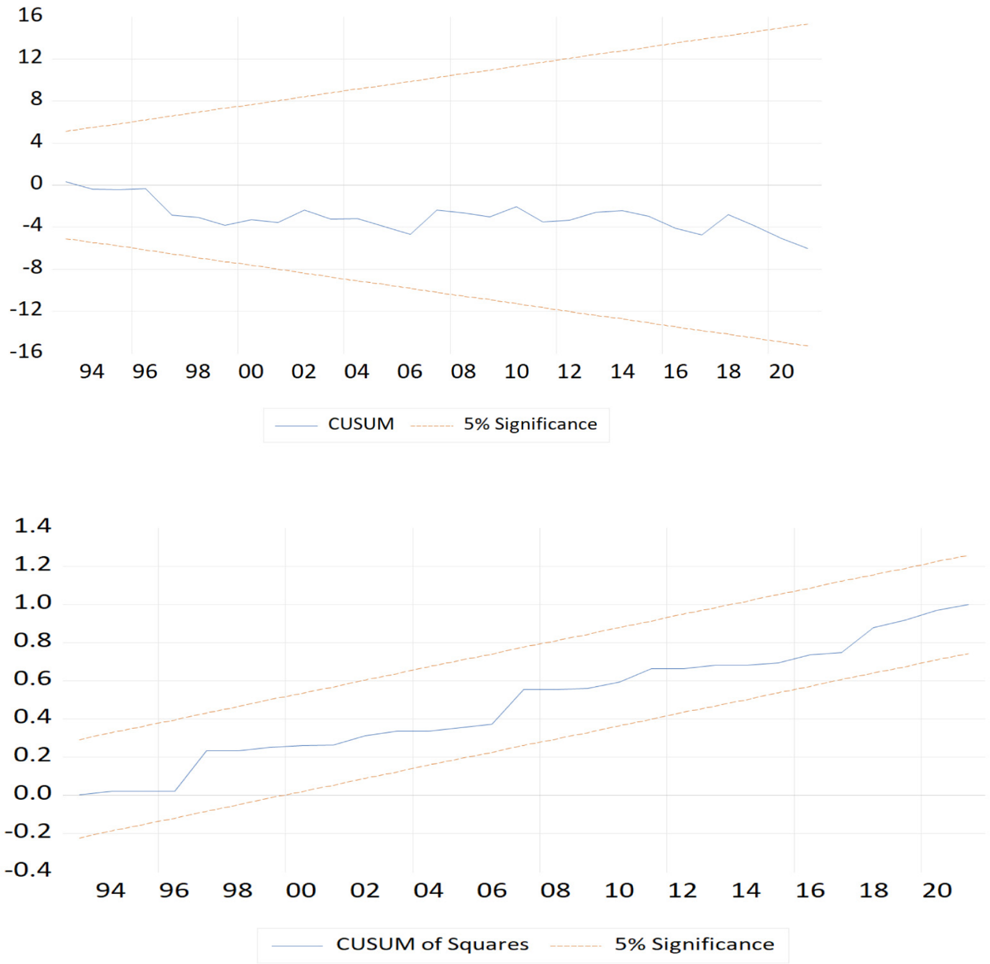

Fig. 2. Results of the CUSUM and the CUSUMQ Tests.
Source: The authors' calculations.

4.4. Additional robustness checks

Finally, we adopted the Dynamic Ordinary Least Squares (DOLS) regression method introduced by Stock and Watson (1993) to assess the long-term validity of the findings obtained from the ARDL estimations. The results in Table 8 confirm the validity, reliability, and consistency of the ARDL model results. These findings demonstrate that GQI and urbanization reduce CO_2 emissions. In contrast, economic growth and urbanization increase these CO_2 emissions. In short, decisions can be made based on these findings with an element of certainty.

5. Concluding remarks

This paper examined the dynamics of carbon emissions between 1970 and 2021 in the United States, focusing on factors such as the GQI, income per capita, globalization, and urbanization. The findings reveal that GQI and urbanization significantly impact environmental quality by reducing CO_2 emissions. However, economic growth and urbanization continue to push up CO_2 emissions. The reliability of these findings is confirmed by the results obtained from the DOLS estimations.

Table 8
Robustness checks: DOLS estimations.

Variable	Coefficient	Std. Error	*t*-statistic
GQI	−0.678***	0.063	−10.71
logGDPC	0.653***	0.177	3.691
logGI	−1.752***	0.393	−4.458
URP	0.024***	0.003	6.953
Constant	3.040***	0.180	16.84
R-squared	0.975	Mean dependent var	3.706
Adjusted R-squared	0.963	S.D dependent var	0.038
S.E of regression	0.007	Sum squared residual	0.002

*** $p < 0.01$.

The above findings can significantly influence the United States' environmental policies for the future course of action. The above results confirm the immediate necessity of a greater share of cleaner energy in energy composition. This would require a quick expansion of the renewable portfolio standards (RPS) and the adoption of more ambitious green energy targets. Firms will have more opportunities to switch to renewable energy sources. Besides, more financial incentives and tax credits should be designed to facilitate developing and deploying green energy projects, making them more economically viable and attractive to potential investors. In addition, by investing in R&D, the government can foster innovation and drive advancements in green energy, making it more efficient, affordable, and accessible (Zhou and Wang, 2022). Increased funding should support basic and applied research and public–private partnerships to accelerate the development of cutting-edge technologies and their successful integration into the existing energy infrastructure. Policymakers can also implement a carbon tax to price carbon emissions and encourage businesses and people to reduce CO_2.

Besides, the United States should strengthen the existing international agreements that aim at reducing CO_2 emissions globally, such as the Paris Agreement in 2015. Moreover, supporting sustainable trade practices and international collaboration with other countries should be promoted to develop joint research projects, exchange expertise, and encourage innovation in clean energy and sustainable practices.

Finally, the above findings are limited to the sustainability and environmental implications of the current development and urbanization trends in the United States. These findings necessitate a strict implementation of green infrastructure initiatives and enforcement of stringent emission regulations. Besides, sustainable urban planning and development practices that prioritize compact cities, mixed land use, and efficient transportation systems should be promoted. Future papers can focus on other developing and developed economies to understand the determinants of carbon emissions.

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