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Research Article

Role of Renewable Energy, Economic Growth, Agricultural Productivity, and Urbanization Toward Achieving China's Goal of Net-zero Emissions

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Abstract
An increase in carbon dioxide (CO_2) is expected to raise the Earth's temperature, leading to consequences such as glacier melt, rising sea levels, changes in weather patterns, and increased frequency of droughts and hurricanes. To restrict global warming to a maximum of 1.5°C, as outlined in the Paris Agreement, emissions must be reduced by 43% by 2030 and reach net zero by 2050. This investigation thoroughly examines the relationship between GDP growth, agricultural production, renewable energy use, urbanization, and CO_2 emissions in China from 1965 to 2023. Employing complex econometric models, such as Autoregressive Distributed Lag (ARDL), the research delivers a thorough analysis. The results indicate a substantial inverse connection between agricultural productivity and CO_2 releases, highlighting the efficacy of organic farming practices for ecological protection. Economic growth, despite its statistically small effect on pollution, highlights the necessity for ecologically sound and technologically sophisticated enhancement plans. The research underscores the significance of green power adoption in reducing CO_2 emissions in China in accordance with international initiatives for ecologically friendly production. The strong association between urbanization and CO_2 emissions implies difficulties in reconciling urban expansion with protecting the ecosystem. The study provides important guidance for formulating specialized green initiatives in China, aiding the country's goal of achieving net-zero emissions by 2060. The report offers a framework for healthy development, highlighting the benefits of farming and clean energy while tackling the challenges posed by urbanization, as China's experiences parallel those of other rising nations. This thorough research enhances the worldwide dialogue on addressing global warming and promoting responsible growth.

Keywords: Carbon neutrality, renewable energy, economic growth, urbanization, agricultural productivity, net-zero emissions.

Introduction

Significant people's actions that release atmospheric CO_2 include deforestation, the use of fossil fuels for electricity, and production procedures [1]. Human activities greatly intensify the greenhouse gas (GHG) effect, resulting in climatic alterations and several ecosystem challenges. The combustion of fossil fuels produces GHGs, including CO_2, which significantly contribute to environmental problems and climate change [2]. A significant amount of investigations suggest that around 76% of GHG emissions consist of carbon dioxide. The rising temperature concern has attracted worldwide focus, resulting in efforts such as the Paris Agreement aimed at mitigating the release of CO_2 and fostering equitable growth [3]. China, currently ranked 116th out of 132 countries in the most recent Environmental Performance Index (EPI), confronts ecological problems associated with swift GDP growth, intensified by pollution, which negatively affects people's health.

The incidence of extreme events is rising as the world's weather deteriorates [4]. The primary factors contributing to climate change include the increased adoption of sustainable power, the depletion of natural resources, and the release of GHGs into the atmosphere [5]. People have expressed numerous concerns about the potential ecological repercussions of the Belt and Road Initiative (BRI) since its inception in 2013. Environmentalists express concern that China's ongoing national ecological crisis exceeds all other natural disasters in magnitude, particularly with air and water pollution. China dominates worldwide GHG emissions, accounting for approximately fifty percent of global CO_2 emissions alongside India and other Asian countries [6]. Chinese scholars have recognized that ecological difficulties could hinder the BRI's objectives. The BRI's augmented GDP would lead to elevated levels of waste, pollution, and GHGs. The BRI's extensive activities and substantial resource demands distinguish it from an ecologically viable perspective. In recent times, China's CO_2 releases have increased at an annual rate of 8%, but the CO_2 emissions of BRI nations have risen at a rate of 5% per annum. Between 2001 and 2016, Chinese funders make investments in 240 coal-powered energy plants across 65 BRI regions, thereby impacting the natural health of these nations.

Subsequent to the 11th Five-Year Plan (2006–2010), the reduction of coal consumption and the substitution with alternative forms of energy have been paramount in the ensuing programs. China has recently reiterated the importance of green development and the pressing necessity to transition to renewable energies [7]. The global dedication to environmental sustainability may shift if China hastens to switch to green power supplies in alignment with its objective to peak greenhouse gas emissions by 2025, as outlined in its 14th Five-Year Plan of Action. China's objective of achieving carbon offsets by 2060 will be pivotal in expediting the nation's sustainable energy future and reducing pollution to net zero. Any approach to achieve this objective must commence with China generating the bulk of its electricity from renewable energies and rapidly augmenting the utilization of this sustainable energy when practicable. China must expedite the transition to renewable energy and make a decisive departure from coal. Moreover, China must cease the construction of new power plants powered by coal, prioritize the generation of power from alternative resources, substitute thermal coal with cleaner energies, and reduce commercial coal consumption through technological advancements and reorganization. China must significantly alter its energy composition by elevating the share of non-fossil fuel power to 84% and completely eliminating coal-fired power plants by 2060. Concerns arise about the future of several power plants currently under construction or in the planning stages, as they could either become idle assets or continue to generate pollution and GHG releases for decades.

There are indications that advocates in the energy field might look for increased financing through the pretense of "promoting energy security" and positioning coal as crucial for securing future electric power, given the growing emphasis on energy stability. Local authorities reliant on extractive sector profits frequently advocate for the continuation of coal extraction. To mitigate this dependence, it is essential to implement tax and pricing measures, together with the cooperative identification of alternative tax allocations for municipalities. In addition to pledges to halt the construction of new coal-fired power plants, these initiatives should be enacted to bolster renewable energy output. Furthermore, it is imperative to ensure a "just transition" for employees and support affected coal communities. In conjunction with an occupational retraining strategy to aid influenced coal miners in securing a possibility, it may encompass explicit and thorough legislation for health care and remuneration. The livelihood in the coal sector is antiquated and,

therefore, precarious. Employees in China, similar to their counterparts in other countries, would benefit from the authorities prioritizing 21st-century employment opportunities above those of the 20th century.
The BRI, a major development and commercial program that includes numerous nations, has demonstrated China's dedication to ecological benefits. This suggests that China will imminently discontinue financing both domestic and international coal-fired energy initiatives. Spending on alternative energy technologies primarily propels China's objective of establishing a carbon-neutral power sector. We will integrate more cost-effective solar photovoltaic (PV) and wind power with industrial electricity preservation systems to facilitate extensive adoption. Promoting lower emissions in economic activity through enhanced electrification, like the movement from renewable-powered to electric vehicles, is a crucial element of an effective energy revolution [8]. Moreover, network administration is improving, and the costs of preserving energy are decreasing. It is plausible that these advances in technology will persist. By 2030, China's electrical supply may derive from non-fossil energy sources, resulting in energy prices that are 11% lower than those under the current operational mechanisms. It is expected that the current expenditure trends for solar power will remain. Renewable energy provides substantially greater prospects to China than petroleum and coal [9]. China has established an ambitious objective to attain net-zero CO_2 releases by the year 2060. Such substantial ambition illustrates the countries' resolve to preserve biodiversity and mitigate worldwide warming. China aims to foster a more equitable and ecologically sound environment by attaining net-zero emissions, signifying the equilibrium between the volumes of CO_2 emitted into the surroundings and the same level extracted. These strategic steps support worldwide attempts to tackle global warming and shift toward an economy with no emissions.
The main goal of the paper is to analyze the level of environmental gains achieved via various initiatives in China and to evaluate the magnitude to which GDP expansion contributes to climate change and the release of CO_2 in the country. This research investigates the correlation between China's CO_2 emissions and its agricultural output, GDP growth, urbanization, and utilization of alternative energy resources. This study addresses numerous inadequacies in previous analyses and possesses significance and originality in the following areas: This analysis is distinctive as it assesses China's CO_2 emissions derived from primary renewable energy supplies. Secondly, the current research will bridge an information deficit regarding China's agriculture practices and CO_2 releases. This investigation may provide more insights for researchers and administrators. The ARDL framework was employed to forecast China's CO_2 emissions from 1965 to 2023. Furthermore, the study's conclusions will empower officials in China's agricultural, monetary, and urbanization sectors to reduce CO_2 emissions.

Literature review

Globally, researchers have thoroughly examined the connection between CO_2 emissions and financial variables, uncovering intricate processes that vary by geography and economic state. A multitude of examinations have investigated the correlation between CO_2 releases and multiple financial metrics worldwide, using a range of factors and approaches. Liu et al. [10] investigated the relationship between CO_2 pollution and GDP progress in OECD and OIC nations, revealing an upward correlation between pollution and GDP growth. Aslam et al. [11] explored the correlation between CO_2 emissions and GDP development in China, highlighting that although per capita GDP ultimately intensifies pollutants, factors such as industrialization, trade liberalization, and the number of people also play significant roles in elevating CO_2 emissions. Danish et al. [12] assert that revenue growth intensifies damage to the environment by enlarging the ecological footprint. This underscores the imperative of achieving equilibrium between ecological preservation and growth in the economy, accentuating the importance of incorporating sustainability issues into business growth strategies.
The relationship between GHG emissions, GDP growth, and the use of clean energy has achieved major concern as it has vital implications for GDP growth and the protection of ecosystems. Karaaslan and Çamkaya [13] examined both long- and short-term links among GDP, green energy use, and CO_2 emissions in Turkey. Their analysis reveals that the adoption of alternative power resources mitigates long-term CO_2 emissions, while economic growth and reliance on fossil fuels exacerbate pollution. Erdoğan et al. [14] discovered that the long-term effects of GDP and clean electricity on CO_2 outputs were unbalanced,

highlighting the complex interplay between the conservation of biodiversity and GDP growth. Moreover, emphasizing the importance of sustainable energy for environmental preservation, Shah et al. [15] found that enhancing the use of green energy is essential for reducing CO_2 emissions.

The relationship between agriculture, GDP expansion, and the release of CO_2 has been a central theme in longevity studies, especially with the potential of renewable energy to alleviate ecological impacts. Aydoğan and Vardar [16] examined the interrelationship of CO_2 emissions, GDP, and agricultural value-added in the E7 countries within the agricultural setting. Their findings validate the Environmental Kuznets Curve (EKC) hypothesis, indicating that while farming techniques and GDP growth increase CO_2 emissions, the use of green power mitigates them. This illustrates how the use of renewable energy in agriculture may reduce dependence on fossil fuels and enhance ecological longevity. In South Africa, Bekun [17] investigated the detrimental effects of financial growth and agricultural practices on the environment. Saidmamatov et al. [18] reported analogous results, utilizing panel data from Central Asia and revealing that agricultural value-added reduced emissions, but GDP growth had a positive correlation with CO_2 emissions. Shakoor et al. [19] employed the ARDL structure in Pakistan to demonstrate that food production and the use of renewable energy both reduce CO_2 emissions. Collectively, these investigations underscore the intricate interconnections among business activity, agricultural procedures, energy use, and negative ecological effects across diverse geographic areas, emphasizing the imperative for tailored expansion and long-term sustainability strategies.

The effects of urbanization on the release of CO_2 have become a significant subject of research, especially because of its complex association with prosperity and biodiversity issues. Urbanization's significant contribution to CO_2 emissions has garnered significant attention due to its intricate relationship with financial growth and ecological effects. Zambrano-Monserrate [20] analyzed CO_2 emissions in OECD nations and identified an upward trend involving expansion and urbanization, which exacerbates ecosystem damage. Liu et al. [10] and Kong et al. [21] also found a correlation between urbanization and CO_2 emissions in China and African nations, reinforcing the notion that increased urbanization can exacerbate ecological issues. Raihan et al. [22] highlighted the influence of urbanization on greenhouse gas emissions in Thailand, demonstrating its worldwide impact on natural health. Khan et al. [23] expanded their analysis to South Asian nations, noting the beneficial effects of urbanization on CO_2 emissions while also admitting the capacity of renewable energy to alleviate these effects. This national viewpoint provides an in-depth understanding of the environmental impacts of urbanization in various situations, highlighting the necessity for deliberate measures to reconcile urban expansion with conservation efforts.

Notwithstanding the comprehensive research on the interconnections among GDP growth, green power, and the release of CO_2 worldwide [24-28], substantial gaps persist in comprehending the particular phenomena within China. The contradictory results about China's urbanization and CO_2 emissions highlight the necessity for localized studies to thoroughly evaluate the determinants affecting atmospheric results. Overcoming these discrepancies will yield a more sophisticated comprehension of the intricate connections between China's revenue generation and its ecological responsibility. This will facilitate the formulation of tailored policies aimed at reducing GHGs and promoting equitable growth. Collaboration endeavors among scholars, lawmakers, and business partners will be crucial for enhancing data collection, assessment, and evidence-based choices to foster long-term prosperity in China.

Methodology

Data and empirical model

The data on CO_2 emissions were collected from Our World in Data (OWD) [29], whereas the data on renewable energy consumption was collected from Energy Institute [30]. In addition, the data on economic growth, agricultural productivity, and urbanization were collected from the World Development Indicators (WDI) [31] database by the World Bank. The database's broad structure, sourced from recognized worldwide organizations, guarantees the legitimacy and integrity of the material used for research. The set of data employed encompasses the years 1965 to 2023. The extensive 59-year period of China's data allows for a comprehensive analysis of the rapid changes among these critical components, offering important perspectives into the complex linkages that affect the release of CO_2. Table 1 presents a description of the data. Before conducting the analysis, the variables were transformed into their logarithmic form to ensure that the dataset had a normal distribution. Figure 1-5 presents the annual trends of CO_2 emissions, green energy usage, GDP expansion, agricultural productivity, and urbanization in China.

Table 1. Description of the variables.

Variable	Sign	Logarithmic form	Measurement units	Source
CO_2 emissions	CE	LCE	Ton per capita	[24]
Renewable energy use	RE	LRE	Exajoules	[25]
Economic growth	EG	LEG	GDP per capita (current US$)	[26]
Agricultural productivity	AP	LAP	Agriculture, forestry, and fishing, value added (% of GDP)	[26]
Urbanization	UR	LUR	Urban population (% of total population)	[26]

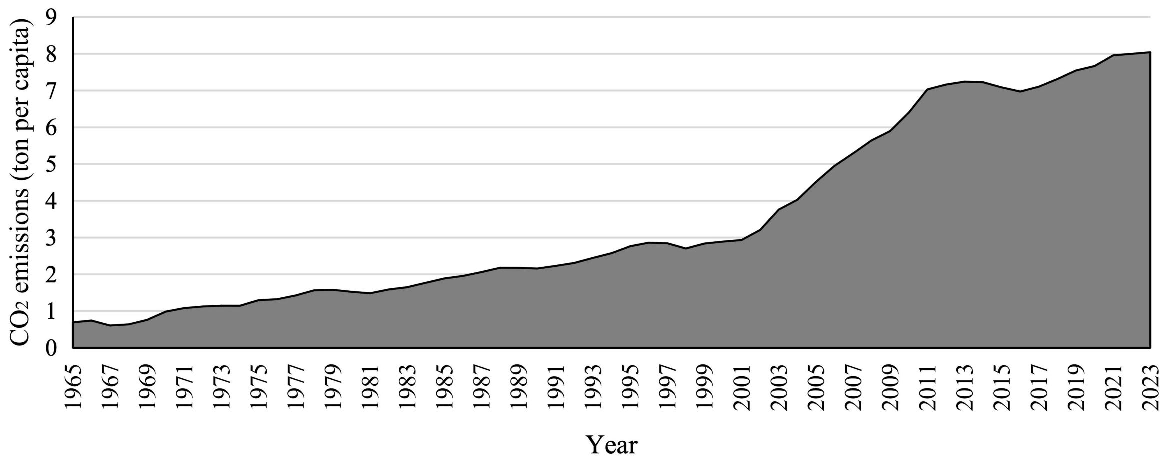

Figure 1. Annual trend of CO_2 emissions in China.

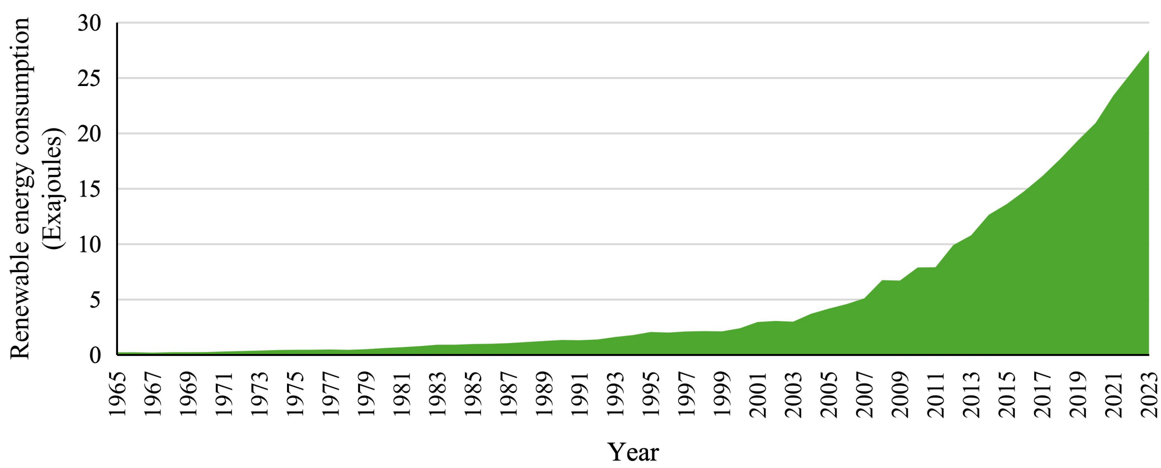

Figure 2. Annual trend of renewable energy consumption in China.

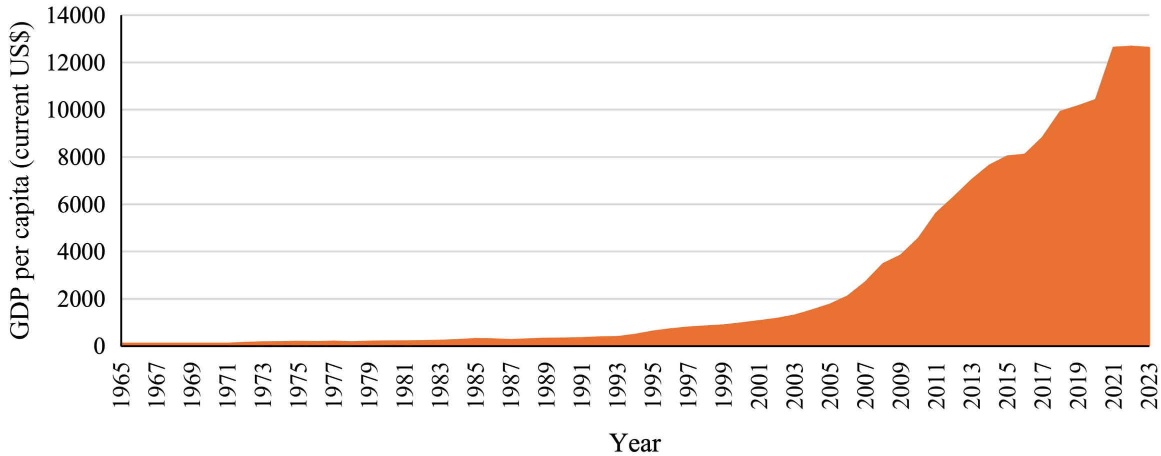

Figure 3. Annual trend of economic growth in China.

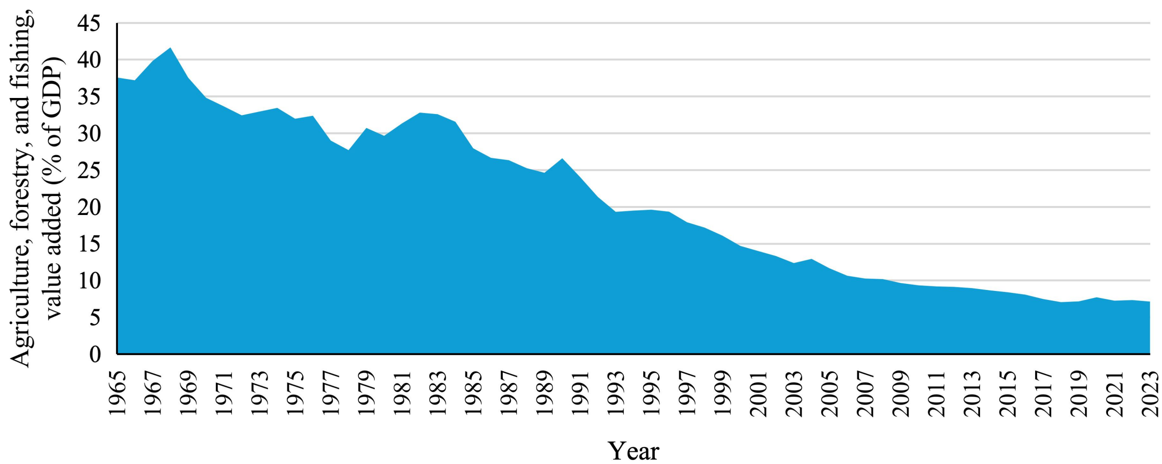

Figure 4. Annual trend of agricultural productivity in China.

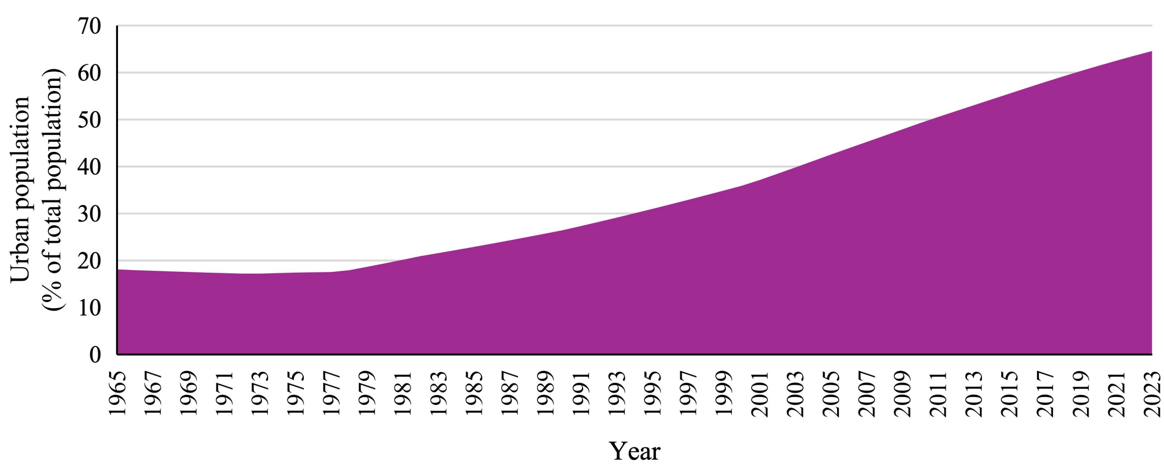

Figure 5. Annual trend of urbanization in China.

The following is the economic formula that accounts for each factor associated with CO_2 emissions:

$$CE = f(RE, EG, AP, UR) \quad (1)$$

The econometric model at time "t" can be written as:

$$LCE_t = \tau_0 + \tau_1 LRE_t + \tau_2 LEG_t + \tau_3 LAP_t + \tau_4 LUR_t + \varepsilon_t \quad (2)$$

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

Econometric strategies

This research used the ARDL methodology [32] to investigate the relationships between the variables. For reliable regression evaluation, data stationary patterns are essential, especially in cointegration approaches such as ARDL. To ascertain if the parameter possesses a unit root, indicating an irregular series, three statistical assessments were incorporated: the augmented Dickey-Fuller (ADF) test [33], the Dickey-Fuller generalized least squares (DF-GLS) test [34], and the Phillips-Perron (P-P) assessment [35]. 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 [32]. 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 [32]. The ARDL limit testing, utilized to explore the sustained associations across the chosen variables, is delineated as follows:

$$\Delta LCE_t = \tau_0 + \tau_1 LCE_{t-1} + \tau_2 LRE_{t-1} + \tau_3 LEG_{t-1} + \tau_4 LAP_{t-1} + \tau_5 LUR_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta LCE_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta LRE_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta LEG_{t-i} + \sum_{i=1}^{q} \gamma_4 \Delta LAP_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta LUR_{t-i} + \varepsilon_t \quad (3)$$

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:

$$\Delta LCE_t = \tau_0 + \tau_1 LCE_{t-1} + \tau_2 LRE_{t-1} + \tau_3 LEG_{t-1} + \tau_4 LAP_{t-1} + \tau_5 LUR_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta LCE_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta LRE_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta LEG_{t-i} + \sum_{i=1}^{q} \gamma_4 \Delta LAP_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta LUR_{t-i} + \theta ECT_{t-1} + \varepsilon_t \quad (4)$$

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

Table 2 provides a detailed summary of statistical measures for the factors, including normality outcomes, skewness, kurtosis, Jarque-Bera statistics, and their corresponding probability. All variables have 59 annual observations from 1965 to 2023 in relation to China. Skewness projections, nearing zero for every factor, indicate a range that closely approximates normalcy. The data on CO_2 emissions and agricultural productivity exhibit negative skewness, whereas the data on other factors show positive skewness. We meticulously analyzed the kurtosis values to check whether the series exhibited characteristics of a heavy-tailed or light-tailed distribution relative to a normal distribution. All of them exhibit platykurtic characteristics and regularly yield values below 3, as evidenced by observational evidence. Moreover, likelihood assessments from the Jarque-Bera testing confirm the normality of all aspects, offering further validation of the dataset's analytical soundness.

Table 2. Summary statistics of the variables.

Variables	LCE	LRE	LEG	LAP	LUR
Mean	0.98	0.69	6.65	2.88	3.43
Median	0.94	0.58	6.16	2.97	3.40
Maximum	2.08	3.31	9.45	3.73	4.17
Minimum	-0.50	-1.58	4.52	1.95	2.84
Std. Dev.	0.77	1.45	1.63	0.59	0.46
Skewness	-0.08	0.22	0.43	-0.25	0.14
Kurtosis	1.94	1.92	1.74	1.54	1.57
Jarque-Bera	2.83	3.36	3.71	3.84	3.22
Probability	0.24	0.19	0.16	0.15	0.17
Observations	59	59	59	59	59

Table 3 showcases the outcome of the unit root tests. 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). The results highlight the significance of utilizing the ARDL approach, which guarantees the credibility of future regression studies by verifying the linearity of the parameters and strengthening the accuracy of the researcher's claims.

Following the confirmation of data stationarity by unit root examinations, this work adopted the ARDL bounds examination to analyze the sustained link within the parameters. Table 4 delivers the findings from the implementation 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 unit root tests.

Variables		LCE	LRE	LEG	LAP	LUR
ADF	I(0)	-0.99	-1.27	-1.51	-0.33	-1.58
	I(1)	-5.30***	-8.04***	-5.82***	-6.61***	-4.02***
DF-GLS	I(0)	-0.78	-0.96	-0.52	-1.97	-1.65
	I(1)	-5.29***	-6.86***	-5.68***	-6.48***	-4.87***
P-P	I(0)	-1.13	-1.45	-1.19	-0.40	-1.30
	I(1)	-5.03***	-8.06***	-5.83***	-6.56***	-5.28***

***$p<0.01$

Table 4. Results of ARDL bounds test.

Test statistic	Estimate	Significance levels	I(0)	I(1)
F-statistic	12.33	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 represents the outcome of the ARDL simulation, which demonstrates the short- and long-term connections between the factors. The negative coefficients of LRE imply that CO_2 releases are mitigated by 0.44% (short-run) and 0.86% (long-run) for each 1% spike in the adoption of green power. The LEG coefficients are also negative but negligible, implying that a 1% boost in GDP will cut CO_2 releases by 0.01% (short-run) and 0.03% (long-run). Moreover, the negative coefficients for LAP show that a 1% rise in agricultural output can diminish CO_2 emissions by 0.48% (short-run) and 0.61% (long-run). On the other hand, according to the LUR's strong positive coefficients, for every 1% upsurge in urbanization, the release of CO_2 will be 1.07% (short-run) and 1.32% (long-run).

Table 5. Results of ARDL simulation.

Variables	Long-run			Short-run		
	Coefficient	t-statistic	p-value	Coefficient	t-statistic	p-value
LRE	-0.86***	-5.63	0.00	-0.44***	-5.04	0.00
LEG	-0.03***	-3.41	0.00	-0.01***	-3.29	0.00
LAP	-0.61***	-3.94	0.00	-0.48***	-3.71	0.00
LUR	1.32***	4.72	0.00	1.07***	4.68	0.00
C	19.97	1.41	0.11	-	-	-
ECT (-1)	-	-	-	-0.59***	-4.20	0.00
R^2	0.97					
Adjusted R^2	0.96					

Note: LRE = renewable energy, LEG = economic growth, LAP = agricultural productivity, LUR = urbanization. ***p<0.01

The value of ECT is -0.59 and significant at 1% thresholds, corroborating the evidence of persistent integration. It illustrates that variations in the independent factors are linked with about 59% of long-term changes in CO_2 emissions. 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 6 presents the ARDL diagnostic assessment conclusions. The lower value of the Jarque-Bera coefficient and the insignificant p-value illustrate 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 analyze if the model was properly specified. The insignificant p-value from the test demonstrates that the model is appropriately specified.

Table 6. Diagnostic test results.

Diagnostic tests	Coefficient	p-value	Decision
Jarque-Bera	0.81	0.67	Normal distribution residuals
Breusch-Godfrey LM	0.95	0.45	No autocorrelation
Breusch-Pagan-Godfrey	0.78	0.62	No heteroscedasticity
Ramsey RESET	0.76	0.59	Properly specified model

China's use of green power exhibits a substantial inverse relationship with the release of CO_2, corroborated by prior research discoveries [36-45]. The continuous convergence across various studies highlights the strength of the observed association. The inverse relationship indicates that as China's reliance on clean energy sources increases, CO_2 emissions decrease, demonstrating the capacity of renewable resources to promote a sustainable planet. The relationship between using clean electricity and CO_2 emissions is favorable because of numerous critical considerations. Primarily, due to fossil fuels being a major contributor to CO_2 outputs, transitioning to alternative sources of energy typically involves diminishing their consumption. Wind and geothermal energy are highlighted in China's sustainable development strategy and fundamentally cleaner options that reduce the overall carbon impact. Moreover, the integration of green power resources corresponds with international initiatives to mitigate global warming by decreasing reliance on renewable energy and ecologically detrimental energy resources. China's emphasis on the renewable energy sector reflects its dedication to sustainable development. Policies by governments, technological developments, and major investments in sustainable equipment are crucial in facilitating this transformation. This report provides lawmakers and interested parties with useful ideas by offering tactics to mitigate the costs of green power and lessen dependency on fossil fuels. The inverse link demonstrates the effectiveness of these strategies in fostering a healthier and more resilient energy landscape, which significantly contributes to the global effort to create a future free of emissions.

The unfavorable association between CO_2 emissions and GDP progress in China corroborates prior studies [37,40,44,46-54] that demonstrate the opposite relationship between CO_2 releases and GDP expansion. This unforeseen association necessitates an examination of basic variables. China's recent deliberate efforts to emphasize responsible growth and environmental preservation are responsible for this adverse correlation. The nation's focus on technological advancements and efficiency improvements in the burgeoning economy has led to the extensive adoption of greener and more environmentally sustainable technologies. Investments in alternative energies, enabled by monetary resources from economic expansion, substantially reduce the carbon intensity of diverse economic activity. This increased awareness, along with governmental measures promoting ecologically sustainable behaviors, has facilitated a societal transition toward greener practices. Awareness, along with governmental measures promoting ecologically sustainable behaviors, has facilitated a societal transition towards greener practices. The negative association may indicate a shift toward environmentally friendly purchasing patterns, prompting firms to implement better manufacturing operations. China's flourishing economy, along with a dedication to innovative technology and conservation, serves as a catalyst for the decrease of CO_2 emissions.

The opposite connection between agricultural output and CO_2 emissions in China has major consequences for understanding the complex structure of sustainable development. Prior research [55-60] confirms the discovery. This adverse correlation indicates that China's agriculture methods are crucial in reducing CO_2 emissions via diverse environmentally sustainable approaches. The negative coefficients indicate that a rise in crop output correlates with a drop in CO_2 emissions, underscoring the ecological benefits associated with Chinese agriculture. Responsible agricultural practices, including organic cultivation and precise farming, facilitate this decline by enhancing resource efficiency and mitigating ecological harm. Aforestation initiatives, involving the meticulous planting of trees, function as carbon sinks, sequestering atmospheric carbon emissions. Moreover, carbon absorption in soils used for agriculture, facilitated by methods such as crop rotation and less cultivation, contributes to mitigating emissions. Moreover, utilizing clean energy supplies in agricultural practices enhances ecological effectiveness. The implementation of solar or wind energy for irrigation and agricultural practices diminishes dependence on fossil fuels, leading to reduced CO_2 emission. China's focus on renewable energy aligns with global efforts to transition toward sustainable and environmentally friendly business practices. The negative correlation between farming output and CO_2 releases in China emphasizes the advantages of organic farming. This corresponds with the nation's dedication to sustainable governance, providing vital perspectives for policymakers and those aiming to harmonize economic growth with ecological consciousness.

Urbanization explores a significant upward link with CO_2 emissions in China, confirming conclusions from prior research [40,61-67]. This persistent pattern illustrates the complicated issue of urbanization's exacerbation of CO_2 emissions. The favorable correlation can be ascribed to elevated energy demand, augmented industrial operations, and heightened transport needs linked to fast urbanization. The use of electricity typically increases with the expansion of urban areas, frequently depending on fossil fuels that substantially contribute to CO_2 emissions. Industrial expansion occurs mainly in metropolitan areas, and the increase in automobile traffic exacerbates the emission of high-carbon contaminants. The report advocates the implementation of ecologically sound urbanization strategies to counter this alarming trend. This entails incorporating energy-efficient devices into municipal buildings and advocating for green habits among city inhabitants. The focus on green areas and forestry efforts acts as a countermeasure to the increase in CO_2 emissions and alleviates the effects of urban heat islands. Exercise caution with immigration, as the flow of individuals into urban regions may burden current utilities and intensify pollution problems. Promoting the consideration of mid-sized and small cities instead of megacities is suggested as a method to stimulate revenue growth and improve productivity. In summary, heightened energy use, along with intensified commercial and logistic activity in urban regions, primarily drives the positive link between urbanization and CO_2 releases in the country. The proposed policies seek to harmonize urban expansion with a healthy environment, highlighting the necessity for deliberate city design and ecological action to alleviate the negative ecological effects of urbanization.

Conclusion and policy recommendations

The investigation reached significant conclusions by examining the intricate relationships among green energy usage, GDP growth, agricultural output, urbanization, and CO_2 emissions in China from 1965 to 2023. Three unit root tests and bound tests supported the ARDL calculation, enabling a close examination of both short- and long-term interactions. The substantial negative coefficients associated with renewable power utilization underscore the essential importance of sustainable energy for achieving environmental sustainability. The substantial negative coefficients associated with renewable power utilization underscore the essential importance of sustainable energy for achieving environmental sustainability. Economic progress illustrates the intricacies of its relationship with pollutants, highlighting the importance of technical advancements and environmental initiatives. The opposite relationship between CO_2 emissions and agricultural productivity underscores the necessity for ethical farming methods to mitigate ecological loss. The positive coefficients for urbanization indicate difficulties in reconciling urban expansion with efforts to reduce emissions. These findings establish a solid basis for formulating green laws in China, highlighting the necessity for focused initiatives that utilize the benefits of clean energy, GDP growth, and farming while tackling the challenges posed by urbanization. As China aims for net-zero pollution by 2060, the findings from this study provide pragmatic guidelines for promoting responsible growth and addressing global warming, applicable both domestically and to other emerging nations encountering analogous issues. This study's findings provide multiple suggested policies for reducing CO_2 emissions and attaining net-zero emissions in China.

To enhance dynamism in China's transition to a viable development approach, it is essential to expedite innovation in advanced green power technologies and circular economy methodologies. Investing substantial resources in studies and innovations aimed at cost reduction and efficiency enhancement of green power supplies like wind, solar, and hydropower can achieve this. Moreover, promoting progress in grid integration and energy storage systems will facilitate the incorporation of renewable energy resources into the existing structures. Moreover, enhancing the implementation of equitable growth strategies, including reuse and recycling, along with waste reduction, may augment resource conservation while diminishing resource utilization and ecological impact. The public sector, academia, and community groups must collaborate to foster an environment conducive to advances in technology and long-term prosperity.

The structure of global commerce strongly influences Chinese climate regulations and legislation. China occupies a pivotal position in the world's economy, leading to the prioritization of economic growth and industrial advancements in trade agreements. This could adversely impact the ecosystem and exhaust resources. Commercial agreements and legislation must incorporate ecological factors to ensure alignment with sustainability goals. This may involve establishing environmental guidelines and requirements for foreign and domestic products, promoting ethical production practices, and encouraging international

cooperation on ecological problems. Moreover, promoting ecologically sustainable practices through trade rules, such as prioritizing eco-friendly products, can steer global commerce toward resilience.
The farming sector significantly influences China's ecological policies and procedures. The primary sources of GHG pollution in agriculture are methane from cattle and nitrous dioxide (N_2O) from pesticides. Farming activities are frequently the target of green laws designed to mitigate pollutants and promote environmentally friendly agriculture. Establishing crop credentials and norms that are centered on the environment, promoting environmentally sound farming through monetary rewards, and integrating ecological issues into trade contracts and bargaining are effective methods to align trade with sustainability targets. Supporting research and innovation to develop greener farming technologies and methods can further enhance the aim of achieving equilibrium between agricultural output and environmental conservation.
Rapid urbanization in China puts stress on assets and accelerates pollution, requiring stringent environmental restrictions. China employs energy-efficient construction methods, green buildings, and mass transit to achieve its objective of growing cities sustainably. Encouraging the use of alternative power sources and rigorously enforcing restrictions may mitigate impacts on the environment. Policies can align with conservation goals by prioritizing green technologies and designing urban systems. Effective implementation and monitoring of environmentally sustainable practices during urbanization necessitate interaction among administrations, enterprises, and societies, as well as global partnerships.
Civil society and citizens are essential in shaping China's environmental strategy through the promotion of reform, accountability among lawmakers, and enhanced comprehension. Increased public engagement may enhance transparency among public officials and entrepreneurs by encouraging more open decision-making procedures. It is crucial to advocate for the general public's understanding of environmental issues in order to enhance these components and improve longevity outcomes. This may encompass educational efforts, seminars, and campaigns aimed at raising consciousness about ecological problems and encouraging public engagement in policy discussions. Moreover, providing individuals a platform to express their perspectives on ecosystem issues can facilitate the establishment of community engagement and feedback mechanisms, ultimately leading to more accessible and effective policy outcomes.
The investigation has specific constraints, although it provides valuable insights into China's CO_2 emissions. It primarily focuses on GDP, green energy use, urbanization growth, and agricultural production, limiting its scope. This may be further examined in the near term by incorporating additional social and ecological factors such as interest rates, commerce, foreign direct investment, technical innovation, industrialization, globalization, and inflation. Also, including more greenhouse gases in the study, such as sulfur oxides (SO2), N2O, and methane (CH4), and looking at them over a larger area (a group of countries) might help us get a better picture. Such research would expand our expertise base and furnish further information for formulating ecologically sustainable policies for equitable development.

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