GREEN ENERGY, TECHNOLOGY ADOPTION, AND ENVIRONMENTAL SUSTAINABILITY IN CHINA

WANG, Y.[1*] – IGHARO, A. E.[2,3*] – AL-FARYAN, M. A. S.[4] – ONOYOM, M. O.[5] – WARA, S. T.[6]

[1]*School of Marxism, China University of Geosciences, Wuhan, 430074 Hubei, China*

[2]*Economics Department, Edwin Clark University, Kiagbodo, Delta State, Nigeria*

[3]*DEPECOS Institutions and Development Research Centre (DIaDeRC), Ota, Nigeria*

[4]*Board Member and Head of the Scientific Committee at The Saudi Economic Association, Riyadh, Saudi Arabia*

[5]*Department of Economics, University of Calabar, Calabar, Nigeria*

[6]*Edwin Clark University, Kiagbodo, Delta State, Nigeria*

[*]*Corresponding author*
e-mail: Wangyuan20250723@163.com

(Received 25th Jul 2025; accepted 26th Sep 2025)

Abstract. This study investigates the dynamic relationship between green energy consumption, technology adoption, economic growth, and environmental sustainability in China, a country at the forefront of balancing industrial advancement with ecological preservation. Employing the Autoregressive Distributed Lag (ARDL) model on time series data, the research explores both the short-run and long-run interactions among these variables. The findings reveal that technology adoption significantly enhances environmental sustainability in the long run, affirming the importance of innovation-driven strategies in addressing ecological challenges. Conversely, GDP demonstrates a negative long-run impact, suggesting that China's economic growth, still largely reliant on fossil fuel-driven industrialization, adversely affects environmental quality. Interestingly, green energy consumption, despite its positive short-run effect, does not exhibit a statistically significant influence in the long run, indicating potential inefficiencies or structural bottlenecks in its implementation. The error correction term confirms the presence of a stable long-run equilibrium, while diagnostic tests affirm the robustness and reliability of the model. Granger causality tests further suggest weak short-run predictive relationships among the variables, with a near-significant causality flowing from environmental sustainability to GDP. These outcomes underscore the complexity of China's sustainable development trajectory, highlighting the need for more integrated and regionally inclusive green policies. The study recommends enhancing renewable energy infrastructure, strengthening regulatory frameworks, and accelerating the diffusion of green technologies. Overall, the results offer important implications for policymakers seeking to harmonize economic development with environmental goals in the context of China's transition toward a low-carbon, sustainable economy.

Keywords: *renewable transition, innovation, low-carbon development, climate policy, sustainable growth*

Introduction

Over the past two decades, China has emerged as both a global leader in economic growth and the world's largest emitter of greenhouse gases. This dual role presents a complex challenge: how can rapid industrialization and urbanization coexist with commitments to environmental sustainability? In response, China has initiated a robust green energy transition anchored in large-scale renewable energy deployment and aggressive technology adoption. These initiatives are motivated by a blend of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

environmental, economic, and strategic imperatives and have transformed China into a key factor in the global sustainability landscape (Ma et al., 2019; Nasir et al., 2022; Osabohien et al., 2024).

According to Amin et al. (2024), energy transition is particularly evident in its extraordinary growth in renewable energy capacity. By 2024, the country had already exceeded its 2030 renewable energy targets, with over 1,878 GW of installed capacity surpassing the combined contributions of most developed nations (Liu et al., 2024, 2025; Dou et al., 2025). This capacity is dominated by solar and wind energy installations, driven by industrial policy support, economies of scale, and declining unit costs. As documented by Wang et al. (2023), China added more solar capacity in 2023 alone than any other country in a single year, contributing significantly to the global drop in solar PV costs. These developments have been supported by substantial investments in ultra-high-voltage transmission lines and energy storage technologies that enhance the reliability and integration of intermittent renewable sources (Zhao and Chen, 2022; Nasir et al., 2022; Meng et al., 2025; Zhang et al., 2025).

Technology adoption has played a central role in this transformation. Research by Xu et al. (2023) using autoregressive distributed lag (ARDL) modeling confirms that advancements in renewable energy technology are positively correlated with long-term improvements in environmental quality in China. Similarly, innovations in green finance have been critical enablers of sustainability. Since the inception of China's green finance policy framework in 2015, the country has become the largest issuer of green bonds globally. Empirical studies, such as those by Zhang and Lu (2022), reveal that green financial instruments directly support investments in renewable energy infrastructure, energy efficiency, and clean transportation, which cumulatively reduce carbon emissions and promote green GDP growth.

From a regulatory standpoint, the Chinese government has implemented policies that incentivize low-carbon technologies and penalize heavy polluters. These include carbon trading schemes, subsidies for clean energy production, and stricter emissions standards for coal-fired plants. Yet, as noted by Chen et al. (2022), despite significant progress, coal still accounts for over 60% of China's electricity generation. This reliance creates a paradox within China's green agenda: while renewable energy is booming, coal expansion continues in parallel, primarily to safeguard energy security and economic stability, especially in high-demand industrial zones (Igbal et al., 2021; Jiang and Yuan, 2025; Huang et al., 2025).

Several studies highlight the regional dimensions of technology adoption and green energy integration in China. For example, Huang et al. (2021) observed that the Beijing–Tianjin–Hebei region has become a model for green urban development, leveraging clean technologies to reduce emissions and improve air quality. At the same time, rural provinces often lag due to limited access to financing and technical expertise. This imbalance underscores the need for targeted policy interventions and technology transfer mechanisms to ensure equitable progress across regions.

Also, China's push for environmental sustainability is not confined to energy production alone. Efforts are also underway to transition toward a circular economy. Jiang and Li (2023) found that technologies supporting recycling, green manufacturing, and waste-to-energy systems are gradually being integrated into China's industrial sectors. In addition, the proliferation of smart grid infrastructure and digital energy platforms has enhanced efficiency in energy distribution and demand-side management (Fang et al.,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

2023; Agbo et al., 2023). These digital systems enable real-time monitoring of emissions and energy usage, which facilitates better environmental governance.

Nevertheless, China’s green transformation faces several structural and institutional challenges. Overcapacity in the solar and wind manufacturing sectors has led to inefficiencies and oversupply in global markets, raising concerns about economic waste and market distortions (Luo and Ye, 2023). Legal and administrative barriers also hinder the full implementation of green energy projects, particularly at the local level where bureaucratic fragmentation and inconsistent policy enforcement prevail (Sun and Wang, 2022; Frontiers in Environmental Science, 2024). To address these gaps, scholars recommend enhanced regulatory harmonization, streamlined permitting processes, and greater inter-agency coordination.

International cooperation has also become a cornerstone of China’s sustainability strategy. Through initiatives such as the Belt and Road Initiative (BRI), China is exporting green technologies and building renewable infrastructure in developing countries. However, there is a tension between China’s domestic environmental commitments and the environmental footprint of its overseas projects. As Li and He (2024) argue, ensuring that exported energy infrastructure aligns with sustainability goals is essential to maintaining China's credibility as a green technology leader.

Also, scholarly attention has increasingly turned to the environmental Kuznets curve (EKC) hypothesis within the Chinese context. Multiple studies suggest that China's emissions follow an inverted-U shape in relation to income, meaning emissions rise with industrialization but decline after reaching a certain income threshold (Zheng et al., 2022; Plos one, 2024). However, the EKC does not hold uniformly across sectors or regions, indicating that proactive policy and innovation are still needed to accelerate decoupling between economic growth and environmental degradation.

The broad objective is to enhance the integration of green energy and technology adoption to promote environmental sustainability in China. While the specific objectives include: Increasing the deployment of renewable energy sources such as solar and wind power; fostering innovation in clean technologies to reduce carbon emissions; implementing policies that encourage sustainable practices among industries and communities to mitigate environmental degradation and promote ecological balance.

In conclusion, China’s efforts toward green energy deployment, technology adoption, and environmental sustainability represent a complex but ambitious model of systemic transformation. Its achievements in renewable capacity expansion, smart grid development, and green finance leadership are commendable, yet ongoing coal dependency, industrial overcapacity, and regulatory inconsistencies present enduring obstacles (Nwachukwu et al., 2022). Future strategies must focus on deepening institutional reform, promoting inclusive technology diffusion, and reinforcing global collaboration in clean innovation. With coordinated efforts, China could set a precedent for emerging economies seeking to harmonize economic development with environmental integrity.

Literature review

Wang et al. (2025) examined the influence of environmental regulation on green technology adoption in Chinese industry. Using firm-level innovation data and regression analysis over 2010–2022, they found that stricter emission standards significantly

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

accelerated investment in clean technologies, particularly among manufacturing enterprises.

Amin et al. (2025) found that renewable energy and innovation accelerate U.S. decarbonization. Osabohien et al. (2025) revealed that business density and finance shape the energy–sustainability balance in East Asia. Luan et al. (2025) confirmed clean energy drives industrial growth via GMM. Imandojemu et al. (2025) highlighted renewable technology's quantile effects on OECD carbon neutrality.

Osabohien et al. (2024) and Mohamed et al. (2024) affirmed renewables reduce emissions in Africa. Degbedji et al. (2024) stressed institutional quality, while Guo et al. (2025) linked governance and resources to Asian sustainability. Wang et al. (2024), Adeleye et al. (2021), Osabohien et al. (2023) and Du et al. (2025) emphasized innovation, digital infrastructure, and social–environmental synergy for long-run ecological improvement.

Zhao (2024) studied "The role of green ammonia in meeting challenges toward sustainable development in China" using DEA modeling of six regions. The paper identified green ammonia as a promising low-carbon energy carrier that can enhance energy security, reduce fossil fuel dependence, and support industrial decarbonization by 2030.

Cui (2025) in "AI-Driven Digital Transformation and Firm Performance in Chinese Industrial Enterprises", employed panel regression and structural equation modeling on data from 6,300 firms (2015–2022). The results showed that green digital innovation mediates the positive link between AI adoption and firm performance, especially when coupled with human–AI collaboration.

Xu et al. (2024) in PLOS ONE compared public sentiment and renewable energy trends using a Grey Prediction Model. They confirmed China's leadership in green energy deployment and emphasized the need to align public discourse with policy goals to achieve sustainable development.

Li et al. (2025) applied FMOLS, DOLS, Q-GMM, and IV-2SLS to assess how income, technology, and energy equity affect sustainability in 39 high-income nations, including China. They found that income growth, equity improvements, and energy transition policies each significantly enhance environmental sustainability.

Scientific Reports (2025) conducted a meta-analysis using ARDL models on literature across regions. They confirmed a long-term negative relationship between CO_2 emissions and technological innovation, renewable energy adoption, and economic growth, implying renewables support decarbonization.

Chen et al. (2025) investigated green tech, green investments, and CO_2 emissions using MMQR over provincial data for 1998–2020. Contrary to conventional expectations, they found that green technology investments were associated with higher CO_2 in some quantiles and that the inverted-U-shaped EKC remains applicable.

Frontiers in Environmental Science (2024) used textile-industry time-series analysis (1995–2020) and panel regression to investigate the effects of environmental policy, innovation, and renewable adoption on sectoral performance, finding that innovation combined with regulation significantly enhances environmental efficiency.

Ma and Lin (2022) studied 264 Chinese cities (2006–2017) using a partially linear functional coefficient panel model. They showed that green technology innovation reduced CO_2 emissions significantly post-2010, especially in cities with higher human capital, working partly through industrial upgrading.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

Shahbaz et al. (2022) analyzed the impact of financial inclusion on pollutant and CO_2 emissions using provincial panel data. They found that improved access to finance supports renewable energy investments and pollutant reduction, suggesting finance is a key enabler of sustainability.

Zhao et al. (2022) utilized super-efficiency DEA and spatial econometrics to explore environmental regulation's U-shaped effect on green growth and renewable energy deployment. They discovered spatial spillovers and that regulation intensity enhances renewable deployment and green GDP beyond a threshold.

Fang et al. (2019) examined determinants of innovation in fossil and renewable energy technologies using panel regression. They found that price signals impact fossil innovation more strongly, but government support is crucial for promoting clean technology development.

Lin and Zhou (2021) constructed an entropy-weighted TOPSIS index of green economic growth (2000–2017). Using panel regression, they showed that green innovation, environmental regulation, urbanization, FDI, and industrial structure all significantly influenced growth, with regional heterogeneity observed.

Huang et al. (2021) performed a comparative study of Beijing–Tianjin–Hebei cities using case-based mixed methods. They demonstrated that green urban technologies significantly reduced air pollution and emissions, offering a replicable model for other metropolitan regions.

Jin et al. (2021) (Renewable Energy) utilized Bayesian panel VAR models to capture non-linear and asymmetric effects of renewables, innovation, and globalization on emissions. They found that higher adoption of renewable energy and green innovation yielded larger emission reductions at extreme pollution levels.

Afanasiev et al. (2024) investigated green patents, renewable energy consumption, and their roles in China using PCSE estimation for panel data. The study showed that green patent activity and renewable energy consistently promote green growth and emission reductions.

Music et al. (2023) used panel threshold models on BRICS+ countries, including China, to examine technological innovation effects on green growth. They found that the positive impact of green technologies on green growth is significant only once countries surpass a certain income threshold, implying context-specific policy needs.

Qiu et al. (2025) used DYNARDL on 1990–2017 data to assess nuclear energy's role in the circular economy. They reported a negative long-run impact, cautioning that nuclear power requires complementary environmental technologies and systems integration to improve sustainability.

Tian (2023) created an environmental attention index for 30 provinces (2007–2019), and through panel regressions identified that higher environmental focus by governments significantly reduces CO_2, especially in western China, with informatization amplifying this effect.

Cui and Wang (2021) evaluated regional ETS pilot schemes using synthetic control methods. They found that local carbon markets significantly decreased firm-level emissions, demonstrating the effectiveness of emissions trading at the subnational level.

Taken together, these studies provide valuable evidence of the complex interactions between green technology, energy use, and sustainability in China. However, much of the existing literature focuses either on sector-specific dynamics, such as textiles or urban clusters, or relies on cross-country meta-analyses that obscure country-level heterogeneity. Few studies explicitly test the joint effects of green energy consumption,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

technology adoption, and economic growth within a unified econometric framework, especially distinguishing between short- and long-run dynamics. By applying an ARDL approach and grounding the analysis in Ecological Modernization Theory, this study addresses these gaps. It contributes new empirical evidence by quantifying the effectiveness of green energy consumption relative to GDP and technological innovation in shaping environmental sustainability outcomes in China, thereby offering a more detailed understanding of policy trade-offs and priorities.

Methodology

This study is underpinned by the Ecological Modernization Theory (EMT), which posits that environmental protection and economic development are not inherently contradictory. Rather, through technological innovation, institutional reforms, and proactive environmental policies, modern economies particularly transitioning ones like China can decouple economic growth from environmental degradation (Mol and Spaargaren, 2000). According to EMT, the adoption of green technologies and clean energy is a strategic mechanism through which industrial societies reconfigure production systems toward sustainability.

This theory is appropriate for China's case, as the country is undergoing rapid technological transformation while simultaneously attempting to reduce its ecological footprint. EMT supports the notion that policies promoting renewable energy, technological innovation, and infrastructure upgrades can be harmonized with efforts to enhance environmental sustainability.

Model specification

The study applies the Autoregressive Distributed Lag (ARDL) model developed by Pesaran, Shin, and Smith (2001), which is well-suited for analyzing long-run and short-run dynamics among variables regardless of whether the underlying series are I(0) or I(1), provided none are I(2). This approach is particularly suitable for small or medium sample sizes and accommodates different lags for different variables.

The basic ARDL form of the model for investigating the relationship between Environmental Sustainability (ES), Green Energy (GE), and Technology Adoption (TA) is specified as:

$$\Delta ES_t = \beta_o + \sum_{i=1}^{p} \beta_1 \, \Delta ES_{t-1} + \sum_{i=0}^{q} \beta_2 \, \Delta GE_{t-1} + \sum_{i=0}^{r} \beta_3 \, \Delta TA_{t-1} + \sum_{i=0}^{s} \beta_3 \, \Delta GDP_{t-1} + \lambda_1 ES_{t-1} + \varepsilon_{it} \quad \text{(Eq.1)}$$

where:
ES_t = Environmental sustainability (proxied by adjusted net savings or CO_2 emissions),
GE_t = Green energy consumption (% of total energy use),
$TA_{\ t}$ = Technology adoption (proxied by green patents or R&D on clean energy),
$GDP_t =$ Economic growth (GDP per capita),
Δ = First difference operator,
ε_{it} = White noise error term.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

The coefficients λ_1 measure the long-run relationships, while the summation terms represent short-run dynamics.

ARDL Bounds Testing approach

The Bounds Testing method is used to test for the existence of a long-run relationship between the variables. The null hypothesis of no cointegration is tested using:

$H_o = \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$

$H_i = \lambda_1 \neq 0$

If the calculated F-statistic exceeds the upper critical bound, we reject the null and conclude that a long-run relationship exists.

Long-run equation

$$ES_t = \delta_o + \delta_1 GE_t + \delta_2 TA_t \delta_3 GDP_t + \mu_t \quad \text{(Eq.2)}$$

where $\delta_1\ to\ \delta_3$ are the long-run elasticities.

Short-run error correction model (ECM)

Once a long-run relationship is confirmed, the error correction model (ECM) is estimated as:

$$\begin{aligned}\Delta ES_t = \theta_0 + \sum_{i=1}^{p} \theta_1 \Delta ES_{t-1} + \sum_{i=0}^{q} \theta_2 \Delta GE_{t-1} + \sum_{1=0}^{r} \theta_3 \Delta TA_{t-1} \\ + \sum_{i=0}^{s} \theta_4 \Delta GDP_{t-1} + \varphi ECM_{t-1}\end{aligned} \quad \text{(Eq.3)}$$

where:

ECM_{t-1} = Error correction term derived from the long-run model,

φ = Speed of adjustment coefficient; expected to be negative and significant.

Prior to estimating the ARDL model, the time series properties of the variables were examined using both Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit root tests. These tests were conducted to confirm that none of the variables were integrated of order two, I(2), which would invalidate the ARDL approach. The results, presented in *Table 3*, indicate that the variables are a mix of I(0) and I(1), thereby justifying the application of the ARDL framework.

Variable description and data sources

The study relies on annual time series data covering the period 1970–2023, providing 54 observations for each variable. This period was selected to capture China's structural transformation, including phases of industrial expansion, renewable energy adoption, and policy reforms, while ensuring data availability and consistency across indicators (*Table 1*).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

Table 1. *Variable description and data sources*

Variable	Proxy/Measurement	Source
Environmental Sustainability (ES)	Adjusted Net Savings (% of GNI) or CO_2 emissions per capita	WDI
Green Energy (GE)	Renewable energy consumption (% of total energy use). It is important to note that green energy consumption in this study is not measured by installed renewable capacity, which may overstate actual utilization due to curtailments, storage inefficiencies, and transmission losses. Instead, we rely on the World Development Indicators' definition of renewable energy consumption, which quantifies the share of renewable energy actually consumed as a percentage of total final energy use at the national level. This distinction ensures that the indicator reflects the energy effectively delivered and utilised, thereby separating it from conventional sources within China's aggregate energy supply mix.	WDI
Technology Adoption (TA)	Green patents or R&D on renewable energy	WDI
GDP per capita (GDP)	Constant 2025 US$	WDI

In this study, an "observation" refers to a single annual data point for each variable, resulting in 54 yearly observations covering the period 1970–2023. All data are aggregated at the national level, ensuring that they capture trends representative of the entire Chinese economy and energy system rather than selected provinces or regions. By drawing on World Development Indicators (WDI) and other internationally validated sources, the inputs used are consistent, standardized, and nationally representative, thereby allowing for robust econometric analysis of country-wide dynamics.

This ARDL-based methodological framework offers a theoretically grounded and statistically robust pathway to analyze how green energy deployment and technology adoption affect environmental sustainability outcomes in China.

Results and discussion

Descriptive statistics

Table 2 reports the descriptive statistics of the variables employed in the study. Beyond the descriptive statistics, trends in China's green energy production and consumption reveal the scale and dynamics of its transition. National data indicate that renewable energy production has risen sharply since the early 2000s, driven primarily by hydropower, solar, and wind expansion, while consumption has followed a similar trajectory, albeit at a slower pace due to integration challenges and storage losses. Between 2005 and 2023, the share of renewable energy in total final energy use increased from less than 8 percent to over 16 percent, reflecting significant structural change in China's energy mix. The divergence between production and consumption highlights persistent issues of grid curtailment, transmission bottlenecks, and seasonal variability, highlighting the importance of technological and policy interventions to fully translate production capacity into effective consumption.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

Table 2. *Descriptive statistics*

	LNES	LNGE	LNTA	LNGDP
Mean	74.10499	16.58943	23.06837	161.3295
Median	22.67558	14.67164	23.04100	117.2908
Maximum	524.9054	43.61702	36.96508	536.9169
Minimum	0.099180	4.265403	12.24041	49.77684
Std. Dev.	116.8204	9.212496	4.146336	106.1992
Skewness	2.080260	1.169410	0.375290	1.608928
Kurtosis	7.042849	4.440494	5.343238	5.540799
Jarque-Bera	75.72274	16.97648	13.62180	37.82307
Probability	0.000000	0.000206	0.001102	0.000000
Sum	4001.669	895.8294	1245.692	8711.792
Sum Sq. Dev.	723291.2	4498.114	911.1815	597747.8
Observations	54	54	54	54

Note: LNES = Log of Environmental Sustainability; LNGE = Log of Green Energy Consumption; LNTA = Log of Technology Adoption; LNGDP = Log of Gross Domestic Product. Source: Author Computation Using EVIEWS 9

The descriptive statistics presented in the table offer insightful information about the distributional characteristics of four key variables: Environmental Sustainability (ES), Green Energy Consumption (GE), Technology Adoption (TA), and Gross Domestic Product (GDP) in China, based on 54 observations. The analysis aids in understanding the central tendencies, variability, and distributional properties of the data, which are foundational for robust econometric modeling.

Starting with Environmental Sustainability (ES), the mean value is 74.10, but its high standard deviation (116.82) and wide range (from 0.10 to 524.91) suggest significant fluctuations in environmental outcomes over the observed period. The skewness of 2.08 and kurtosis of 7.04 indicate a right-skewed and leptokurtic distribution, implying the presence of extreme positive values. The Jarque-Bera statistic confirms non-normality at a 1% level, emphasizing the need for transformation or robust estimation techniques.

For Green Energy Consumption (GE), the mean is 16.59 with a standard deviation of 9.21, showing moderate variability. The minimum and maximum values (4.27 and 43.62 respectively) indicate increasing but uneven adoption of green energy sources. A skewness of 1.17 and kurtosis of 4.44 also confirm a non-normal, positively skewed distribution. The Jarque-Bera test reinforces this with a significant p-value, suggesting the distribution is not Gaussian.

Technology Adoption (TA) is relatively stable, with a mean of 23.07 and a narrow standard deviation of 4.15. The skewness (0.38) and kurtosis (5.34) show that the data is approximately symmetric but still leptokurtic, indicating moderate outliers. While the Jarque-Bera test suggests slight deviation from normality, the distribution is less extreme compared to ES and GE.

Gross Domestic Product (GDP), with a mean of 161.33 and a high standard deviation of 106.20, shows substantial economic heterogeneity. The values range from 49.78 to 536.92, reflecting China's rapid economic transformation. The positive skewness (1.61) and high kurtosis (5.54) point to a long right tail and peakness, confirmed by a significant Jarque-Bera statistic.

In summary, the data reveals considerable variability across variables, especially in ES and GDP, driven by China's evolving environmental and economic policies. The non-

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

normality observed necessitates the application of econometric models robust to heteroskedasticity and outliers, such as ARDL with logarithmic transformations.

Unit root result

To examine the stationarity properties of the series, ADF and PP unit root tests were conducted; the results are summarized in *Table 3*.

Table 3. *ADF and PP unit root test*

	ADF TEST					PP TEST				
Variables	Intercept	Trend & Intercept	None	First Diff	Status	Intercept	Trend & Intercept	None	First Diff	Order of Integration
lnES	-1.118	-1.608	0.426	-4.353***	I(1)	-0.796	-1.151	1.409258	3.423**	I(1)
LnGE	-3.335**				I(0)	-2.779*				I(0)
lnTA	-1.809	-3.797**				-2.229	-3.797**			I(0)
GDP	-2.589	-2.991	-0.497	-5.556***	I(1)	-1.926	-2.471	-0.401	-5.465***	I(1)

Note: ***, ** and * significant at 1%, 5% and 10% respectively. Source: Computed by the author using EVIEWS version 9

The results from the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests reported in the document provide important preliminary insights into the stationarity of the series, which is a necessary condition for selecting appropriate econometric models, especially in time series and panel data analysis. The four variables assessed are: Environmental Sustainability (lnES), Green Energy Consumption (lnGE), Technology Adoption (lnTA), and Gross Domestic Product (GDP), all in logarithmic form.

The unit root tests reveal that lnES and GDP are non-stationary at level but become stationary after first differencing, indicating that they are integrated of order one, I(1). This suggests that environmental sustainability and economic output follow a stochastic trend, and any shock to these series can have long-term effects. For policymakers in China, this implies that disruptions to GDP or environmental quality, such as policy shifts or global shocks, may have lasting implications on the country’s growth-environment nexus. Thus, sustainable development policies need to be forward-looking and robust against such shocks.

In contrast, lnGE (green energy consumption) and lnTA (technology adoption) are stationary at level, i.e., I(0). This indicates that these variables are mean-reverting, and short-term shocks to green energy consumption or technology use do not persist over time. Economically, this suggests that China's efforts in promoting renewable energy and technological upgrades exhibit a form of structural stability likely a result of consistent policy frameworks, innovation incentives, and the maturation of green sectors.

The presence of mixed integration orders (I(0) and I(1)) makes the Autoregressive Distributed Lag (ARDL) model appropriate for analyzing the long-run and short-run dynamics among the variables. The fact that green energy and technology adoption are stationary while GDP and environmental sustainability are not reflecting the dynamic and transitioning nature of China's economy where core structural variables like output and sustainability are still evolving, while policy-influenced sectors like green energy and innovation have achieved relative equilibrium.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

In summary, the stationarity properties of the variables align with China's economic trajectory marked by long-term transformation in macroeconomic and environmental indicators, alongside relative policy-induced stability in energy and technological domains. This validates the relevance of using an ARDL framework to uncover both short-run policy impacts and long-run development relationships.

Correlation analysis of the variables used for estimation

The correlation matrix provides preliminary insights into the linear relationships among the variables (*Table 4*).

Table 4. *Correlation result*

	LNES	LNGE	LNTA	GDP
LNES	1	0.266	-0.669	-0.525
LNGE	0.266	1	0.022	-0.396
LNTA	-0.669	0.022	1	0.498
GDP	-0.525	-0.396	0.498	1

Source: Author computation using EVIEWS 9

Environmental sustainability (lnES) exhibits a negative correlation with both technology adoption (−0.669) and GDP (−0.525), suggesting that increases in economic output and technological use in China may currently be associated with environmental trade-offs possibly due to industrial emissions or unsustainable production practices. However, lnES shows a weak positive correlation (0.266) with green energy consumption (lnGE), implying that higher use of green energy modestly contributes to better environmental outcomes.

Interestingly, technology adoption (lnTA) is positively correlated with GDP (0.498), reinforcing the idea that technological advancement supports economic growth. This correlation is particularly interesting because it highlights the dual role of technology adoption in China's development pathway. On one hand, it confirms that investments in technological innovation directly support economic expansion by enhancing productivity, industrial upgrading, and global competitiveness. On the other hand, when contrasted with the weak correlation between technology adoption and green energy consumption (0.022), it suggests that much of the technological progress has been growth-oriented rather than environmentally focused. This asymmetry highlights the importance of aligning technological innovation with green objectives to ensure that the economic benefits of technology also translate into long-term sustainability gains. Yet, its weak correlation with green energy (0.022) indicates that technological changes are not necessarily aligned with green energy initiatives. Similarly, green energy and GDP are negatively correlated (−0.396), implying that economic growth may still be somewhat reliant on non-renewable energy sources.

In summary, the correlation results reflect the complexity of China's development pathway: while technology and growth are intertwined, their current patterns appear misaligned with environmental sustainability. This underscores the need for integrated policy frameworks that harmonize growth, innovation, and ecological resilience.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

ARDL Bound Co-integration test

The ARDL Bounds Co-integration test result provides evidence of a long-run equilibrium relationship among the variables under investigation Environmental Sustainability, Green Energy Consumption, Technology Adoption, and GDP in China. The calculated F-statistic of 6.310 exceeds the upper bound critical values at the 1%, 5%, and 10% significance levels (which are 5.23, 4.23, and 3.74 respectively for I(1)) (*Table 5*).

Table 5. *ARDL bound co-integration test*

Test Statistics		Value
F- Statistics		6.310
Significance	**I(0) Bound**	**I(1) Bound**
10%	2.97	3.74
5%	3.38	4.23
1%	4.3	5.23

Source: Computed by the author using EVIEWS version 9

Economically, this implies that despite the variables having mixed orders of integration (I(0) and I(1)), they are co-integrated, meaning they share a stable long-run relationship. In the context of China’s development, this suggests that changes in green energy consumption, technological innovation, and economic output jointly influence environmental sustainability over time.

This result validates the use of the ARDL model for examining both short-run dynamics and long-run impacts. It also provides a strong foundation for policy inferences indicating that integrating green energy and technology policies with macroeconomic planning can yield sustainable environmental outcomes in the long run. This reinforces the importance of aligning innovation and growth strategies with climate objectives in China’s transition toward a green economy.

ARDL long run estimated result

After conducting bound test with evidence of long run cointegration. In the result estimated in *Table 6*, it depicts long run result on the relationship Environmental Sustainability, green energy consumption, technology adoption and gross domestic product in China.

Table 6. *ARDL long run estimated result*

Dependent Variable = Environmental Sustainability			
Variables	**Coefficient**	**Std. Error**	**T-statistics**
LNGE	-0.819	0.747	-1.096
LNTA	0.735**	0.272	2.700
GDP	-1.429***	0.409	-3.487
@TREND	0.160***	0.012	13.201

Note: ***, ** and * significant at 1%, 5% and 10% respectively. Source: Computed by the author using EVIEWS version 9

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

The ARDL long-run estimation results reveal critical insights into the determinants of environmental sustainability in China. The dependent variable is environmental sustainability, while the explanatory variables include green energy consumption (LNGE), technology adoption (LNTA), GDP, and a time trend.

The coefficient of technology adoption (LNTA) is positive and statistically significant at the 5% level (0.735, $t = 2.700$), indicating that technological advancement contributes positively to environmental sustainability in the long run. This suggests that China's investments in cleaner technologies and innovation are effectively mitigating environmental degradation.

Conversely, GDP exerts a significant negative effect (−1.429, $t = -3.487$, significant at 1%), implying that economic growth, in its current form, is detrimental to environmental sustainability. This result aligns with the early stages of the Environmental Kuznets Curve (EKC) hypothesis, where growth leads to increased pollution and environmental stress, possibly due to heavy reliance on industrial output and fossil fuels.

Green energy consumption (LNGE) shows a negative but statistically insignificant effect (−0.819, $t = -1.096$). This suggests that although green energy use is increasing, it has yet to yield a significant long-term positive impact on environmental outcomes likely due to limited scale or inefficiencies in deployment.

The positive and highly significant time trend (0.160, $t = 13.201$) underscores a structural improvement in environmental sustainability over time, potentially driven by progressive policies, international climate commitments, and public awareness.

In summary, the findings emphasize that while technological adoption drives environmental gains, current economic growth patterns undermine sustainability. For green energy to have a meaningful impact, further policy support and structural integration into the energy mix are necessary.

Short run estimating result

The short-run ARDL estimation results provide a dynamic picture of the immediate effects of green energy consumption, technology adoption, and GDP on environmental sustainability in China. The analysis highlights both short-term adjustments and the speed at which the system returns to long-run equilibrium (*Table 7*).

Table 7. *Short run estimating result*

Dependent Variable = Environmental Sustainability			
Variables	**Coefficient**	**Std. Error**	**T-statistics**
D(LNES(-1))	0.547***	0.104	5.235
D(LNGE(-1))	0.195***	0.071	2.769
D(LNTA(-4))	-0.121***	0.034	-3.523
D(GDP(-3))	0.137**	0.045	3.040
D(GDP(-4))	0.217***	0.047	4.621
C	0.937***	0.150	6.227
CointEq(-1)	-0.155***	0.026	-5.979

Note: ***, ** and * significant at 1%, 5% and 10% respectively. Source: Computed by the author using EVIEWS version 9

The lagged value of environmental sustainability (D(LNES(-1))) is positive and highly significant (0.547, $t = 5.235$), indicating strong persistence in environmental outcomes.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

This means past improvements in environmental quality tend to influence current performance, reflecting inertia in environmental systems.

Green energy consumption (D(LNGE(-1))) exerts a positive and statistically significant effect (0.195, $t = 2.769$), suggesting that in the short run, increases in green energy use contribute meaningfully to environmental sustainability. This marks a notable contrast to the long-run result, implying that immediate impacts of renewable energy deployment are more visible before diminishing over time without structural reinforcement.

Technology adoption (D(LNTA(-4))) has a negative and significant coefficient (−0.121, $t = -3.523$), indicating that earlier technological investments may initially exert pressure on the environment, possibly due to transitional emissions or implementation inefficiencies. However, this effect is likely reversed in the long run, where technology shows a positive impact.

GDP enters significantly in both the third (0.137, $t = 3.040$) and fourth lags (0.217, $t = 4.621$), demonstrating that economic growth contributes positively to environmental sustainability in the short run perhaps due to increased fiscal space for environmental programs or temporary green investments.

The error correction term (CointEq(-1)) is negative and significant (−0.155, $t = -5.979$), confirming the existence of a stable long-run relationship. The coefficient indicates that approximately 15.5% of the deviation from long-run equilibrium is corrected each period, signifying a moderate speed of adjustment.

In summary, the short-run dynamics reveal that green energy and economic growth positively affect environmental sustainability, while technology has a delayed, initially adverse impact. The model confirms a stable long-run equilibrium, underscoring the importance of sustained and well-sequenced policies to balance short-term progress with long-term environmental goals.

Diagnostic results

The diagnostic test results confirm the reliability and robustness of the estimated ARDL model for analyzing the relationship between environmental sustainability, green energy consumption, technology adoption, and GDP in China (*Table 8*).

Table 8. *Diagnostic results*

Serial Autocorrelation		**Ramsey Reset Test**		**Normality Test**	
F-statistic	Probability	F-statistic	Probability	Jarque Bera	Probability
2.381507	0.1109	0.226	0.823	1.496	0.473

Note: ***, ** and *significant at 1%, 5% and 10% respectively. Source: Computed by the author using EVIEWS version 9

Firstly, the Breusch-Godfrey Serial Correlation LM test reports an F-statistic of 2.3815 with a probability of 0.1109, which is above the conventional 5% significance threshold. This implies that the null hypothesis of no serial correlation cannot be rejected, confirming that the residuals of the model are not serially correlated and the model is correctly specified in terms of its dynamic structure.

Secondly, the Ramsey RESET test, which checks for functional form misspecification, yields an F-statistic of 0.226 and a probability value of 0.823. This high p-value strongly

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

suggests that there are no omitted variables or incorrect functional forms in the model, thereby reinforcing the model's internal consistency and appropriate specification.

Lastly, the Jarque-Bera test for normality gives a value of 1.496 with a probability of 0.473, indicating that the residuals are normally distributed. Normality of residuals is essential for the validity of inference, especially in small samples, ensuring that standard errors and hypothesis tests are reliable.

In summary, the diagnostic results affirm that the model is free from serial correlation, functionally well-specified, and characterized by normally distributed residuals. This enhances the credibility of the model's estimates and its suitability for policy interpretation.

Pairwise Granger causality tests

The Pairwise Granger Causality tests reveal that there is no strong evidence of causal relationships among the variables at the conventional 5% significance level (*Table 9*). However, a near-significant result is observed for Environmental Sustainability Granger causing GDP ($F = 3.11$, $p = 0.0537$), which suggests a potential unidirectional causality from environmental improvements to economic performance, albeit weak. This aligns with green growth literature suggesting that sustainable environmental policies can enhance productivity and economic resilience over time.

Other causal pathways such as from GDP, GE, and TA to ES, or among GE and TA show non-significant F-statistics with high p-values, indicating the absence of short-run predictive power between the variables. This may be due to policy lags, structural rigidities, or the need for broader systemic reforms for interactions to manifest significantly.

Table 9. *Pairwise Granger causality tests*

Null Hypothesis:	Obs	F-Statistic	Prob.
GDP does not Granger Cause ES	52	0.62574	0.5393
ES does not Granger Cause GDP		3.11358	0.0537
GE does not Granger Cause ES	52	0.08614	0.9176
ES does not Granger Cause GE		0.03968	0.9611
TA does not Granger Cause ES	52	0.37056	0.6923
ES does not Granger Cause TA		0.54438	0.5838
GE does not Granger Cause GDP	52	0.10901	0.8969
GDP does not Granger Cause GE		0.31251	0.7331
TA does not Granger Cause GDP	52	0.99728	0.3766
GDP does not Granger Cause TA		0.31426	0.7319
TA does not Granger Cause GE	52	2.30322	0.1111
GE does not Granger Cause TA		1.33498	0.2730

Discussion of findings

The empirical findings reveal complex insights into the relationship between green energy consumption, technology adoption, GDP, and environmental sustainability in China. In the long run, technology adoption exerts a statistically significant and positive influence on environmental sustainability, emphasizing the role of innovation in

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

mitigating environmental degradation. This aligns with Wang et al. (2025) and Ma and Lin (2022), who found that technological innovation, particularly in clean energy and industrial upgrading, significantly reduces carbon emissions across Chinese cities.

Equally, GDP shows a strong negative effect on sustainability in the long run, suggesting that China's current growth trajectory, still heavily reliant on industrial production and fossil fuels, compromises environmental goals. This supports the Environmental Kuznets Curve (EKC) hypothesis (Zheng et al., 2022), where growth initially worsens environmental quality before potential improvements at higher income levels.

Interestingly, green energy consumption despite China's rapid expansion has an insignificant long-term effect. This may reflect deployment inefficiencies, regional disparities, or lagged benefits, as noted by Luo and Ye (2023) regarding overcapacity and integration challenges in China's renewable sector.

In the short run, however, green energy and GDP positively influence sustainability, while technology initially exerts a negative effect—possibly due to adjustment costs or transitional emissions. The significant and negative error correction term confirms a stable long-run equilibrium, indicating policy consistency.

Granger causality tests show weak short-run predictive links, yet environmental sustainability nearly Granger-causes GDP, reinforcing Li and He's (2024) proposition that environmental progress can drive economic gains via green investment.

Collectively, these results emphasize that while China is advancing on a green path, aligning economic growth, energy policy, and technological innovation remains crucial. Future progress hinges on deeper structural reforms, coordinated policy efforts, and sustained investment in clean technologies to harmonize development with environmental integrity.

It is also important to recognize that the descriptive statistics, particularly the high standard deviations for environmental sustainability and GDP, reflect substantial spatiotemporal heterogeneity within China. Aggregated national-level data may mask important regional differences between industrialized and less-developed provinces, as well as between urban and rural contexts. While this study relies on national time series data to provide a macro-level perspective, future research could disaggregate the analysis to account for subnational variation. Evaluating industrialized versus non-developed regions separately would provide a clearer understanding of how regional disparities shape the effectiveness of green energy adoption and environmental outcomes.

Conclusion and recommendations

In conclusion, this study has empirically examined the interlinkages among green energy consumption, technology adoption, GDP, and environmental sustainability in China using an ARDL framework. The findings reveal that while technological innovation significantly enhances environmental sustainability in the long run, economic growth driven by industrialization and fossil fuel dependence undermines these efforts. Green energy consumption, despite its short-run benefits, shows no significant long-run impact, highlighting potential inefficiencies and implementation gaps in the sector. The presence of a stable long-run relationship among the variables and the model's robustness suggests that China's sustainability transition is structurally consistent but still challenged by systemic economic pressures.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

Based on these findings, the study recommends that China deepen its green energy reforms by addressing deployment inefficiencies, particularly through grid modernization and regional integration. Efforts should also focus on decoupling GDP growth from environmental degradation by incentivizing low-carbon industries and enhancing environmental taxation. Furthermore, technological innovation must be broadly diffused across regions, including rural and industrial zones, to achieve inclusive environmental benefits. Lastly, regulatory consistency, institutional reforms, and strong enforcement mechanisms are essential to translate green policies into measurable environmental outcomes.

In addition to identifying gaps in regional policy implementation, this study highlights concrete policy directions already being pursued in China. For example, the national carbon emissions trading scheme (ETS), operational since 2021, serves as a market-based instrument to reduce emissions intensity across key industrial sectors. The Renewable Energy Law (amended in 2009 and subsequently strengthened) mandates grid companies to purchase renewable electricity, while fiscal subsidies and feed-in tariffs support the expansion of solar and wind power. The Green Finance Policy Framework introduced in 2015 and updated in 2020 mobilizes capital toward low-carbon infrastructure through green bonds and preferential credit. Furthermore, the 14th Five-Year Plan (2021–2025) explicitly sets targets for peaking carbon emissions before 2030 and achieving carbon neutrality by 2060, embedding green energy and technology adoption as central pillars. By explicitly incorporating these existing policy pathways, this study situates its theoretical contribution within China's broader institutional framework and underscores the need to strengthen regional integration to complement national efforts. By harmonizing growth, innovation, and sustainability, China can reinforce its leadership in global environmental governance and set a benchmark for other emerging economies.

Funding. This research received no external funding.

Competing interest. Authors declare no competing interest.

REFERENCES

[1] Adeleye, B. N., Osabohien, R., Lawal, A. I., De Alwis, T. (2021): Energy use and the role of per capita income on carbon emissions in African countries. – PLoS ONE 16(11): e0259488. https://doi.org/10.1371/journal.pone.0259488

[2] Afanasiev, M., Liu, Y., Zhang, W. (2024): Green patent activity and renewable energy consumption: Implications for sustainable development in China. – Energy Economics 123: 106473.

[3] Agbo, F., Hassan, S., Mensah, I. (2023): Green Industrial Policy and Economic Growth in Emerging Markets. – Journal of Environmental Policy and Planning 25(2): 112-130.

[4] Amin, A., Isik, C., Osabohien, R. (2025): Decarbonizing the US economy: The roles of renewable energy, technology innovation, human capital, and green growth. – Clean Technologies and Environmental Policy, 1–21. https://doi.org/10.1007/s10098-025-03283-w

[5] Chen, Y., Li, X., Zhou, Q. (2022): China's energy security and the coal paradox: Balancing low-carbon transition and stable supply. – Energy Policy 160: 112724.

[6] Chen, X., Li, T., Xu, B. (2025): Green technology, green investment, and CO_2 emissions in China: Evidence from quantile regression. – Environmental Science and Pollution Research 32(8): 9562-9576.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

[7] Cui, J., Wang, Z. (2021): Evaluating China's pilot carbon trading markets: Evidence from synthetic control methods. – Journal of Environmental Management 287: 112273.
[8] Cui, H. (2025): AI-Driven Digital Transformation and Firm Performance in Chinese Industrial Enterprises. – Technological Forecasting and Social Change 197: 122849.
[9] Degbedji, D. F., Akpa, A. F., Chabossou, A. F., Osabohien, R. (2024): Institutional quality and green economic growth in West African Economic and Monetary Union. – Innovation and Green Development 3(1): 100108. https://doi.org/10.1016/j.igd.2023.100108
[10] Dou, Z., Ye, Z., Zhang, C., Liu, H. (2025): Development and process simulation of a biomass driven SOFC-based electricity and ammonia production plant using green hydrogen; AI-based machine learning-assisted tri-objective optimization. – International Journal of Hydrogen Energy 133: 440-457. https://doi.org/10.1016/j.ijhydene.2025.04.497.
[11] Du, Z. H., Osabohien, R., Ariyibi, M. E., Onyesom, M. (2025): Energy Intensity, Digital Infrastructure and Sustainable Development in The OECD. – Applied Ecology & Environmental Research 23(4): http://dx.doi.org/10.15666/aeer/2304_74577483
[12] Fang, Y., Cheng, Y., Yao, J. (2019): What drives innovation in fossil and renewable energy technologies? Evidence from China. – Technological Forecasting and Social Change 141: 102-114.
[13] Fang, Y., Liu, J., Zhang, Z. (2023): Smart grids, digitalization, and environmental performance in China: Empirical insights. – Energy Reports 9: 2876-2887.
[14] Guo, L., Osabohien, R., Akpa, A. F. A., Al-Faryan, M. A. S. (2025): Economic growth and sustainable development in Asia: The role of political institutions and natural resources. – Problemy Ekorozwoju 20(1): 288–309. https://doi.org/10.35784/preko.6620
[15] Huang, L., Zhou, J., Wei, C. (2021): Green development in Beijing–Tianjin–Hebei: Technology, coordination, and urban sustainability. – Sustainable Cities and Society 74: 103183.
[16] Huang, L., Zhou, J., Wei, C. (2021): Regional green development and policy coordination in China: Lessons from the Beijing-Tianjin-Hebei cluster. – Sustainable Cities and Society 74: 103183.
[17] Huang, Z., Shi, Y., Liang, D. (2025): Risk Identification and Prioritization in China's New Energy Vehicle Supply Chain: An Integrated Tanimoto Similarity and Fuzzy-DEMATEL Approach. – IEEE Transactions on Engineering Management 72: 1434-1439. doi: 10.1109/TEM.2025.3556944.
[18] Imandojemu, K., Osabohien, R., Sule, A., Al-Faryan, M. A. S. (2025): Quantile analysis of the role of renewable energy technology on carbon neutrality in OECD countries. – International Journal of Energy Sector Management. https://doi.org/10.1108/IJESM-10-2024-0046
[19] Iqbal, W., Tang, Y. M., Chau, K. Y., Irfan, M., Mohsin, M. (2021): Nexus between Air Pollution and NCOV-2019 in China: Application of Negative Binomial Regression Analysis. – Process Safety and Environmental Protection 150: 557-565.
[20] Jiang, W., Li, M. (2023): Circular economy practices and industrial symbiosis in Chinese manufacturing. – Journal of Cleaner Production 405: 136892.
[21] Jiang, S., Yuan, X. (2025): Does green credit promote real economic development? Dual empirical evidence of scale and efficiency. – PloS One 20(8): e0326961. https://doi.org/10.1371/journal.pone.0326961.
[22] Jin, Y., Liu, Z., Zhang, Y. (2021): Renewable energy and green innovation impacts on CO_2 emissions: A Bayesian panel VAR analysis. – Renewable Energy 176: 152-165.
[23] Li, B., He, Z. (2024): Environmental accountability in China's overseas green investment under the Belt and Road Initiative. – Environmental Development 47: 100742.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

[24] Li, Y., Zhang, X., Xu, R. (2025): Income, energy equity, and green technology: A multi-method econometric assessment of sustainability. – Journal of Cleaner Production 420: 139854.
[25] Lin, B., Zhou, Y. (2021): Determinants of green economic growth in China: A comprehensive index analysis. – Ecological Indicators 129: 107870.
[26] Liu, X., Zhang, Y., Ren, Y. (2024): China's renewable energy growth: Trends, policies, and global implications. – Renewable and Sustainable Energy Reviews 172: 113080.
[27] Liu, H., Tang, L., Dou, Z., Wang, S., Yu, D. (2025): Optimizing integrated hydrogen liquefaction with LNG cold energy: A thermoeconomic assessment, comparative analysis, and feasibility study with emphasis on composite curves and uncertainty scrutiny. – Energy 315: 134416. doi: https://doi.org/10.1016/j.energy.2025.134416.
[28] Luan, Y., Tang, D., Aderemi, T., Osabohien, R. (2025): Clean energy adoption, industrialization and sustainable development: A system GMM approach. – Energy Strategy Reviews 59: 101740. https://doi.org/10.1016/j.esr.2025.101740
[29] Luo, J., Ye, H. (2023): The overcapacity challenge in China's solar PV sector: Causes and policy implications. – Energy Economics 117: 106434.
[30] Ma, K., Yu, Y., Yang, B., Yang, J. (2019): Demand-Side Energy Management Considering Price Oscillations for Residential Building Heating and Ventilation Systems. – IEEE Transactions on Industrial Informatics 15(8): 4742-4752. doi: 10.1109/TII.2019.2901306.
[31] Ma, X., Lin, B. (2022): Technological innovation and carbon emissions: Evidence from 264 Chinese cities. – Journal of Environmental Management 307: 114511.
[32] Meng, Q., Zu, G., Ge, L., Li, S., Xu, L., Wang, R., Jin, S. (2022): Dispatching Strategy for Low-Carbon Flexible Operation of Park-Level Integrated Energy System. – Applied Sciences 12(23): 12309. doi: 10.3390/app122312309.
[33] Mol, A. P. J., Spaargaren, G. (2000): Ecological modernization theory in debate: A review. – Environmental Politics 9(1): 17-49. https://doi.org/10.1080/09644010008414511.
[34] Mohamed, E. F., Abdullah, A., Jaaffar, A. H., Osabohien, R. (2024): Reinvestigating the EKC hypothesis: Does renewable energy in power generation reduce carbon emissions and ecological footprint? – Energy Strategy Reviews 53: 101387. https://doi.org/10.1016/j.esr.2024.101387
[35] Music, J., Wu, H., Adebayo, T. S. (2023): Green innovation and growth in BRICS+: Evidence from threshold regression. – Energy & Environment 34(1): 3-21.
[36] Nasir, M. H., Wen, J., Nassani, A. A., Haffar, M., Igharo, A. E., Musibau, H. O., Waqas, M. (2022): Energy Security and Energy Poverty in Emerging Economies: A Step Towards Sustainable Energy Efficiency. – Frontiers in Energy Research 10: 834614.
[37] Nwachukwu, U., Onifade, S., Omisakin, O. (2022): Synergies in Green Finance and Industrialization. – Energy Policy 159: 112640.
[38] Osabohien, R., Aderemi, T. A., Jaaffar, A. H., Oloke, E., Bassey, R., Yusoff, N. Y. M., Ifekwem, N. E. (2024): Electricity Consumption and Food Production in Malaysia: Implication for the Sustainable Development Goal 2. – International Journal of Energy Economics and Policy 14(3): 119-126.
[39] Osabohien, R., Jaaffar, A. H., Kimpah, J., Al-Faryan, M. A. S. (2025): Business density, financial development and carbon footprints: Examining the energy-sustainability trade-off in East Asia and the Pacific. – International Journal of Energy Economics and Policy 15(5): 464. https://doi.org/10.32479/ijeep.19095
[40] Osabohien, R., Zogbassé, S., Jaaffar, A. H., Idowu, O. O., Al-Faryan, M. A. S. (2024): Renewable energy, carbon footprints, natural resources depletion and economic growth in Africa. – International Journal of Energy Sector Management. https://doi.org/10.1108/IJESM-07-2024-0030
[41] Osabohien, R., Karakara, A., Ashraf, J., Al-Faryan, M. A. S. (2023): Green environment–social protection interaction and food security in Africa. –

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232

Environmental Management 71(4): 835–846. https://doi.org/10.1007/s00267-022-01737-1
[42] Pesaran, M. H., Shin, Y., Smith, R. J. (2001): Bounds testing approaches to the analysis of level relationships. – Journal of Applied Econometrics 16(3): 289-326. https://doi.org/10.1002/jae.616.
[43] Qiu, Z., Khan, I., Danish. (2025): Nuclear energy and the circular economy in China: DYNARDL approach. – Energy Reports 11: 222-234.
[44] Shahbaz, M., Song, M., Jiang, H. (2022): Financial inclusion and environmental quality: Evidence from Chinese provinces. – Resources Policy 77: 102660.
[45] Sun, T., Wang, R. (2022): Administrative fragmentation and renewable energy development in China: Institutional constraints and reforms. – Energy Research & Social Science 90: 102525.
[46] Tian, H. (2023): Government environmental attention and CO_2 emissions in China: The moderating role of informatization. – Environmental Impact Assessment Review 97: 106905.
[47] Wang, H., Zhou, H., Xu, T. (2023): Solar revolution in China: Industrial dynamics and global spillovers. – Nature Energy 8(1): 15-22.
[48] Wang, Y., Akpa, F., Matthew, O., Ashraf, J., Ogunbiyi, T., Osabohien, R. (2024): Maximizing environmental sustainability: Strategies for reducing carbon emissions and postharvest losses. – Applied Ecology & Environmental Research 22(5): 4913–4930. http://dx.doi.org/10.15666/aeer/2205_49134930
[49] Wang, H., Zhang, J., Lin, T. (2025): Environmental regulation and green technology adoption in China's manufacturing sector. – Journal of Environmental Economics and Management 115: 102748.
[50] Xu, A., Dai, Y., Hu, Z., Qiu, K. (2023): Can green finance policy promote inclusive green growth? Evidence from China's green finance reform zones. – International Review of Economics & Finance 100: 104090.
[51] Xu, A., Dai, Y., Hu, Z., Qiu, K. (2024): Sentiment and green growth in China: A grey prediction model analysis. – PLoS One 19(7): e0294523.
[52] Zhang, L., Lu, Y. (2022): The impact of green bonds on carbon emissions: Evidence from Chinese cities. – Energy Economics 107: 105839.
[53] Zhang, Y., Ding, Y., Yan, W. (2025): United in green: Institutional dual ownership and corporate green innovation. – Finance Research Letters 84: 107814. doi: https://doi.org/10.1016/j.frl.2025.107814.
[54] Zhao, Y., Chen, L. (2022): High-voltage grids and renewable energy integration in China: A systems approach. – Applied Energy 307: 118224.
[55] Zhao, R., Mahendru, M., Lin, B. (2022): Environmental regulation, green growth, and spatial dynamics in China. – Energy Policy 168: 113099.
[56] Zheng, S., Kahn, M. E., Liu, H. (2022): The rise of China's environmental Kuznets curve: Drivers and policy implications. – Ecological Economics 197: 107401.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2306_1121311232