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-RESEARCH ARTICLE-

ASSESSING THE LOW-CARBON ECONOMY AND ITS IMPACT ON THE ENERGY CONSUMPTION: THE CASE OF CHINA

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—Abstract—

China has declared its commitment to achieving peak carbon emissions by 2030, consistent with its broader objective of advancing towards a greener and more sustainable economic framework. A key element of this transition is the transformation of national energy consumption patterns. Drawing on data from 30 provinces between 2005 and 2020, this study constructs a comprehensive indicator to assess progress in low-carbon development. The analysis investigates the extent to which improvements in low-carbon practices affect energy utilisation, while distinguishing these effects from those linked to economic growth. Results demonstrate that enhanced low-carbon performance substantially reduces energy consumption across different measurement approaches. Additional robustness checks, conducted using a component index framework, support these findings. Notably, significant regional disparities emerge, with the western provinces exhibiting the most pronounced decline in energy demand. These variations suggest that low-carbon strategies are not uniformly effective across all regions and that regional characteristics influence outcomes. The study provides valuable insights into how tailored low-carbon measures can strengthen energy efficiency and contribute to national climate objectives. Such evidence equips policy-

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makers to design region-specific strategies that accelerate the shift towards a low-carbon economy while promoting balanced provincial development.

Keywords: Low-Carbon Economy, Energy Consumption, China.

INTRODUCTION

The large-scale combustion of fossil fuels has driven a sharp rise in greenhouse gas concentrations, particularly carbon dioxide, and is recognised as the principal cause of anthropogenic climate change since the nineteenth century (Kohse-Höinghaus, 2023) Consequently, reducing carbon dioxide emissions and advancing towards a low-carbon economy have become central priorities within global climate policy and the broader sustainable development agenda (Dale, 2021) As the largest emitter of CO_2, accounting for about 31 percent of global emissions in 2020 (Shi et al., 2022), China plays a pivotal role in international decarbonisation efforts. Fossil fuels remain the source of nearly 80 percent of the country's primary energy consumption and therefore represent the main contributor to carbon dioxide emissions.

China's 14th Five-Year Plan (2021–2025), launched in March 2021, affirms a clear commitment to accelerating the transition towards a low-carbon economy by reducing carbon intensity and ensuring that carbon dioxide emissions peak before 2030. However, reconciling emission reductions with continued economic growth poses a considerable challenge, largely due to the nation's reliance on fossil fuel-based energy (Yan et al., 2023). Shifts in China's energy consumption patterns are expected to exert significant influence on global climate trajectories (Olabi & Abdelkareem, 2022) For this reason, formulating strategies that both accelerate the transition to a low-carbon economy and address the scale of energy demand has become a crucial task for Chinese policy-makers.

To achieve sustainable outcomes, China must integrate the relationship between low-carbon development and energy utilisation into long-term strategic planning. A notable outcome of pursuing a low-carbon economy is the increased reliance on renewable energy sources, with solar and wind energy playing an expanding role (Murshed et al., 2021) Furthermore, technological innovations such as advanced battery storage, electric mobility, and intelligent energy systems are contributing to greater efficiency and reduced overall consumption (El Bassam, 2021). Beyond technological advances, the shift also encourages behavioural changes, leading individuals to adopt energy-saving practices, invest in efficient appliances, and select electricity providers that align with sustainable objectives.

Although conceptual frameworks and theoretical benefits of a low-carbon economy have been extensively discussed, empirical research directly linking such transitions to observed changes in energy consumption remains limited. Few studies have explored

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how low-carbon development affects actual energy use, leaving important questions unresolved: To what extent has the low-carbon economy taken root across Chinese provinces? In what ways does it shape electricity consumption? Do these effects vary regionally? To address these questions, this study constructs a low-carbon economy index for 30 provinces, covering the period 2005 to 2020, and assesses its implications for energy consumption.

The study makes three primary contributions to existing knowledge on low-carbon economic development. First, it introduces a multidimensional index that evaluates progress across five dimensions: economic productivity, societal advancement, technological development, environmental stewardship, and energy system transformation. This composite index provides a more accurate and comprehensive measure of China's movement towards a low-carbon economy compared with earlier approaches. Second, it examines the correlation between energy utilisation and the adoption of low-emission economic pathways, offering a methodological framework that can support China in meeting its climate and carbon reduction goals. Third, it analyses the mechanisms through which low-carbon strategies shape energy demand and consumption. These include production efficiency across multiple levels, industrial structural reforms, and continuous technological innovation, while also highlighting the role of regional heterogeneity in shaping outcomes. The findings present practical implications for aligning evolving energy consumption patterns with long-term objectives for sustainability and environmental protection. This multidimensional approach provides a policy foundation for guiding the transition towards a cleaner, greener, and more resilient economy.

LITERATURE REVIEW

Overview of the Low-Carbon Economy

The concept of a low-carbon economy is relatively new. (Zhongyu & Zhongxiang, 2021) note that it was first introduced by Kinzig and Kammen and later formalised in the United Kingdom's 2003 Energy White Paper (DTI, 2003). This policy document defined a low-carbon economy as one that minimises the use of natural resources and environmental degradation while simultaneously maximising economic output. At a broader level, the transition to a low-carbon model signifies a global reconfiguration of production systems, cultural values, lifestyles, and national priorities. The G20 has also provided its interpretation of the term, describing it as an economy characterised by carbon efficiency and sustainable growth, which entails low energy consumption, reduced emissions, and environmentally responsible development (Nascimento et al., 2022) Central to this transition is the gradual replacement of high-emission energy sources such as coal and oil with clean energy technologies, supported by innovation and strategies that align economic progress with environmental sustainability.

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A growing body of academic research uses diverse indicators to evaluate the progress and maturity of low-carbon economic systems. For example, (Niu et al., 2022) employed a three-stage data envelopment analysis to assess low-carbon development in the twenty largest carbon-emitting countries between 2000 and 2012. Their method assessed efficiency by measuring how limited resource inputs could sustain economic growth, represented by GDP, while simultaneously lowering carbon emissions, thereby highlighting the strategic importance of pursuing a low-carbon development trajectory.

In a similar vein,Yu et al. (2022) applied the generalised Divisia index method to analyse the shift towards low-carbon practices in OECD countries from 1992 to 2018. Their study concentrated on carbon intensity, defined as the volume of carbon dioxide emitted per unit of economic output, to determine whether these economies were moving towards sustainable low-carbon growth models. Despite their contributions, such approaches may not fully capture the complexity of low-carbon economic transformation. Many provide fragmented perspectives and overlook important developmental dimensions. Developing a more comprehensive and inclusive low-carbon economy index therefore requires the integration of multiple datasets to generate a more accurate and holistic assessment of sustainability progress across different countries and regions.

Low-Carbon Economy and Energy Consumption

Although the connection between low-carbon development and energy consumption has gained increasing attention, empirical studies directly examining the effect of low-carbon economic transitions on energy demand remain limited. Recent scholarship has incorporated Energy-Economy-Environment (3E) integrative models to analyse the multi-dimensional interdependence of economic activity, environmental challenges, and energy use (Dong et al., 2023; Lv et al., 2024; Raihan & Mainul Bari, 2024). However, these traditional frameworks often neglect social factors that are critical to shaping outcomes. To address this gap, the Economy-Society-Energy-Environment (ESEE) nexus has been developed, integrating variables such as population dynamics, urbanisation, and policy heterogeneity.

According to (Shi et al., 2022), the transformation of the energy sector lies at the heart of China's broader transition towards a low-carbon economy, with repercussions extending into both economic and social subsystems. At a basic economic level, rapid growth often corresponds with higher energy consumption due to industrial expansion and infrastructure development (Shahbaz et al., 2022). Conversely, social dynamics may exert a mitigating effect. For example, high population density in eastern, central, and western regions of China has been associated with reduced per capita energy consumption, reflecting efficiency gains in densely populated areas. From an environmental perspective, stringent regulatory frameworks designed to curb pollution and emissions can suppress energy demand, highlighting the importance of

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environmental governance in shaping consumption patterns (Paramati et al., 2022). Collectively, these findings suggest that energy use under a low-carbon framework is determined by a complex interaction of economic, social, and environmental subsystems.

Within China, the pursuit of low-carbon growth is considered a strategic pathway towards sustainable development (Shi et al., 2022) The country has emerged as a focal point for research into decarbonisation and its implications for energy systems. National programmes, including the Low-Carbon City Pilot (LCP) initiative and the dual-carbon targets of peaking emissions by 2030 and achieving carbon neutrality by 2060, have attracted substantial academic interest (Li et al., 2025; Shen & Sun, 2023; Wang et al., 2023). The LCP programme, launched in 2010, demonstrated measurable impacts, with household electricity consumption declining by 10 percent and fuel expenditure dropping by 58.6 percent in pilot cities, particularly among well-educated populations, through the promotion of environmental awareness (Shen & Sun, 2023). These results align with broader patterns in which urbanisation and the expansion of the middle class increase overall energy demand, yet targeted awareness initiatives help to constrain growth (Liu & Zhang, 2023). Despite this progress, regional disparities persist: eastern provinces benefit more from clean energy adoption due to higher levels of urbanisation and research and development investment, while central and western provinces rely primarily on industrial restructuring to reduce emissions (Yang et al., 2023)

Literature Gap

Although earlier studies have explored the relationship between the low-carbon economy and energy consumption, several research gaps remain. First, there is a lack of comprehensive evaluation indicators for the digital economy, with existing approaches remaining limited and without a unified framework. Second, while the low-carbon economy is designed to reduce carbon emissions, further inquiry is required to clarify its influence on patterns of energy consumption. Third, given China's vast geographical scale, there is an insufficient body of research addressing how low-carbon economic development shapes regional disparities in energy use.

ASSESSING THE LOW-CARBON ECONOMY IN CHINA

The central variable examined in this study is the low-carbon economy index. This index is constructed by evaluating five dimensions: economic, social, technological, environmental, and energy structure. As noted by Zhongyu and Zhongxiang (2021), these dimensions collectively capture the overall competitiveness of a low-carbon economy.

Economic Development

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To understand the financial implications of transitioning to a low-carbon economy, it is essential to examine its economic dimension. Economic growth is typically determined by the scale of production and the composition of industries. Substantial variations exist across Chinese provinces in terms of overall output, which partly explains the uneven pace of transition towards a low-carbon model. These disparities are largely shaped by differences in industrial structure, a trend already highlighted in prior research (Liu et al., 2020). From an economic perspective, assessing these dynamics provides insights into the long-term feasibility and sustainability of low-carbon initiatives. This study compiles a set of economic indicators central to evaluating low-carbon progress. These include measures of Gross Domestic Product (GDP), such as GDP per capita and annual GDP growth, as well as information on industrial composition, which determines the speed and ease of the transition process.

The indicators further reflect the economic contributions of various sectors, including construction and services, alongside trade performance measured through the balance of imports and exports of goods and services. Inflows of foreign direct investment are also incorporated. Collectively, these measures offer a comprehensive understanding of economic dynamics under low-carbon development and provide guidance for designing region-specific strategies.

Social Development

From the perspective of social development, public participation and societal support are essential for ensuring the success of a low-carbon transition.(Chilvers et al., 2021) examined public perceptions of sustainability transformations, highlighting the significance of social dimensions such as demographic change and quality of life. Incorporating these considerations ensures that the transition is inclusive and responsive to the needs of diverse communities. In line with this approach, the present study employs urban population, population density, and population growth as indicators of demographic progress within the index. To capture living standards, the analysis further integrates measures such as the Gini coefficient, the consumer price index, and the unemployment rate.

Technical Development

Endogenous growth theory suggests that technological innovation, driven by investment in research and development (R&D), enhances the efficiency of both energy production and consumption. Such advancements generate more efficient technologies that reduce by-product emissions and consequently lessen reliance on natural resources (Han et al., 2024). Continuous progress in science and technology further stimulates the development of new innovations, creating a cycle of advancement. For instance, energy-specific technologies contribute to the low-carbon transition by lowering emissions, improving resource efficiency, and reshaping value chains. These outcomes

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build upon established renewable technologies, such as wind and solar, which collectively accelerate decarbonisation across multiple sectors. In this study, R&D expenditure and the number of researchers engaged in R&D are employed to capture the level of technological capability. Additionally, scientific and technical journal publications, together with patent applications, are incorporated as indicators to evaluate scientific and technological advancement.

Environmental Development

From an environmental perspective, the primary goal of advancing a low-carbon economic framework is to mitigate adverse ecological impacts, particularly those linked to climate change. Evaluating environmental performance requires the use of specific indicators that measure both air pollution and ecological conservation practices, as these provide insights into the effectiveness of low-carbon strategies in safeguarding ecosystems and natural resources (Liu et al., 2021). In this study, a range of indicators is applied to assess environmental quality and degradation. These include annual concentrations of PM2.5, per capita carbon dioxide (CO_2) emissions, total CO_2 output, and CO_2 intensity. Among these, PM2.5 levels provide a direct measure of air quality, while the carbon-related metrics serve as indirect yet significant markers of environmental stress. Collectively, these indicators demonstrate the extent to which low-carbon initiatives influence environmental conditions.

The selected carbon metrics, encompassing per capita emissions, aggregate CO_2 discharge, and carbon intensity, highlight both the magnitude and severity of pollution and its role in driving global warming (Xue et al., 2023). In addition to these pollution indicators, ecological conservation factors are also incorporated. The share of forested land and the degree of fertiliser application are utilised to illustrate efforts toward natural resource protection and the promotion of green development. Taken together, these measures provide a comprehensive assessment of environmental sustainability within the framework of a low-carbon economy.

Energy Structure

Achieving a low-carbon future necessitates fundamental transformations in patterns of energy production and consumption, with the electricity sector occupying a central role (Kabeyi & Olanrewaju, 2022). A clear understanding of the energy system, including the shares of renewable and fossil fuels, is essential for reducing fossil fuel dependence and building sustainable supply chains. Key indicators include per capita energy use, energy productivity, and the fossil fuel share in the energy mix, alongside the distribution of electricity generation by coal, oil, and natural gas..

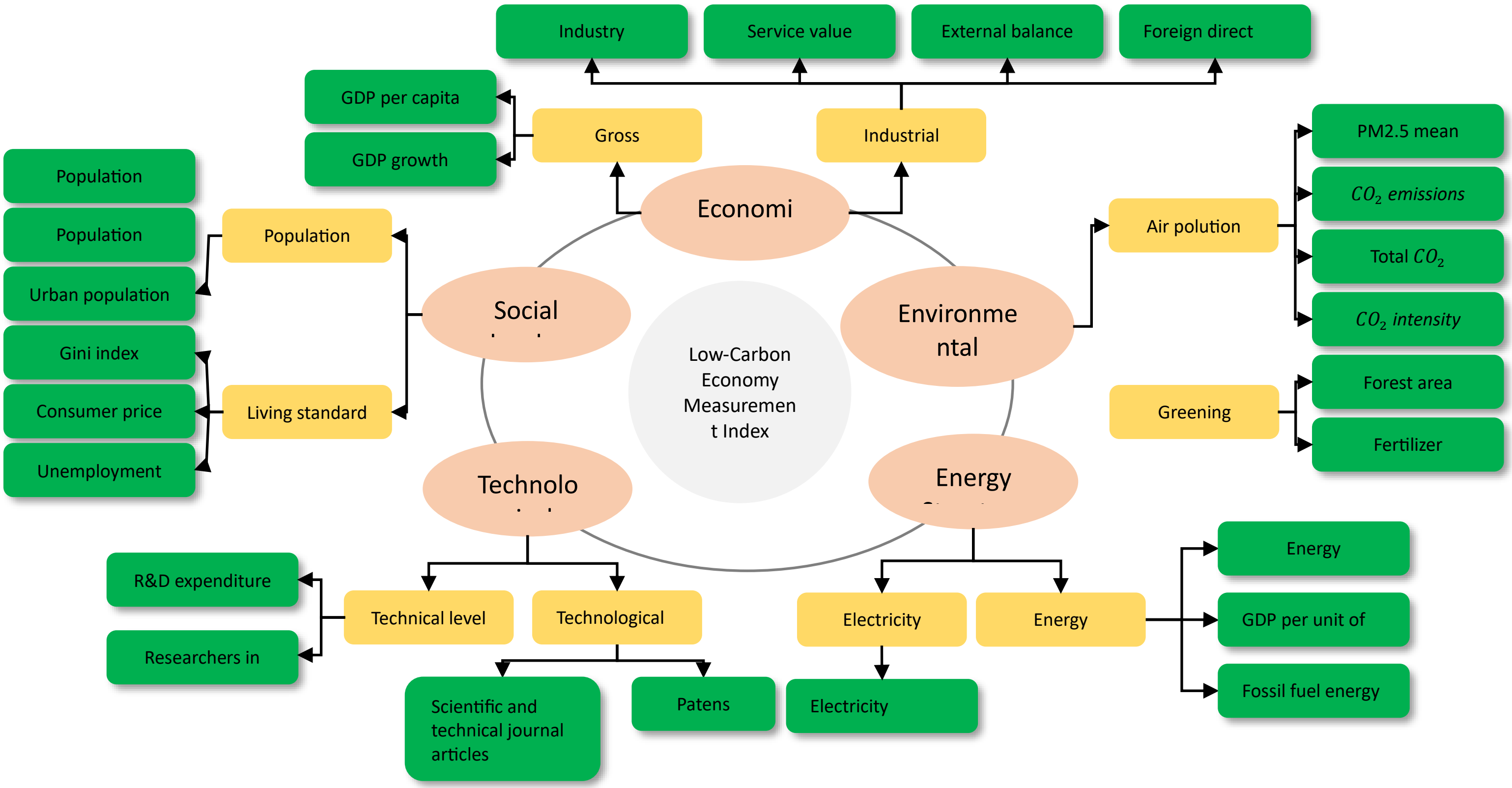

Figure 1: The Framework of the Low-Carbon Measurement Index
Source: Compiled by the Author
Note: The blue boxes represent secondary indicators, and the green boxes represent tertiary indicators.3.2. The Calculation Method: The Entropy Weight Method

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Monitoring these metrics helps assess energy efficiency, track carbon intensity, and guide policy for low-carbon development. The structure of the low-carbon economy measurement index is shown in Figure 1

This study applies the entropy weight method to provide an objective evaluation of the low-carbon economy index constructed from the 26 indicators discussed earlier. Given the variation in measurement units across the indicators, a standardisation process is undertaken to ensure comparability and to accurately determine the relative weight assigned to each indicator (Kabeyi & Olanrewaju, 2022). The data model used in this analysis is expressed as follows:

$$x'_{ijk} = \begin{cases} \dfrac{x_{ijk} - x_{min\,k}}{x_{max\,k} - x_{min\,k}}, as\ x\ is\ a\ positive\ value\ of\ an\ indicator \\ \dfrac{x_{min\,k} - x_{ijk}}{x_{min\,k} - x_{max\,k}}, as\ x\ is\ a\ negative\ value\ of\ an\ indicator \end{cases} \tag{1}$$

Where $x_{min\,k}$ and $x_{max\,k}$ denote the lowest and highest values of the kth indicator in i provinces and cities in j years, respectively. After standardizing each indicator, x'_{ijk} in equation (1), the value is a number between 0 and 1, indicating the relative size of the indicator. Accordingly, the proportion of indicator k for province i, relative to the aggregate value of indicator k across all provinces, is defined as:

$$y_{ijk} = \frac{x'_{ijk}}{\sum_i \sum_j x'_{ijk}} \tag{2}$$

Thereafter, the entropy measure corresponding to indicator k is computed according to the following expression:

$$S_k = -\frac{1}{\theta} \sum_i \sum_j y_{ijk}\, ln\left(y_{ijk}\right), \theta > 0\ and\ \theta = ln(ij) \tag{3}$$

Based on the entropy value, the information redundancy of indicator *k* can be computed as follows: $g_k = 1 - S_k$. Consequently, the weight assigned to indicator k is estimated using the following formulation:

$$w_k = \frac{g_k}{\sum_k g_k} \tag{4}$$

Furthermore, the composite low-carbon economy index is formulated as:

$$h_{ij} = \sum_k w_k\, x'_{ijk} \tag{5}$$

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Characteristics of the Low-Carbon Economy Measurement Index

Figure 2 illustrates the provincial disparities in the low-carbon economy index across China. Over the examined period, Guangdong and Beijing consistently occupied the leading positions, with index values of 0.659 and 0.619 respectively in 2020, underscoring their pivotal roles in advancing low-carbon development. Notably, Guangdong surpassed Beijing that year to secure the highest ranking, a position attributable to its status as the province with both the largest GDP and the most rapid industrial expansion, which has placed it at the forefront of national efforts to peak carbon emissions by 2030 and achieve carbon neutrality by 2060 (Wu et al., 2023)

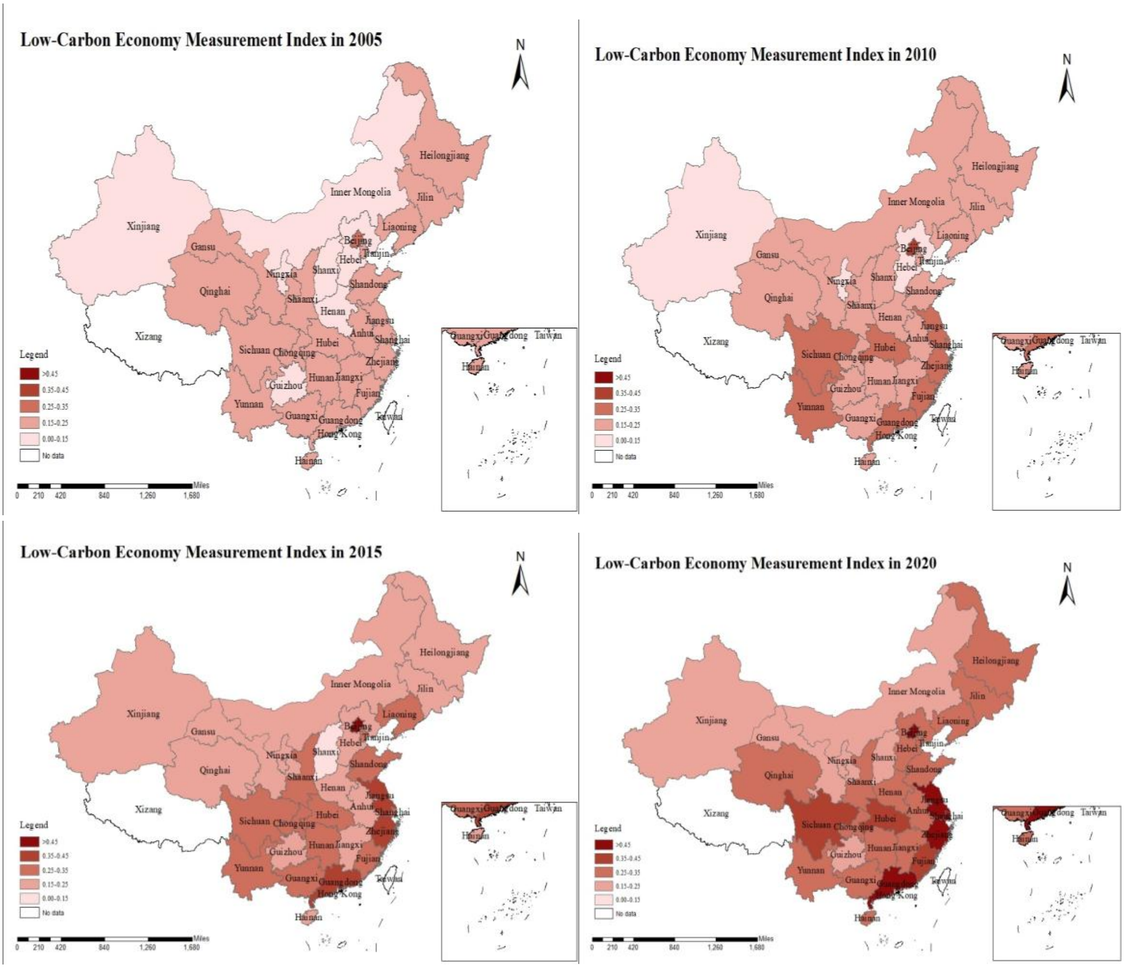

Figure 2: The Low-Carbon Economy Level of China's 30 Provinces in Selected Years
Source: Compiled by the Author

A distinct spatial pattern is evident, with eastern coastal provinces achieving higher index scores, whereas central and western regions exhibit relatively weaker performance. This distribution mirrors China's broader economic geography, where

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variations in energy intensity and industrial composition have reinforced regional imbalances in the trajectory of low-carbon economic development (Liu et al., 2020). While the central provinces have made modest advances, progress in the wtern region has been hindered by entrenched high-energy dependence and lagging industrial structures. Nonetheless, the west holds significant potential to capitalise on its rich renewable energy resources and to accelerate the decarbonisation of traditional sectors. Although low-carbon development is not yet prioritised in this region, future trends suggest that more substantial and systematic progress is likely to emerge.

METHOD AND DATA

Baseline Model

To examine the direct influence of low-carbon economic development on energy consumption, the baseline model is formulated as follows:

$$\boldsymbol{EC_{it} = \alpha_0 + \alpha_1 LEC_{it} + \alpha_k X_{it} + u_i + \nu_i + \varepsilon_{it}} \quad (6)$$

Here, i and t denote the province and time, respectively; EC refers to energy consumption; LEC represents the level of low-carbon economy development; X is a vector of control variables; u_i and ν_i indicate province-specific and time-specific fixed effects and ε_{it} is the random error term.

Variables

This study utilises panel data from 30 Chinese provinces covering the period 2005 to 2020 to analyse the impact of low-carbon economic development on energy consumption. The provincial-level perspective provides greater insight into regional heterogeneity and the underlying dynamics shaping energy use across the country. The primary dependent variable is total energy consumption, expressed in logarithmic form (LnEC). This transformation reduces volatility, stabilises the series, and enhances the reliability of the regression results. The key explanatory variable is the low-carbon economy index (LEC), which measures the extent of low-carbon development in each province. The detailed procedure for constructing the LEC is outlined in Section 3.2. By integrating these two measures, the study identifies spatial patterns and evaluates the effectiveness of low-carbon initiatives in different regions of China.

To account for other influences on energy consumption, five control variables are included, capturing economic, social, and environmental dimensions. First, economic performance is represented by GDP per capita (measured in units of ten thousand yuan). Higher levels of income typically drive industrial expansion, greater consumption, and rising household demand for electricity, thereby linking GDP per capita with increasing energy use (Canh et al., 2021). Second, population density is incorporated as the natural logarithm of the number of residents per square kilometre. High-density urban areas

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often exhibit greater efficiency in energy use, as they benefit from shared infrastructure, public transportation systems, and modern energy-efficient buildings (Papadakis & Katsaprakakis, 2023).

Third, technological progress is proxied by R&D expenditure as a share of GDP. Since technological innovation is a critical driver of efficiency improvements, higher R&D intensity is expected to reduce energy demand (Shahbaz et al., 2022). Fourth, environmental regulation is captured by the ratio of investment in pollution control to the output of the secondary industry. This indicator reflects the extent to which environmental policies incentivise cleaner production practices and industrial upgrading (Yan et al., 2023; Yu & Wang, 2021) Finally, trade openness is measured as the logarithm of total imports and exports relative to GDP. Greater trade activity can contribute to higher energy demand through production growth, but it can also accelerate the diffusion of energy-saving technologies and practices (Chen et al., 2022) Together, these control variables provide a comprehensive framework for evaluating the diverse economic, social, and institutional factors that influence energy use in Chinese provinces.

Data

This study relies on a comprehensive and diverse range of authoritative data sources to underpin its analytical framework. The principal datasets were obtained from established annual statistical publications, including the China Energy Yearbook, China Emission Accounts and Datasets, China Environmental Statistics Yearbook, and the China Science and Technology Statistical Yearbook. Collectively, these resources provide extensive coverage of national patterns across multiple dimensions relevant to energy, environment, and technological development. Complementary data were drawn from the official platform of the National Bureau of Statistics of China (NBS), in addition to a variety of regional and provincial statistical yearbooks, thereby enhancing the depth and granularity of the dataset.

Notwithstanding the comprehensiveness of these sources, certain data limitations necessitated the exclusion of specific regions—namely Hong Kong, Macau, Taiwan, and Tibet—from the final dataset. These omissions were implemented to maintain analytical consistency and ensure the comparability of observations across provinces. Table 1 presents a summary of the main statistical indicators incorporated into the analysis, including population characteristics, levels of energy consumption, emissions data, and measures of industrial performance. All data underwent a rigorous process of validation to safeguard accuracy and reliability, ensuring alignment with the research objectives.

Table 1: The Descriptive Statistical Results

Variable	Definition	N	Mean	Std. Dev.	Min	Max

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LnEC	Natural Logarithm of Total Energy Consumption	480	4.663	0.708	2.107	6.079
LEC	Low-Carbon Index	480	0.241	0.087	0.104	0.661
GDP	Gross Domestic Product Per Capita	480	4.219	2.745	0.520	16.420
LnPD	Natural Logarithm of Population Density	480	5.439	1.276	2.017	8.275
RD	Research and Development Expenditure	480	1.580	1.108	0.181	6.473
ER	Environmental Regulation	480	0.348	0.301	0.004	2.451
LnTO	Natural Logarithm of Trade Openness	480	2.928	0.967	-0.339	5.114

RESULTS

Benchmark Regression

To evaluate the influence of low-carbon economic development on energy demand, baseline regression outcomes are presented in Table 2. Model robustness improves progressively as control variables are incorporated in successive stages. Column (1) reports results without controls, whereas columns (2) to (5) introduce variables incrementally. Across all model specifications, the coefficient of the low-carbon economy index consistently retains a negative sign, indicating a stable inverse relationship. Quantitatively, a 1% increase in the index corresponds to an approximate 0.94% decline in energy demand. This outcome suggests that China's pursuit of a low-carbon transition exerts a substantive moderating effect on energy consumption, aligning with its national objectives of carbon peaking and eventual neutrality. Notably, this transition does not impede GDP growth, thereby supporting the argument that environmental progress and economic expansion can advance in tandem (Shi et al., 2022).

The control variables provide further insight into the mechanisms shaping energy consumption. The negative coefficient on GDP per capita indicates that rising income levels are broadly associated with improved energy efficiency and a general reduction in aggregate demand. This association may be attributed to the wider integration of renewable technologies, whose growing presence in the energy structure bolsters China's progress toward its emissions peak (Zhang & Zhang, 2021). Similarly, the significant negative coefficient of population density (LnPD) (Muzayanah et al., 2022) suggests that densely populated regions achieve lower per capita energy use, likely owing to extensive reliance on public transportation and shared service infrastructure. Nevertheless, the dual dynamics of increasing affluence and rapid urban expansion pose challenges: higher levels of household income and urbanisation are typically accompanied by greater ownership of energy-intensive devices and private vehicles, both of which elevate overall energy demand (Zarco-Periñán et al., 2021)

The baseline regression findings thus provide an important perspective on the trajectory of China's energy use.

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Table 2: Results of the Low-Carbon Economy-Energy Consumption Nexus

Dependent Variable	**LnEC**	**LnEC**	**LnEC**	**LnEC**	**LnEC**	**LnEC**
	(1)	(2)	(3)	(4)	(5)	(6)
LEC	-0.691***	-0.714***	-0.955***	-0.918***	-0.942***	-0.945***
	(0.144)	(0.186)	(0.171)	(0.178)	(0.179)	(0.180)
GDP		0.002	-0.026***	-0.026***	-0.026***	-0.026***
		(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
LnPD			1.083***	1.091***	1.098***	1.102***
			(0.113)	(0.114)	(0.114)	(0.114)
RD				-0.010	-0.010	-0.011
				(0.013)	(0.013)	(0.013)
ER					0.022	0.022
					(0.021)	(0.021)
LnTO						0.006
						(0.016)
Constant	4.321***	4.323***	-1.414**	-1.455**	-1.500**	-1.537**
	(0.031)	(0.032)	(0.599)	(0.602)	(0.603)	(0.613)
Observations	480	480	480	480	480	480
Number of Province	30	30	30	30	30	30
R-Squared	0.854	0.855	0.880	0.880	0.880	0.881
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Standard Errors in Parentheses						
*** p<0.01, ** p<0.05, * p<0.1						

The economic slowdown triggered by the COVID-19 pandemic, albeit unintended, accelerated the adoption of cleaner energy sources. With the continued expansion of wind and solar capacity, the pace of overall energy demand growth is expected to decelerate. Simultaneously, the proportion of fossil fuels in the national energy mix is projected to decline. These patterns reinforce China's commitments to peak carbon emissions before 2030 and achieve carbon neutrality by 2060, while sustaining reforms across its industrial and energy sectors.

Robust Analysis

Independent Variable Test

To mitigate potential measurement errors associated with the entropy-based index employed in the baseline regression, this study conducts a robustness assessment by reconstructing the low-carbon economy index using Principal Component Analysis (PCA), hereafter referred to as LEC_pca. PCA is a statistical technique designed to reduce dimensional complexity by transforming a set of interrelated indicators into a

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smaller number of uncorrelated principal components that preserve the majority of the dataset's variance. This procedure not only simplifies interpretation but also isolates the key drivers of variation, thereby enhancing analytical clarity. The regression outcomes based on the PCA-derived index are reported in Column (1) of Table 3. The results remain consistent with the baseline model, reaffirming the stability and reliability of the original conclusions.

Alternative Dependent Variable Test

China's diverse population distribution results in significant variations in energy consumption among provinces. Per capita energy consumption is Given China's heterogeneous population distribution, considerable provincial disparities in energy consumption patterns exist. To capture these differences more comprehensively, the benchmark model is re-estimated using per capita energy consumption (ECPC) as the dependent variable. This substitution enables a more nuanced assessment of energy use that adjusts for demographic scale effects. The regression results, presented in Column (2) of Table 3, demonstrate that the signs and statistical significance of the estimated coefficients are consistent with the baseline findings.

Table 3: Results of the Robustness Check

Dependent Variable	**LnEC**	**ECPC**	**LnEC**
	(1)	(2)	(3)
LEC		-8.508***	-1.268***
		(1.020)	(0.278)
LEC_pca	-0.142***		
	(0.019)		
GDP	-0.021***	-0.066	0.110***
	(0.007)	(0.044)	(0.008)
LnPD	1.077***	2.751***	0.253***
	(0.110)	(0.648)	(0.091)
RD	-0.005	0.062	0.036*
	(0.013)	(0.074)	(0.020)
ER	0.024	0.166	-0.111***
	(0.021)	(0.120)	(0.031)
LnTO	0.016	-0.512***	-0.069***
	(0.016)	(0.093)	(0.025)
Constant	-1.687***	-9.533***	3.309***
	(0.597)	(3.474)	(0.505)
Observations	480	480	480
Number of Province	30	30	30
R-Squared	0.887	0.663	0.669
Standard Errors in Parentheses			
*** p<0.01, ** p<0.05, * p<0.1			

Alternative Estimation Method Test

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An additional robustness verification is carried out through the application of a random effects model. The estimation outcomes are reported in Column (3) of Table 3. Consistent with the baseline specification, the coefficient of the low-carbon economy index retains its negative sign and remains statistically significant at the 1% level. This reinforces the validity of the benchmark regression results and demonstrates that the observed relationship is not sensitive to model specification.

Heterogeneity Analysis

The relationship between energy consumption and the degree of low-carbon economic development demonstrates heterogeneous characteristics across regions, largely influenced by differences in economic growth, technological progress, environmental regulation, population literacy, and energy structures (Lin & Zhou, 2022). This suggests the presence of geographic heterogeneity. To capture such variability, a heterogeneity test was undertaken across 30 provinces. In line with the classification proposed by (Zhang & Zhang, 2021) the provinces were grouped into eastern, central, and western regions for analysis, with the corresponding results reported in Table 4.

Table 4: Analysis of Regional Heterogeneity

Dependent Variable	**LnEC**	**LnEC**	**LnEC**
Region	Eastern	Central	Western
	(1)	(2)	(3)
LEC	-0.092	-0.335	-2.642***
	(0.422)	(0.745)	(0.498)
GDP	-0.053**	-0.014	0.032
	(0.018)	(0.030)	(0.027)
LnPD	0.501	0.741	1.670***
	(0.552)	(1.001)	(0.472)
RD	0.011	0.103	0.021*
	(0.075)	(0.085)	(0.009)
ER	-0.025	0.219	-0.013
	(0.062)	(0.120)	(0.023)
LnTO	-0.244	-0.065	0.049**
	(0.136)	(0.079)	(0.017)
Constant	2.418	0.330	-3.101
	(3.822)	(5.521)	(2.036)
Observations	176	128	176
Number of Province	11	8	11
R-Squared	0.898	0.880	0.960
Year FE	Yes	Yes	Yes
Province FE	Yes	Yes	Yes
Robust Standard Errors in Parentheses *** p<0.01, ** p<0.05, * p<0.1			

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The empirical evidence reveals that the coefficients for low-carbon economic development are statistically insignificant in most regions, with the exception of the western provinces. The Western Growth Strategy has accelerated low-carbon development in this region while simultaneously constraining energy consumption. At the same time, the designation of Shaanxi as a hub for green innovation, coupled with increasing trade links with Belt and Road countries and rapid urbanisation, has contributed to a sharp rise in energy demand (Yang et al., 2023)

For the eastern region, the GDP coefficient is negative and statistically significant. This outcome is attributed to the region's longstanding leadership in national economic performance, particularly in major coastal cities such as Beijing and Shanghai, where greater institutional and financial support for renewable energy and low-carbon transitions is available compared with other parts of the country (Xing et al., 2023). In contrast, the central region lacks the advantages of both high economic capacity and concentrated talent characteristic of the east, as well as the extensive energy reserves found in the west. Nevertheless, ongoing policy initiatives directed towards the development of central China indicate that government support will increasingly focus on enhancing economic growth and promoting energy restructuring in the central provinces (Xue et al., 2022)

CONCLUSION AND POLICY IMPLICATIONS

To investigate the influence of the low-carbon economy on energy consumption patterns, this study constructed a comprehensive low-carbon development index for 30 Chinese provinces over the period 2005–2020. This index served as the basis for examining how low-carbon initiatives shape provincial energy use, while also enabling an assessment of variations across the eastern, central, and western regions of the country. The findings highlight several important insights. First, the index values display a consistent upward trajectory across the 15-year timeframe, indicating sustained progress towards a low-carbon economic structure. Second, the regression estimates confirm a pronounced negative relationship between the index and energy demand. Specifically, a 1% rise in the index corresponds to an approximate 0.945% reduction in energy consumption. This result remains stable under a series of robustness checks, including modifications to control variables, alternative index construction methods, and the application of different econometric models. Finally, the analysis reveals marked regional disparities. The strongest energy-saving effects of low-carbon development occur in the western provinces, whereas the eastern and central regions do not show statistically significant reductions.

POLICY IMPLICATIONS

The findings of this study provide several region-specific policy implications for advancing a low-carbon economy while effectively managing energy consumption across Chinese provinces. First, the results highlight the importance of differentiated policy design at the regional level. Policymakers should formulate context-sensitive measures that reflect the unique economic structures, industrial compositions, and energy consumption patterns of each region. For instance, western provinces demonstrate a relatively stronger responsiveness to low-carbon policies, whereas the eastern and central provinces require more targeted interventions to overcome structural constraints and accelerate progress.

Second, the evidence points to a shortage of policies dedicated to fostering green innovation and the widespread adoption of energy-efficient and low-carbon technologies. Strengthening financial support for R&D is essential. Instruments such as R&D tax incentives, subsidies for clean energy projects, and targeted funding programmes can enhance technological innovation, leading to substantial reductions in energy consumption and carbon emissions over the longer term. Third, reinforcing environmental regulations remains critical. Tighter enforcement of pollution control standards, alongside incentives for clean production, could motivate industries to adopt energy-saving practices. Complementary to regulatory approaches, greater investment in sustainable infrastructure—such as renewable energy systems, public transportation, and environmentally friendly buildings—should be prioritised by both public and private stakeholders to strengthen the foundations for long-term sustainability. Finally, enhanced international collaboration and knowledge sharing can enable lagging regions to access advanced technologies and adapt them to their specific contexts. In summary, an integrated policy mix that combines regionally tailored strategies, innovation-driven incentives, strong environmental governance, and international cooperation will be vital for conserving energy and supporting China's transition toward a resilient low-carbon economy.

STUDY LIMITATIONS

Although this study provides valuable insights into the relationship between energy consumption and low-carbon economic development across Chinese provinces, several limitations should be acknowledged. First, the analysis excludes Hong Kong, Macau, Taiwan, and Tibet due to incomplete or inconsistent data, which restricts the comprehensiveness of the findings. Second, while the low-carbon economy index constructed is comprehensive, it may overlook qualitative dimensions such as the degree of policy enforcement and the speed of technological adoption, both of which can significantly shape low-carbon transitions. Third, the dataset covers the period from 2005 to 2020, which may not fully capture the more recent and accelerated changes in regulation and technological innovation that have influenced China's energy landscape. Moreover, the assumed causal relationship between energy consumption and low-carbon development, even when controlling for key influencing factors, may be subject to endogeneity concerns. Localised environmental initiatives and informal economic activities, which are difficult to quantify, could also contribute to variations in energy use but remain unaccounted for in the model. Future research would benefit from the inclusion of more detailed and granular datasets, which could reduce these gaps and provide a more accurate understanding of the evolving dynamics between low-carbon development and energy consumption.

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