

Spatiotemporal dynamics and innovation mechanisms of green transition in the construction industry: evidence from China

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Abstract

Purpose – This study aims to address a critical gap in sustainability transitions literature by investigating the spatiotemporal evolution and, more importantly, the spatially heterogeneous driving mechanisms behind the green transition in China’s construction industry (GTCI). It moves beyond national averages to uncover how and why drivers vary across regions.

Design/methodology/approach – The authors use an integrated analytical framework to provincial panel data (2011–2021). GTCI level is assessed objectively using the criteria importance through intercriteria correlation–technique for order preference by similarity to ideal solution model. Its temporal dynamics and spatial distribution are analyzed through kernel density estimation and spatial autocorrelation (Moran’s I). The core of the methodology is the application of geographically weighted regression (GWR) to quantify the spatial non-stationarity of key determinants, including enterprise characteristics, environmental regulation and economic structure.

Findings – While the national GTCI shows improvement, regional disparities widen, forming a clear “east-high, west-low” gradient. The GWR results reveal that the effects of core drivers are not uniform but exhibit significant regional heterogeneity. For instance, the positive impact of enterprise scale and environmental regulation intensity is strongest in eastern coastal provinces and attenuates inland, while the role of ownership structure varies in direction across different geographical contexts.

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Originality/value – This study contributes a novel, spatially explicit analytical framework to transition research. By empirically mapping the geographically varying effects of drivers, the authors provide a paradigm shift from one-size-fits-all understandings to a context-sensitive mechanism analysis. The findings offer a robust scientific basis for designing spatially tailored, evidence-based policies to achieve coordinated green development in construction and other geographically vast sectors.

Keywords Green transition, Construction industry, Spatiotemporal evolution, Regional heterogeneity, Sustainability development

Paper type Research paper

1. Introduction

With the climate change, air pollution and resource scarcity continue to intensify, the global community has acknowledged the necessity of a green transition of the economy and society in achieving the Sustainable Development Goals (Change, 2021; Yao, 2020). The construction industry, characterized by high energy consumption, significant air pollution and substantial CO₂ emissions (Feng *et al.*, 2020), is widely regarded as a key sector in driving the transition toward sustainable development (Lai *et al.*, 2017). Data indicates that building operations and construction together account for approximately 40% of global energy consumption and contribute about 37% of global greenhouse gas emissions, positioning them among the top three sources of emissions worldwide. Concurrent with rapid urbanization, the scale of construction activities continues to expand, resulting in a substantial increase in energy demand and carbon emissions from the construction industry (Tengfei *et al.*, 2022). Currently, global nations have used various measures and policies to facilitate the green transition of construction industry (Feng *et al.*, 2020) ranging from mandatory legal regulations (Tan *et al.*, 2021), technological innovation, fiscal subsidies (Beaumont *et al.*, 2016), strategic policies (Gyimah *et al.*, 2025), technology promotion to green certifications (Dhaya *et al.*, 2024).

The green transition of construction industry (GTCI) is a complex system, characterized by shifts in sociotechnical systems toward more sustainable alternatives (Chang *et al.*, 2016). Shifts are required across multiple dimensions such as energy, material, technology, human resources, management, operations, representing a value-chain-wide systemic transformation. Considering the significant heterogeneity of economic development, resources endowment, industrial structure, technological foundation and climate conditions, the GTCI in various regions shows substantial heterogeneity across time and space. Related to this, GTCI is no longer regarded as a static and homogeneous issue, but rather as a dynamic and evolving, spatially heterogeneous systematic project. However, traditional cross-sectional analysis only captures static differences, limiting understanding of temporal-spatial evolution and regional disparities. Thus, conducting temporal-spatial analysis is crucial as the initial step in making differentiated policies from one size fits all to local conditions (Gan *et al.*, 2025a). Meanwhile, it is benefits for dynamically adjusting and optimizing policy instruments by assessing the effectiveness of existing policies and promptly identify emerging bottlenecks and challenges (Gan *et al.*, 2025b). More importantly, it also provides a scientific foundation for promoting regional collaborative governance by revealing the spatial spillover effect of GTCI (Guo *et al.*, 2025).

Existing research on advancing GTCI has evolved along three primary dimensions. The first dimension focuses on technological pathways, exploring specific solutions such as low-carbon buildings (Shi *et al.*, 2015), green buildings (Rachel and Gillad, 2022) and prefabricated buildings (Teng *et al.*, 2018). Recent advancements further investigate advanced nanomaterials for enhanced insulation and recycled materials to reduce resource

consumption (Humaidan *et al.*, 2025; Li *et al.*, 2023), while digital tools like building information modeling (BIM) and Internet of Things (IoT) are increasingly leveraged to optimize design accuracy, improve construction efficiency and facilitate supply chain collaboration (Humaidan *et al.*, 2025; Li *et al.*, 2023; Hossain *et al.*, 2019). The second dimension concentrates on identifying influencing factors, spanning institutional aspects such as legislative system and fiscal subsidies (Zhai *et al.*, 2022), market conditions such as market demand (Geels, 2012) and public awareness (Poortinga *et al.*, 2012) and enterprise-level characteristics such as firm capabilities (Li *et al.*, 2025) and ownership structure (Martínez, 2015). Recent studies have expanded to examine economic resilience, synergistic reduction of construction waste and carbon emissions (Wang *et al.*, 2025) and applied spatial correlation network analysis to reveal complex drivers within China's construction sector (Wang *et al.*, 2025; Wang *et al.*, 2024). The third dimension involves performance evaluation, using methods such as data envelopment analysis (DEA) and multi-level indicator systems to assess efficiency and green total factor productivity at various scales (Guo *et al.*, 2025; Liu *et al.*, 2018; Wang *et al.*, 2024). These research streams are predominantly characterized by static and spatially aggregated analytical frameworks. Consequently, the evolution laws, development trends, regional disparities and spatial characteristics of GTCI remain unexplored. As a necessary precondition for informing future actions of GTCI, analyzing the dynamic spatial and temporal evolution of GTCI is urgent and necessary.

China's construction industry, a pivotal sector, has implemented a plethora of policies to drive green transition within its domain. In recent times, detailed strategic blueprints and technical benchmarks have been introduced to advance this objective. With the transition from high-speed growth to high-quality development, the challenges surrounding GTCI in China have noticeably evolved across time and space (Gan *et al.*, 2025a). In the meantime, the Chinese government announced the "dual carbon" targets in 2020, with the goal of peaking carbon emissions by 2030 and achieving carbon neutrality by 2060. Under this context, several concerns arise: what is the current status of China's GTCI? Are the existing regional disparities in GTCI? How does GTCI evolve over time and space? What are the determinants of GTCI? To address these pressing concerns, the study formulates the following research questions (RQs) derived from the practical challenges faced by policymakers and industry stakeholders:

- RQ1. How has the overall and regional performance of GTCI in China evolved temporally from 2011 to 2021?
- RQ2. What are the spatial distribution characteristics and clustering patterns of GTCI across Chinese provinces? Does it exhibit significant spatial agglomeration or divergence?
- RQ3. What are the key determinants of GTCI, and do their effects remain constant or vary spatially across regions?

Guided by these questions, the specific objectives of this paper are:

- OB1. Quantitatively evaluate GTCI level of 30 Chinese provinces (2011–2021) using a comprehensive evaluation index system and the CRITIC-TOPSIS model.
- OB2. Delineate the dynamic evolution and spatial distribution patterns of GTCI through kernel-density estimation and spatial-autocorrelation analysis, thereby revealing regional disparities and temporal trends.

OB3. Identify the core drivers of GTCI and, using the GWR model, uncover the spatial non-stationarity of their impacts, providing a nuanced understanding of region-specific mechanisms.

Consequently, the research findings furnish a robust scientific basis for formulating evidence-based, regionally tailored and precisely targeted policies – an essential step toward steering China’s construction industry toward a green, low-carbon and sustainable future.

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature. Section 3 outlines the model specifications, methodologies and data sources. Section 4 discusses the evaluation results and other findings. Section 5 summarizes the study’s key findings, research implications and offers policy recommendations. Section 6 summarizes the research findings.

2. Literature review

The GTCI has been regarded as the core elements in achieving China’s high-quality development and the “dual carbon” targets. Recently, several studies have conducted the GTCI evaluation.

2.1 Frameworks for evaluation index system

Research on evaluating GTCI primarily follows two pathways. The first is the input-output indicator evaluation system, which captures the fundamental transformation process by measuring resource commitments against performance outcomes. Input indicators typically include assets, labor, equipment, energy consumption and CO₂ emissions, while output indicators consist of added value, profit and total output value (Zhang, 2020; Teng, 2019). The second is the multi-level indicator evaluation system, which incorporates a broader set of dimensions such as green project deliveries, policy intensity, environmental penalties and investment in pollution control (Zhang, 2020; Qidan *et al.*, 2023). Composite indices like the environmental sustainability index (Siche *et al.*, 2007), ecological footprint accounting (Wackernagel, 2014) and the genuine progress indicator (Singh *et al.*, 2011) are also used to comprehensively assess the status of GTCI.

Recent trends have expanded these frameworks. The rising emphasis on the circular economy has led to the inclusion of indicators like construction waste recycling rates and material reuse potential (Bleischwitz *et al.*, 2022). Concurrently, digitalization indicators, such as the application of BIM and IoT technologies, are increasingly recognized for their role in optimizing processes and enabling green innovation (Manasseh Moses *et al.*, 2025; Guo *et al.*, 2021). Notably, digital transformation itself is now empirically linked to enabling the green total factor productivity of the construction industry (Li *et al.*, 2023). Furthermore, broader concepts like the green resilience of the construction industry have been proposed and measured, reflecting the capacity to maintain and recover performance amidst disruptions (Bai *et al.*, 2025).

2.2 Methodological approaches for measurement and analysis

Several approaches were used in measuring the status of GTCI. The general approach involves constructing a measurement model based on the GTCI index framework. Besides, the method of DEA and related expanded models have been used to examine the efficiency of GTCI, including the EVA-DEA, Slacks Based Measure (SBM)-DEA (Liu *et al.*, 2018), Super Efficiency-DEA (Chen *et al.*, 2022), Super-SBM DEA (Zhou *et al.*, 2019), three-stage DEA (Zhang, 2020) and DEA-Malmquist (Liu *et al.*, 2018). Due to the apparent limitations of inter-temporal comparisons and slack variables, other methods were used, such as the SBM model and grey relational analysis. The SBM model, which fully accounts for the influence of slack

variables, provides advantages in evaluating the efficiency of GTCI (Wang *et al.*, 2021). It has found widespread application in areas such as green total factor productivity, carbon emission efficiency, safety efficiency (Wang and Gao, 2024), energy efficiency, green transition efficiency (Guo *et al.*, 2025) and green building transition efficiency (Li *et al.*, 2024). Grey relational analysis is often used with the Analytic Hierarchy Process method, which allows for both qualitative and quantitative analysis, provides a more objective and accurate assessment of GTCI.

Recently, methodological diversity has increased. Spatial econometric models, including spatial Durbin models and geographically weighted regression (GWR), are increasingly adopted to capture spatial spillover effects and regional heterogeneity (Guo *et al.*, 2025; Wang *et al.*, 2024; Chen and Xie, 2025). Other emerging approaches include configuration analysis fuzzy-set qualitative comparative analysis to explore causal pathways for green development (Li *et al.*, 2023), the integrated Life Cycle Assessment-Multiple Criteria Decision Making (LCA-MCDM) framework for material selection (Mlybari, 2025) and data-driven methods (Xu *et al.*, 2025). At the micro-level, confirmatory factor analysis has been applied to identify and validate key factors influencing sustainable practices (Jaber *et al.*, 2019). While these methods are powerful for identifying whether and which factors matter, they often operate under an implicit assumption of spatial stationarity, estimating average effects that may mask significant local variations.

2.3 Multi-scale assessments and influencing factors

Multi-scale green transition evaluation has been conducted. At the global perspective, Cuiyun and Chazhong (2020) evaluated the green transition level of 49 countries along the “Belt and Road”. At the national level, Liu *et al.* (2018) evaluated tourism energy consumption and carbon emissions in the Yangtze River Economic Belt. At the city level, Zeng *et al.* (2025) explored the green total factor productivity of prefecture-level cities in China. Wang *et al.* (2024) examined the urban green development efficiency in China from a spatial-temporal perspective. Juan *et al.* (2025) demonstrated the regional heterogeneity of the driving factors of urban building carbon emissions using a random forest model. Furthermore, the building and enterprise scale examines micro-level agents, with studies assessing the application of specific green technologies, the environmental performance of firms and the implementation of green building standards (Li *et al.*, 2025). Besides, several factors affecting the green transition have been identified, which can be categorized into distinct groups:

- (1) Institutional and regulatory factors. Reform and opening-up, government intervention and environmental regulation exerted a positive impact on green transition (Zhai *et al.*, 2022). Recent work also examines the complex relationship between ESG performance and substantive green innovation, noting a potential “disconnect” in the construction industry (Lan *et al.*, 2025).
- (2) Market and economic factors. Economic development, market demand, public awareness, urbanization, foreign investment and economic complexity create the external environment for transition (Salimi and Sheikhzeinoddin, 2025).
- (3) Factor supply. Human capital, R&D intensity and green credit supply the essential resources for innovation.
- (4) Enterprise-level factors. Firm size, asset structure, ownership type and managerial capabilities are critical internal determinants. Research shows ownership structure can have a significant impact (Li *et al.*, 2025) and the evolutionary mechanisms of green innovation behavior within firms are key to understanding dynamic change

2.4 Research gaps and innovations

Despite these contributions, the existing literature exhibits several limitations that this study seeks to address. First, while studies on technological pathways, influencing factors and performance evaluation are abundant, they often operate in isolation. Little effort has been made to integrate these dimensions into a coherent spatiotemporal framework capable of tracing the dynamic evolution and spatial clustering of GTCI across Chinese provinces. Moreover, most evaluations remain static, failing to reveal how transition patterns shift over time and space. Second, the methodological approaches predominant in the literature are not designed to explore potential variations in how driving factors operate across different locations. The overall efficiency scores from DEA-based studies offer a unified perspective that may not adequately reflect the geographically diverse realities of China's construction industry. This limitation restricts the practical utility of the findings for informing region-specific policy interventions. Third, while multi-scale assessments have been conducted, they seldom incorporate spatial econometric techniques that can capture interdependence and heterogeneity. This omission hinders the understanding of how GTCI levels in one province may be influenced by neighboring provinces, or why the same factor may have different impacts in different regions.

To address these gaps, this study introduces an integrated spatiotemporal analytical framework with three key innovations:

- (1) a systematic examination of the dynamic evolution and spatial clustering of GTCI using kernel density estimation (KDE) and spatial autocorrelation analysis;
- (2) the application of a GWR model to uncover spatially varying effects of determinants; and
- (3) a methodology that combines objective weighting, spatial econometrics and evolutionary analysis to overcome the methodological limitations observed in prior studies.

3. Research methods

Figure 1 illustrates the methodological workflow. Initially, the GTCI index framework was established. Subsequently, the GTCI status was assessed using the criteria importance through intercriteria correlation (CRITIC) and technique for order preference by similarity to ideal solution (TOPSIS) models. Following is the application of KDE method to investigate the spatial-temporal evolution, complemented by spatial autocorrelation analysis. Finally, factors influencing GTCI were discerned via the GWR model.

3.1 Index framework of GTCI

GTCI is conceptualized as a comprehensive system transformation process where the industry transitions from conventional practices toward sustainable development through improved resource allocation and management. This study uses an input-output perspective to construct the evaluation system, as this framework effectively captures the fundamental dynamic of the transition: how resource commitments are transformed into performance outcomes.

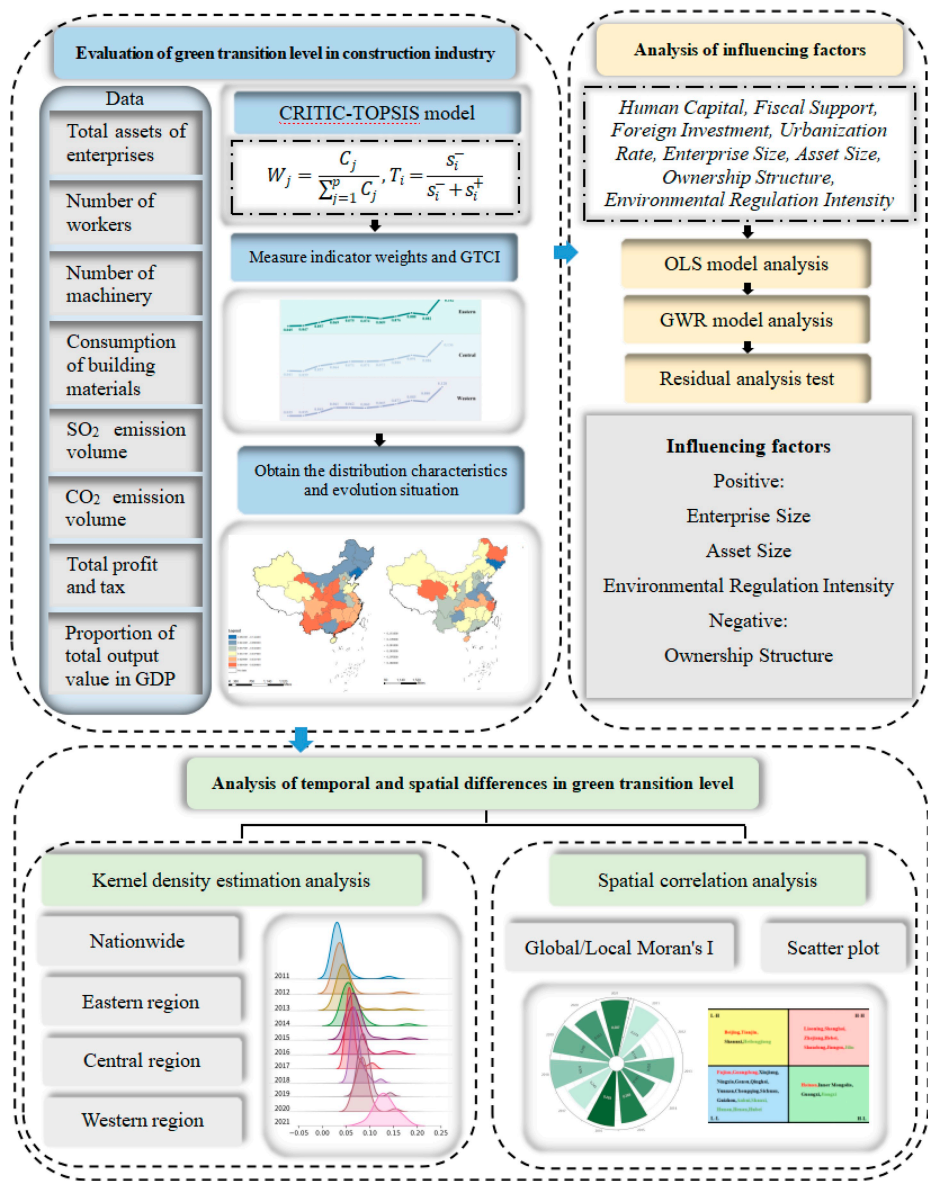


Figure 1. Research framework
 Source: Authors' own work

The input–output perspective provides a scientifically sound framework for measuring the comprehensive development level of GTCI because it directly reflects the core transformation process. Input indicators represent the resources, capabilities and efforts dedicated to advancing green transition, while output indicators manifest the

resulting performance and achievements. A higher level of green transition is intrinsically linked to the system’s ability to transform sustainable inputs into superior multi-dimensional outputs.

A mixed-methods approach was used in this study to identify key GTCI indicators. Eight indicators were selected, encompassing both input and output aspects, to ensure a comprehensive assessment of GTCI. The specific indicators are detailed in [Table 1](#).

Among the indicators, *X4* represents the consumption of five major building materials, calculated using a weighted comprehensive method based on carbon emissions ([Wen et al., 2020](#)). The calculation formula is as follows:

$$X4_i = \sum_{i=1}^5 Q_i \times \nu_i \times (1 - \sigma_i) \tag{1}$$

Q_i indicates the consumption of construction materials for i , where i represents steel, wood, cement, glass and aluminum. The unit of emission factor (ν) of Timber is $\text{kg CO}_2/\text{m}^3$ whilst the units of other emission factors are $\text{kg CO}_2/\text{kg}$. The construction material emission coefficients and recycling coefficients are based on related literature ([Zhou et al., 2024](#)) and detailed in [Table 2](#).

3.2 Criteria importance through intercriteria correlation

The CRITIC model is used to calculate the indicator weights of GTCI. Its strength lies in simultaneously considering both the variability of indicators and the correlations among them, thereby fully leveraging the objective attributes of the data for a more rigorous evaluation ([Ya-Ju and Demi, 2021](#)). Namely, the model evaluates indicators by accounting for the contrast intensity of each indicator and the degree of conflict among them. The corresponding formula is presented as follows:

Table 1. Index framework of GTCI

Primary indicator	Secondary indicator	No.	Weight	Attribute	Calculation	References
Input	Assets	X1	0.202	Positive	Total assets of construction enterprises	(Gan et al., 2025a)
	Labor force	X2	0.101	Positive	Number of construction workers	(Chuanwang et al., 2023)
	Mechanical equipment	X3	0.050	Positive	Number of construction machinery units	(Zhang, 2020)
	Materials	X4	0.090	Positive	Consumption of Five major building materials in the construction industry	(Zhou et al., 2024)
Output	Pollution emission volume	X5	0.001	Negative	SO ₂ emission volume generated by the construction industry	(Gan et al., 2025b)
	CO ₂ Emission Volume	X6	0.086	Negative	CO ₂ emission volume generated by the construction industry	(Yang et al., 2024)
	Total profit and tax	X7	0.129	Positive	Total profit and tax of the construction industry	(Yang et al., 2024)
	Transition degree	X8	0.064	Positive	Proportion of total construction industry output value in GDP of province	(Yang et al., 2019)

Source(s): Authors’ own work

Table 2. The CO₂ emission factors and recycling coefficients of main building materials

Parameter	Cement	Glass	Steel	Aluminum	Timber
Carbon emission factors (v)	0.8150	0.9655	1.789	2.600	-0.8428
Recycling coefficient (σ)	0.45	0.7	0.8	0.85	0.2

Source(s): Authors' own work

$$W_j = \frac{S_j \sum_{i=1}^p (1 - r_{ij})}{\sum_{j=1}^p [S_j \sum_{i=1}^p (1 - r_{ij})]} \quad (2)$$

S_j represents the standard deviation of the indicator j , reflecting the contrast intensity, which indicates the magnitude of the difference in values for the same indicator across different evaluation schemes. r_{ij} represents the correlation coefficient between evaluation indicators i and j , reflecting the conflict between indicators. W_j represents the objective weight.

3.3 Technique for order preference by similarity to ideal solution

TOPSIS is a classical multi-criteria decision-making method that combines conceptual clarity, computational efficiency and result interpretability. The core principle of TOPSIS is grounded in geometric intuition: the optimal alternative should minimize the Euclidean distance to the positive ideal solution while maximizing the Euclidean distance from the negative ideal. The specific formula is as follows:

$$T_i = \frac{\sqrt{\sum_{j=1}^m (c_{ij} - c_j^-)^2}}{\sqrt{\sum_{j=1}^m (c_{ij} - c_j^-)^2} + \sqrt{\sum_{j=1}^m (c_{ij} - c_j^+)^2}} \quad (3)$$

c^+ represents the positive ideal solution for the indicator and c^- represents the negative ideal solution. T_i represents the relative closeness of the sample, indicating that it is closer to the positive ideal solution.

3.4 Kernel density estimation method

The KDE method is used to analyze the spatio-temporal evolution of GTCI during the sampling period. In this study, the Gaussian kernel is selected as the kernel function, which requires only one bandwidth parameter. This function is simple, easy to implement, well-suited for continuous variables and adaptable to various density function shapes. As a non-parametric statistical method, KDE provides flexible distribution estimation. The specific formula is as follows:

$$f(v) = \sum_{i=1}^n \frac{1}{nh} K\left(\frac{v - V_i}{h}\right) \quad (4)$$

$f(v)$ represents the probability density function estimated from the sample variable v , n is the number of samples, V_i is the value of variable v at location i and K is the kernel function for KDE. h is the bandwidth, a smoothing parameter in KDE.

3.5 Spatial autocorrelation analysis

Moran's I is used to analyze the spatial correlation of GTCI. This statistic effectively quantifies spatial patterns and demonstrates robustness in handling data. As a widely

used measure, it enables the examination of both the presence and degree of spatial correlation, making it a common first step in exploring and evaluating spatial dependence in geographical phenomena (Lee and Li, 2017). It is particularly suitable for this study because GTCI is characterized by potential regional clustering, where areas with similar transition levels may be spatially concentrated. The calculation formula presented as follows:

$$Global\ Morans' I = \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\left[\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2 \right] \left(\sum_{i=1}^n \sum_{j=1}^n W_{ij} \right)} \quad (5)$$

$$Local\ Morans' I = \frac{(x_i - \bar{x}) \sum_{j=1}^n W_{ij}(x_j - \bar{x})}{\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2} \quad (6)$$

W_{ij} is the spatial weight matrix of elements i and j and n equals the total number of elements. A 0–1 matrix based on geographical proximity is used in this paper.

3.6 Geographically weighted regression model

The GWR model is used to examine the influencing factors underlying regional differences in GTCI. Its primary strength lies in its ability to capture spatial heterogeneity by allowing the regression coefficients of explanatory variables to vary across geographical locations, thereby overcoming the limitations of the traditional ordinary least squares (OLS) model (Li et al., 2017). Compared with global models such as OLS, which assume spatial stationarity, GWR provides more nuanced insights by identifying location-specific relationships between explanatory variables and GTCI, making it particularly suitable for analyzing spatial variation in green transitions. The specific formula is expressed as follows:

$$Y_i = \beta_0(\mu_i, \nu_i) + \sum_{k=1}^m \beta_k(\mu_i, \nu_i)x_{ik} + \xi_i \quad (7)$$

Y_{it} represents the value of the dependent variable at position i , X_{ik} is the value of the independent variable at position i , (μ_i, ν_i) is the coordinate of the regression analysis point i , $\beta_0(\mu_i, \nu_i)$ is the intercept term, $\beta_k(\mu_i, \nu_i)$ is the regression coefficient and ξ is the error term.

3.7 Data sources

Considering data availability and timeliness, panel data from 30 provincial-level administrative regions in China covering the period from 2010 to 2021 were used for analysis. Due to the unavailability of data, Tibet, Hong Kong, Macao and Taiwan were excluded from the study. Data on assets ($X1$), labor force ($X2$), mechanical equipment ($X3$), pollution emissions ($X5$), total profit and tax ($X7$) and transition degree ($X8$) were sourced from the *China Statistical Yearbook*; materials ($X4$) data were drawn from the *China Construction Industry Statistical Yearbook*; and CO₂ emissions volume ($X6$) data were sourced from the provincial emission inventory of the China Carbon Accounting Database.

It should be noted that the most recent complete data for several indicators were only released in 2021. Particularly the CO₂ emissions volume ($X6$), as an important indicator, is only officially available up to 2021. To ensure the systematicity, consistency and comparability of the evaluation-index system and to avoid introducing additional bias by using estimated or interpolated values, we selected the latest year for which official statistical data are available for all indicators (2021) as the study's endpoint.

4. Results

4.1 Spatial distribution of GTCI

Figure 2 illustrates the overall GTCI values from 2011 to 2021. As depicted in Figure 2a, the GTCI value exhibited a consistent rise from 0.040 in 2011 to 0.135 in 2021, indicating a notable upward trajectory and signifying remarkable advancements in China's construction industry's green transition. Notably, negative growth was observed in 2016 and 2020, yet a substantial surge occurred in 2021, with a remarkable growth rate of 64.48%. This underscores the profound influence of the policy environment and contemporary conditions on GTCI dynamics.

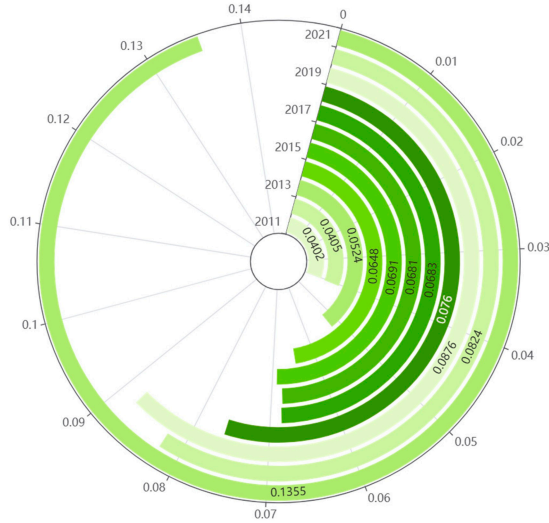
In Figure 2(b), the regional measurement outcomes unveil distinctive features in GTCI variations. Initially, a continuous upward trend is evident across all regions. The national average GTCI steadily rose from 0.045 in 2011 to 0.142 in 2021, with an average annual growth rate of 12.2%, indicating a favorable developmental trajectory. Over time, the average annual growth rate was 13.6% from 2011 to 2015, declining to 4.8% from 2016 to 2020, before surging by 56.1% in 2021. Noteworthy improvements were observed in all provinces, with Beijing ascending from 0.031 in 2011 to 0.171 in 2021, Henan progressing from 0.048 to 0.171 and Guizhou increasing from 0.029 to 0.136, reflecting a nationwide positive transition trend.

Furthermore, stage-specific development patterns are discernible. During 2011–2015, GTCI exhibited stable growth at an average annual rate of 13.6%, with provinces developing in synchrony. Subsequently, from 2016 to 2020, the growth rate decelerated to 4.8%, with certain eastern provinces reaching a plateau. However, in 2021, there was a substantial acceleration in growth, with the national average rate soaring to 56.1%. Notably, eastern provinces excelled, with Beijing witnessing a 98.8% increase, Shanghai up by 148.4%, Jiangsu progressing from 0.097 to 0.139 and Guangdong from 0.085 to 0.149, showcasing robust momentum. In the central region, Jilin advanced from 0.151 to 0.184 and Henan from 0.094 to 0.171, recording significant enhancements.

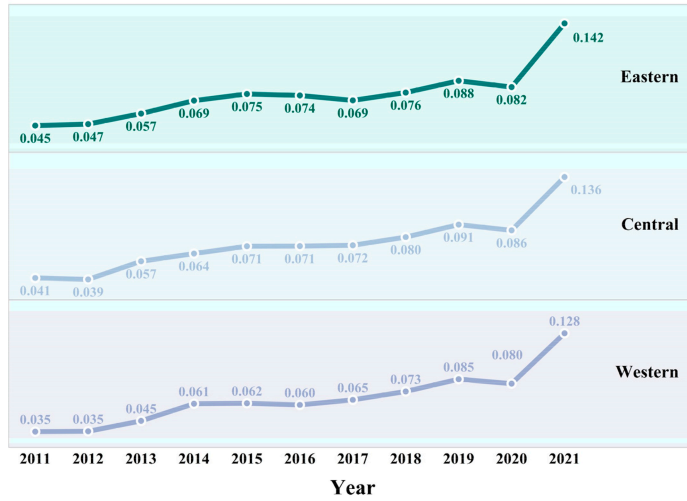
Figure 3 depicts the spatial distribution and temporal evolution of the GTCI across provinces, unveiling a discernible east-west gradient with higher values in the eastern regions and lower values in the western regions. In 2011, as illustrated in Figure 3(a), provinces with elevated GTCI levels were predominantly clustered along the eastern coast. These regions boasted a well-established green building industry chain and a mature market, enabling swift responses to policy directives and fostering the adoption of green building technologies. This conducive environment provided the foundation for the initial stages of the construction industry's green transition. In contrast, central and western regions lagged in GTCI advancements. Moving to 2015, as shown in Figure 3(b), the eastern region sustained its high GTCI levels, while notable progress was observed in the central and western regions. This improvement mirrored both national policy directives and capital injections into these regions, alongside localized endeavors to propel GTCI through initiatives supporting green building technology adoption. By 2021, depicted in Figure 3(c), the eastern region exhibited further GTCI growth, with standout performances from Beijing, Shanghai and other centrally administered municipalities. Concurrently, the central and western regions also showcased significant upward trajectories in their GTCI values.

4.2 Temporal evolution of GTCI

Figure 4 presents the results of the GTCI KDE. Figure 4(a) shows that the midpoint of the national kernel density curve consistently shifts to the right, the height of the main peak gradually decreases and the shape evolves from a tall, narrow peak to a wider, more dispersed form. This indicates that inter-provincial differences are widening, while the overall level continues to improve. Figure 4(b)–(d) reveal that the kernel density curves of



(a) Nationwide

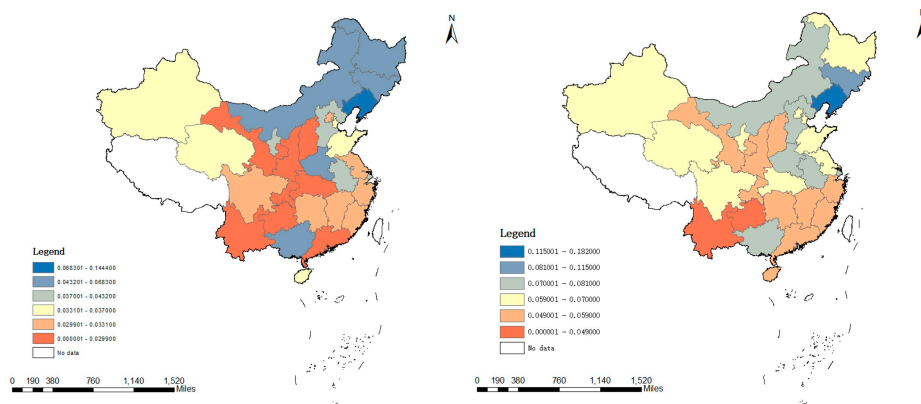


(b) Regions

Figure 2. The overall GTCI value in China

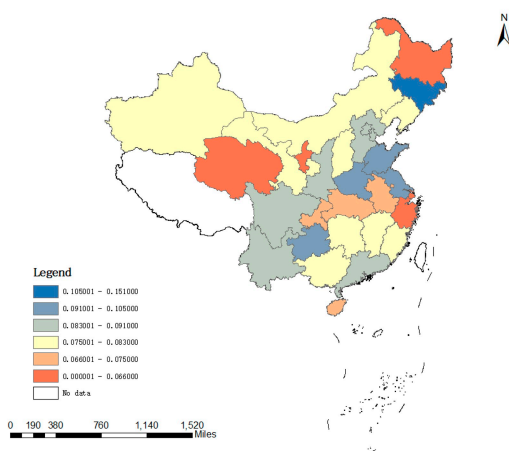
Source: Authors' own work

the three major regions follow patterns similar to the national curve, suggesting that internal coordination within each region is strengthening, although intra-provincial disparities are expanding. In the eastern region, the curve remains farthest to the right and relatively stable, confirming its leading role in the green transition. Its peak becomes flatter, while the right tail



(a) 2011

(b) 2015



(c) 2021

Figure 3. Spatial distribution of the GTCI
Source: Authors' own work

extends further with a gentler slope, reflecting that high-value provinces continue to surpass earlier thresholds. In the central region, the curve shifts markedly to the right but fluctuates upward, indicating unstable GTCI performance and a lack of sustained momentum. The overall shape changes little, but an isolated bulge appears near the main peak, producing a “main peak–island” dual structure. This suggests that some inland provinces, constrained by transportation barriers and funding shortages, have progressed more slowly (Zou *et al.*, 2017). While regional disparities in GTCI persist, some provinces show isolated leaps in performance. In the western region, the peak exhibits a gradual rightward shift,

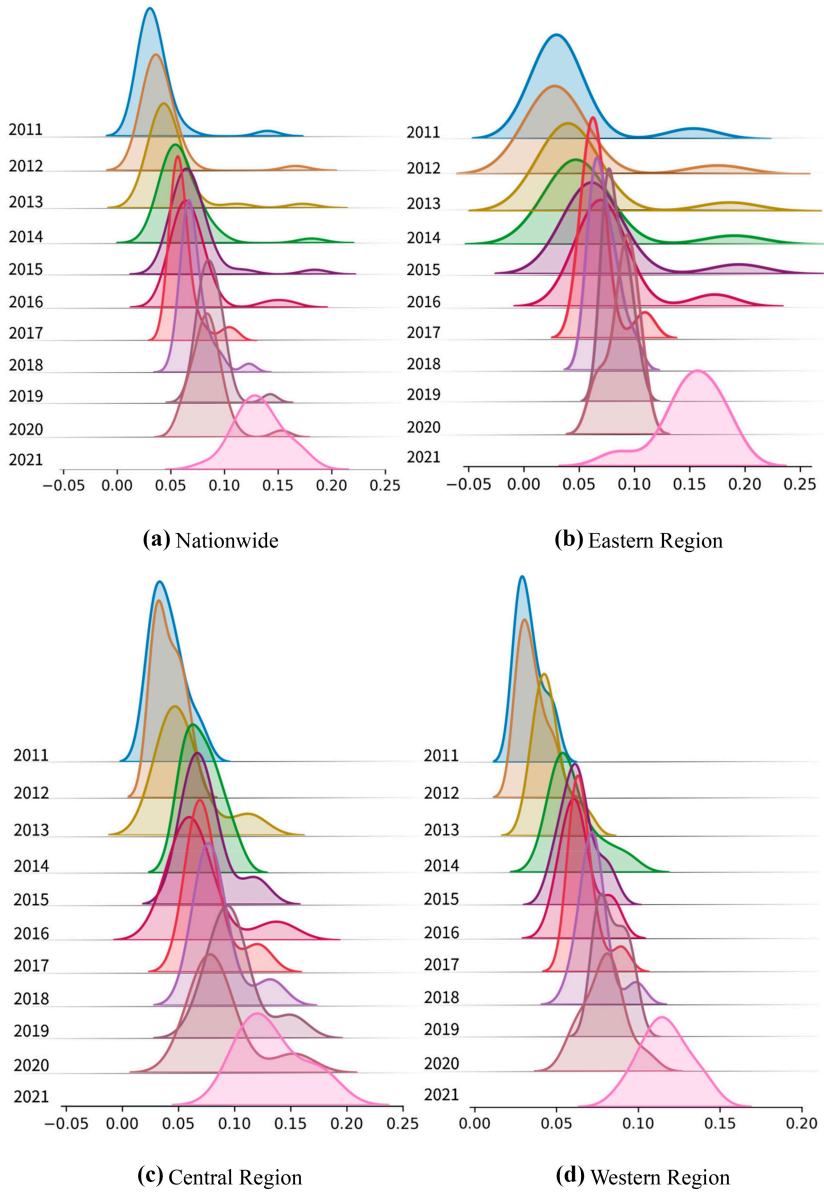


Figure 4. The results of kernel density estimation

Source: Authors' own work

demonstrating a marked upward trend in GTCI. The curves for both the eastern and western regions become progressively narrower and sharper, suggesting that, bolstered by substantial investments in the R&D and application of eco-friendly construction materials, inter-regional disparities are diminishing, and the green transition is becoming more balanced.

Finally, the thickening of the right tails in all regions indicates a rise in the number of provinces with high GTCI, reflecting the growing effectiveness of policy initiatives.

4.3 Spatial correlation analysis of GTCI

Table 3 presents the global Moran's I index. From 2011 to 2021, the index remained positive and consistently passed the significance test at the 10% level, reflecting a persistent spatial agglomeration effect of the green transition across regions. Its values ranged from a low of 0.118 in 2012, reflecting the weakest agglomeration, to a high of 0.305 in 2018, representing the strongest. The temporal trend exhibited a distinctive "W" shape. The index fluctuated upward from 2011 to 2016, peaking in 2016 and reflecting heightened spatial dependence in the green transition. From 2017 to 2018, it increased sharply, reaching its maximum of 0.305 in 2018. Between 2019 and 2021, it declined slightly but remained relatively high, suggesting persistent spatial correlation. However, because the global spatial correlation is only a general measure, further examination using local spatial correlation is required.

Figure 5 presents selected results of the local Moran's I index, where red represents the eastern region, black the central region and green the western region. Most provinces exhibit a positive spatial correlation in GTCI, concentrated primarily in the first and third quadrants, indicating persistent regional imbalances. Overall, GTCI demonstrates a typical "high–low" distribution pattern, characterized by both stability and dynamism. The eastern coastal provinces, particularly those in the Yangtze River Delta – such as Shanghai, Zhejiang and Jiangsu – have consistently remained in the H–H agglomeration area (first quadrant), forming a "high" cluster of green transition. These regions not only sustain high development levels but also continuously improve quality, exerting significant positive spillover effects on surrounding areas and fostering a virtuous cycle of coordinated development. In contrast, many provinces in the central, western and northeastern regions have remained in the L–L agglomeration area (third quadrant), creating a pronounced "lowland effect" and accentuating the east–west development gap. Western provinces such as Gansu, Qinghai and Xinjiang have long been constrained by low development levels, highlighting common challenges in advancing the green transition. Notably, this "lowland" feature exhibits clear spatial continuity, often encompassing entire regions with insufficient momentum, thereby reinforcing regional disparities.

From a dynamic perspective, many provinces have undergone substantial transitions over the past decade. Guangdong shifted from an H–H agglomeration (first quadrant) in 2011 to an L–L agglomeration (third quadrant) in 2021. Similarly, Hainan moved from H–L (fourth

Table 3. Global Moran' I result

Year	Moran' I	Z value	p-value
2011	0.273	2.8	0.005
2012	0.118	1.6	0.055
2013	0.255	2.7	0.007
2014	0.181	2.0	0.023
2015	0.268	2.8	0.005
2016	0.283	3.0	0.003
2017	0.245	2.6	0.009
2018	0.305	3.2	0.001
2019	0.292	3.1	0.002
2020	0.253	2.7	0.007
2021	0.287	3.0	0.003

Source(s): Authors' own work



(a) 2011

(b) 2015



(c) 2021

Figure 5. Local Moran's I result

Source: Authors' own work

quadrant) in 2011 to L-L (third quadrant) in 2021. Henan also transitioned from H-L (fourth quadrant) to L-L (third quadrant), while Hunan, although ultimately remaining in L-L, temporarily shifted to the L-H (second quadrant) category in 2015, reflecting a fluctuating development trajectory. Jiangxi's path was more complex, oscillating repeatedly between H-L and L-L categories, indicating instability in its green transition. Anhui's trajectory is particularly notable: in 2011, it was classified as H-H (first quadrant), but by 2021 it had declined to L-L (third quadrant), representing a significant downgrade that warrants special attention.

4.4 Factors affecting of GTCI

To identify the core drivers of China's GTCI, eight explanatory variables were selected based on established sustainability-transition literature and their relevance to China's construction sector. These variables represent four key dimensions – policy environment, market dynamics, factor endowment and enterprise capacity – and each is supported by well-recognized theoretical foundations:

- (1) Human capital: It is central to technological upgrading and knowledge diffusion. According to innovation systems theory, higher education expands the talent base required for green technologies and management innovation (Nelson and Winter, 1985).

- (2) Fiscal support: Government investment in environmental protection lowers adoption barriers for green technologies. Public policy theory posits that financial incentives shape firms' innovation decisions in resource-intensive industries (Porter and Linde, 1995).
- (3) Environmental regulation intensity: The strength of regulatory signals affects firms' compliance behavior and technological upgrading. Regulatory theory argues that stringent regulations stimulate cleaner production and transition activities (Yin *et al.*, 2022).
- (4) Urbanization rate: Urban expansion drives construction demand and accelerates the diffusion of green building standards. Urbanization theory links population concentration to increased market size and greener development pathways (Wang and Li, 2025).
- (5) Enterprise scale: Firm size influences access to resources, organizational capabilities and the ability to invest in green technologies. The resource-based view (RBV) highlights scale-related advantages in technology adoption and capability accumulation (Chan *et al.*, 2004).
- (6) Asset size: Asset-rich firms can better fund low-carbon upgrades and meet green-building requirements. Under the RBV, financial and physical assets are key enablers of sustainable innovation capacity (Ibshova *et al.*, 2024).
- (7) Ownership structure: State-owned enterprises (SOEs) are often more aligned with national policy goals. Institutional theory indicates that organizational forms embedded in government systems respond more strongly to sustainability mandates (Yu *et al.*, 2024).
- (8) Foreign investment: Foreign-funded enterprises introduce advanced engineering practices and technologies. Technology-transfer theory emphasizes the role of international investment in promoting green innovation through spillovers (Li *et al.*, 2025).

Among them, the data on fiscal support, foreign investment, ownership structure, urbanization rate, average enterprise size and enterprise asset size are sourced from the *China Statistical Yearbook*, the data on human capital is from the statistics of the Ministry of Education, and the data on environmental regulations is from the government work reports of each province.

Table 4 reports the results of the OLS model examining the influencing factors. The variance inflation factor values of all factors are less than 5, indicating that the model does not have a serious multicollinearity problem and the regression results are reliable and robust. The model demonstrates substantial explanatory capacity ($R^2 = 0.693$), suggesting that the incorporated variables collectively capture a significant portion of the regional variation. The regression results reveal significant variation in both the direction and magnitude of factor influences on the green transition of the construction industry. Enterprise scale, asset scale and environmental regulation intensity exert strong positive effects, whereas ownership structure has a constraining effect. Notably, human capital, fiscal support and foreign investment did not pass the significance test; however, this does not necessarily imply irrelevance, but rather suggests potential regional heterogeneity in their effects.

Table 5 presents the results of the GWR model. Compared with the OLS model, the GWR model demonstrates a substantially higher goodness of fit (Adj. $R^2 = 0.796$) and a much lower akaike information criterion, confirming the existence of pronounced spatial heterogeneity in the influencing factors. Analysis of the spatial distribution of regression

Table 4. OLS model results

Variable	Coef	SE	<i>t</i>	<i>p</i>	[0.025 0.975]		VIF
Human capital	0.001	0.007	0.174	0.137	2.549	0.001	2.549
Fiscal support	-0.002	0.005	-0.358	0.276	1.348	-0.002	1.348
Foreign investment	-0.001	0.005	-0.146	0.115	1.593	-0.001	1.593
Urbanization rate	0.005	0.007	0.654	0.435	2.696	0.005	2.696
Enterprise size	0.004	0.005	2.074	0.048**	1.251	0.004	1.251
Asset size	0.007	0.007	2.581	0.012**	2.835	0.007	2.835
Ownership structure	-0.001	0.005	-2.164	0.034*	1.426	-0.001	1.426
Environmental regulation intensity	0.003	0.005	2.291	0.028*	1.448	0.003	1.448
<i>R</i> -squared			0.623				0.623
Adj. <i>R</i> -squared			0.605				0.605
<i>F</i> -statistic			16.192				16.192
Prob (<i>F</i> -statistic)			0.000*				0.000*
AICc			58.401				58.401

Note(s): AICc = Akaike Information Criterion, corrected

Source(s): Authors' own work

Table 5. GWR model results

Neighbors	<i>R</i> -squared	Adj. <i>R</i> -squared	AICc
30	0.896	0.797	-106.366

Source(s): Authors' own work

coefficients indicates that the effects of these factors vary considerably across regions. Figure 6 visualizes these coefficients, categorizing them into seven levels.

Figure 6 shows that enterprise scale in China's GTCI process exhibits pronounced spatial differentiation. This pattern reflects both regional economic imbalances and the spatial limits of scale economy effects. GWR analysis indicates that the positive impact of enterprise scale on green transition attenuates gradually from east to west and from coastal to inland regions. Specifically, the distribution presents a "center-high, periphery-low" structure, with a deep red high-value cluster concentrated in the central core area and secondary high-value rings surrounding it. In contrast, enterprises in the northeast and northwest often face low resource allocation efficiency and limited technological innovation capacity, which weaken the positive effect of enterprise scale on green transition.

The regression coefficients of asset scale are concentrated in the eastern coastal regions, indicating a much stronger positive effect compared with other areas. This pattern aligns with the actual asset distribution in China, where asset-intensive regions such as the Yangtze River Delta and Pearl River Delta promote the diffusion of green building technologies through technological demonstration and talent mobility. In the central and western regions, lighter coefficient values reflect weaker effects, suggesting the attenuation of asset influence with increasing geographical distance.

Ownership structure displays a particularly distinctive spatial distribution. A dark high-value core appears in Northeast China, where coefficient values are significantly higher than those of surrounding areas, forming an independent high-value enclave. This reflects the concentration of state-owned enterprises in the northeast, whose political connections to government often strengthen their motivation and capacity to participate in GTCI. By

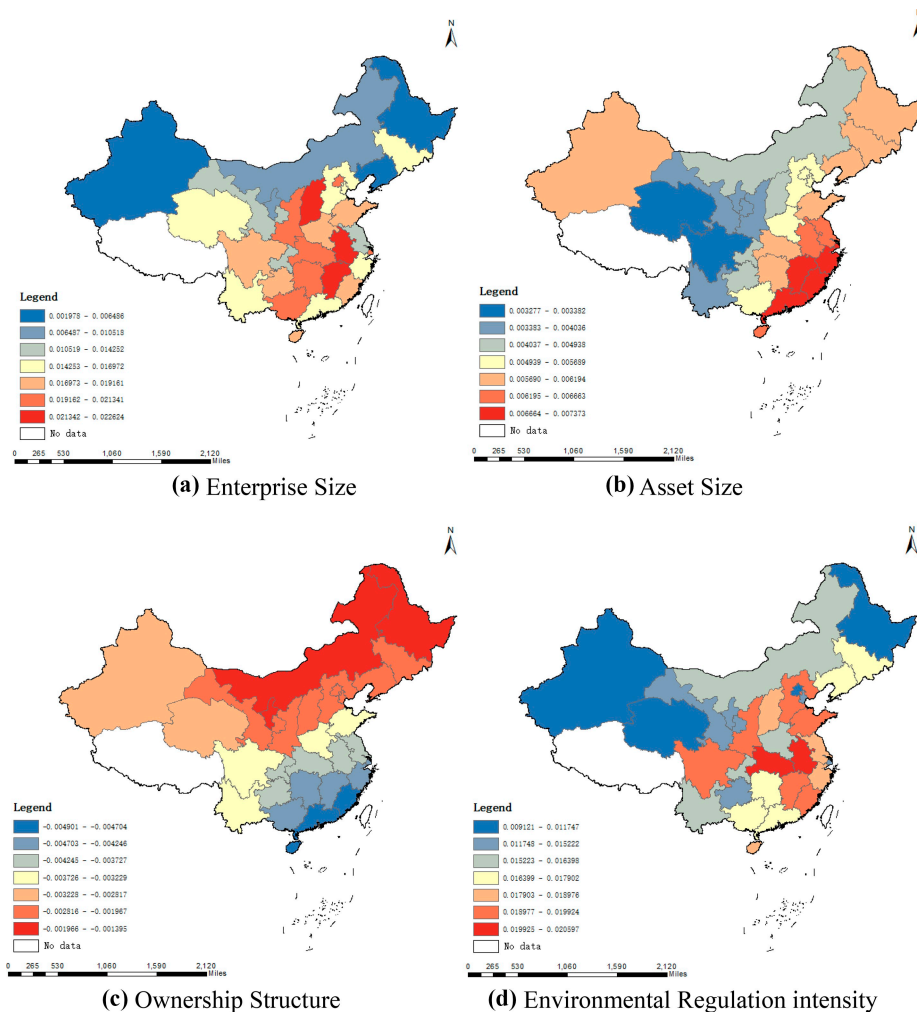


Figure 6. The results of GWR mode
Source: Authors' own work

contrast, southeastern coastal areas show lighter coefficients, reflecting a higher prevalence of private enterprises and stronger marketization.

Environmental regulation intensity is highest in the eastern and central regions, illustrating stronger policy commitment to green transition in these areas. Supported by robust economic capacity, enterprises here respond by investing in pollution-control technology, improving production processes and advancing green technologies, thereby enhancing GTCI. By contrast, the northern and western regions show weaker effects. These areas face more severe environmental challenges and current policies have limited impact, highlighting the need for stronger policy interventions to accelerate green transition.

4.5 Robust test

Residual analysis is used to assess a model’s goodness of fit by examining the residuals, the differences between observed values and the model’s predictions. This analysis checks whether the residuals follow a normal distribution and exhibit homoscedasticity.

Figure 7 shows the residual distribution, which is roughly symmetric and bell-shaped, but with a longer left tail, indicating a slight left-skew. To further test normality, a Q–Q plot (Figure 8) was constructed. Overall, the points lie close to a straight line, suggesting that the residuals are approximately normally distributed. The central points fall almost exactly on the line, whereas the points in the extreme left and right tails deviate slightly, implying that the tails are a bit heavier than those of a perfect normal distribution. Despite these minor tail deviations, the residual distribution is generally close to normal.

Figure 9 displays the residuals plotted against the fitted values. The residuals are centered around the zero line, indicating that prediction errors are small. Their distribution shows no discernible pattern or trend, and there are no obvious outliers; all residuals are confined within a narrow range. Moreover, the variance of the residuals remains roughly constant across the range of fitted values, confirming that the homoscedasticity assumption holds. The lack of a systematic relationship between residuals and fitted values further supports this conclusion.

In summary, the model demonstrates a good fit: residuals are randomly distributed around zero, exhibit constant variance and approximate normality, with only slight deviations in the tails.

5. Discussions

5.1 Summary of main findings

In the context of global sustainable development, the construction industry, characterized by its substantial energy consumption and significant carbon emissions, regards GTCI as a critical lever for attaining dual-carbon goals. GTCI embodies a systematic and multi-dimensional concept. This study moves beyond prior approaches that predominantly relied

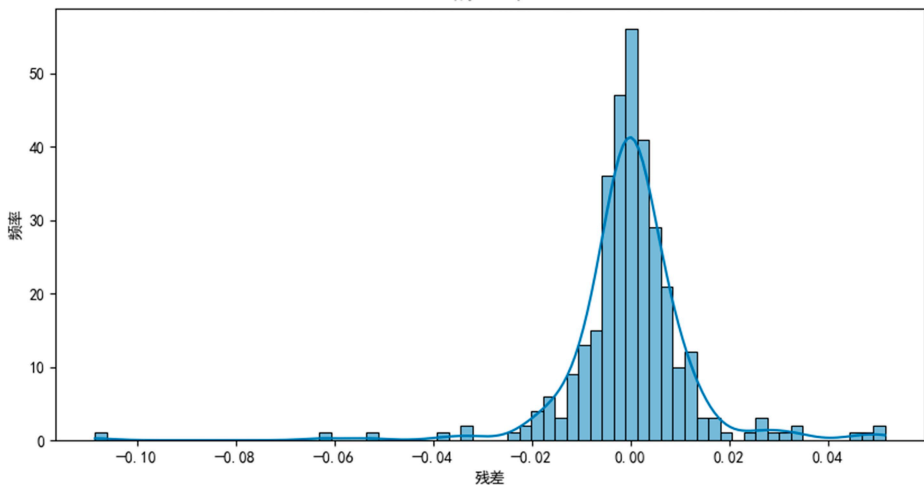


Figure 7. Residual distribution graph
Source: Authors’ own work

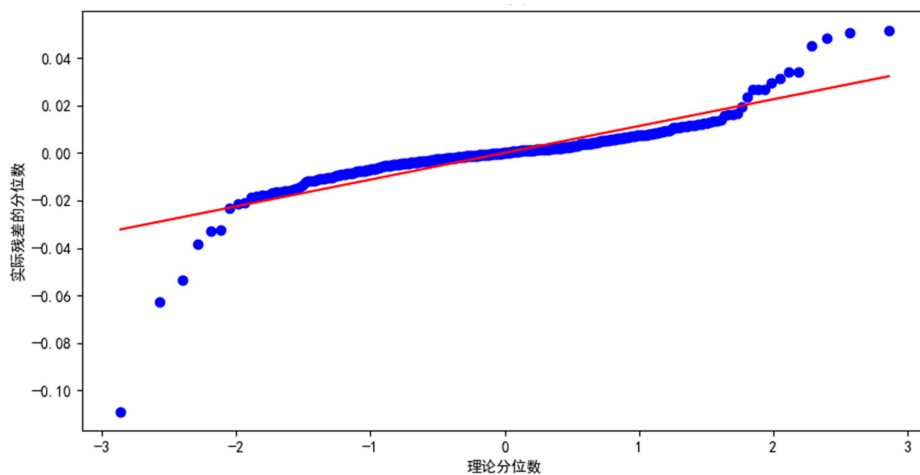


Figure 8. Q-Q plot
Source: Authors' own work

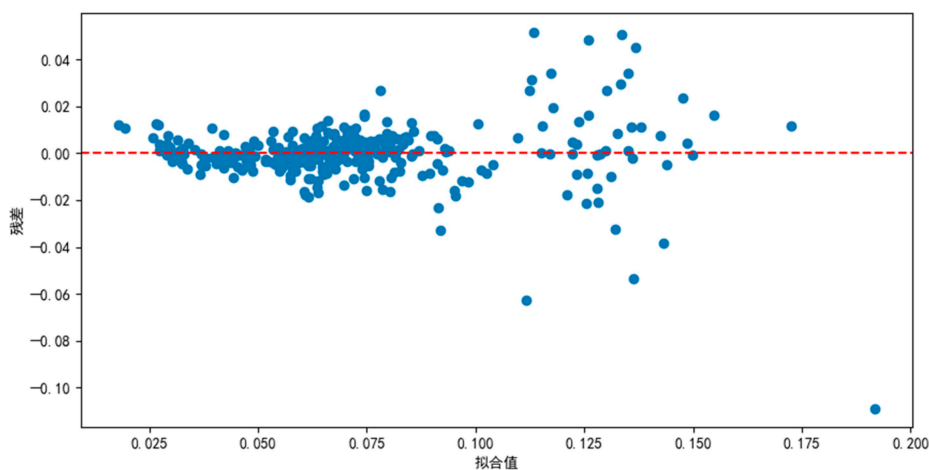


Figure 9. Scatter plot of residuals versus fitted values
Source: Authors' own work

on expert weighting or DEA models, which are known for their subjectivity, error susceptibility and inadequacy in capturing inter-provincial distinctions (Yi *et al.*, 2022; Shen *et al.*, 2010). Unlike these methods that often produce static, non-comparable efficiency scores, our integrated “input-output” framework conceptualizes GTCI as a multi-dimensional dynamic latent variable comparable across provinces and years. Furthermore, micro-governance variables are often overlooked, hampering the elucidation of differences among enterprises within the same region (Darko *et al.*, 2019; Ade *et al.*, 2021). To surmount these limitations, this study integrates a “input-output” framework into the GTCI evaluation system. This integration overcomes single-dimensional constraints in existing literature,

conceptualizing GTCI as a multi-dimensional dynamic latent variable comparable across provinces and years, thereby offering a methodological advancement for more comprehensive and comparable measurement. In addition, multiple influencing variables are integrated, and the GWR model is used to pinpoint key drivers of GTCI, delineate heterogeneous marginal effects across provinces and surpass the limitations of traditional OLS models. This study furnishes new empirical insights into unraveling the underlying causes of regional disparities. Overall, this research enriches theoretical studies on the spatial evolution of green transition capabilities and furnishes a scientific foundation for optimizing regional policy design and fostering coordinated enhancements in GTCI.

The evolution of China's GTCI follows a pattern of "continuous rise-stage differentiation-explosive leap", which aligns with the non-linear transition pathways identified in prior studies (Yao *et al.*, 2023; Jiankun *et al.*, 2021). This pattern reflects a distinct east-high, west-low gradient, primarily influenced by policy, technology and market dynamics. Policy initiatives like the Green Building Action Plan and the Policy on Renewable Energy in Buildings merged regulations with fiscal incentives, reducing technology adoption uncertainties and driving synchronized growth. Subsequent years saw reduced subsidies and upgraded standards, intensifying resource disparities and prompting stage differentiation. Post-2021, the incorporation of dual-carbon goals and the national emission trading system, alongside green finance reforms, led to a significant policy escalation, triggering a transformative leap. In technology, declining costs post-2018, especially in prefabricated construction and energy-efficient buildings, coupled with stringent standards, spurred technology spillovers and marked an economies-of-scale turning point (Costantini *et al.*, 2017). Financially, the early stages featured basic green credit and bonds, with uniform funding availability across provinces. However, over time, financial disparities deepened, with the east benefiting from advanced capital markets, while the central and western regions faced challenges due to limited industrial support and higher financing costs. This interplay of policy, technology and market dynamics not only drove a nonlinear GTCI leap but also reinforced regional disparities between the east and west.

The spatial pattern of China's GTCI unfolds as a continual enhancement accompanied by a widening inter-provincial gap. The persistent rightward shift and flattening of the kernel density curve not only signify the quantitative expansion of this gap but also herald the "disruption of the organizational learning system". This concept offers a novel insight into the underlying mechanism of divergence that moves beyond the static comparisons of provincial rankings common in prior literature. While early policy subsidies and demonstration projects temporarily elevated GTCI levels by promoting standardized technology packages, they failed to establish a sustainable system for ongoing knowledge rejuvenation. With the decline in subsidy policy intensity, leading construction enterprises in several provinces harnessed university-enterprise joint laboratories and green patent-sharing platforms to develop a four-step closed loop of intuition-explanation-integration-institutionalization. These enterprises continued progressing along the learning curve, enhancing their GTCI further. Conversely, numerous small and medium-sized enterprises, lacking access to such knowledge networks, were confined to passively replicating early technology packages. Their inability to achieve secondary learning and institutionalization led clustered observations around the mean to diverge toward both extremes, lowering the peak and widening the distribution. Thus, promoting coordinated regional development poses a substantial challenge in advancing China's GTCI.

China's provincial regions display evolving GTCI dynamics influenced by spatial stickiness, a concept we introduce to explain the stability and occasional reversals of spatial clustering, which static spatial correlation analysis alone cannot adequately capture. High-

level provinces, by setting examples and exerting peer pressure, steer neighboring regions toward a high-level trajectory, forming H–H clusters. In contrast, low-level provinces, constrained by low expectations and lacking successful local models, show reluctance to invest in green development. This, alongside technology and talent outflows, solidifies L–L disparities, reinforcing the east-west gap (Wang and Gao, 2024; Shuoran *et al.*, 2020). Transition instances highlight the reversible nature of stickiness. This provides a more nuanced understanding of path dependence and transition reversals than the relatively rigid interpretations offered by prior cross-sectional spatial analyses. Guangdong’s shift from H–H to L–L occurred as the Yangtze River Delta raised green standards through stringent measures, substantial low-carbon investments and intensive projects. This shift eroded Guangdong’s standing as a “green pioneer”, attracting negative evaluations from external stakeholders and leading to a decline. Similarly, Anhui briefly reached an H–H state via industrial transfers but lacked strong ties with the Yangtze River Delta’s core nodes, hindering the transformation of project benefits into lasting capabilities, making it vulnerable to adjacent depressions. The fluctuating cases of Hunan and Jiangxi emphasize that while external resources can temporarily boost GTCI and reduce spatial stickiness, these effects fade when external focus diminishes, causing provinces to revert to their original paths. This dynamic analysis of spatial stickiness provides a more nuanced understanding of path dependence and transition reversals than static spatial correlation analysis. Overall, the GTCI spatial pattern remains dynamic, with stable transitions achievable through institutional alignment and capability internalization during external shocks.

The operational dynamics of China’s GTCI exhibit a “strong overall effect but weak homogeneity”. This finding alone challenges the implicit assumption in most prior studies that drivers operate uniformly. More critically, our application of the GWR model reveals that this heterogeneity is not random but follows distinct spatial patterns, a finding that traditional OLS models would obscure. First, the influence of enterprise scale reveals a concentric trend characterized by “high central values and declining peripheries” driven by vertical integration and supply chain efficiencies from enterprise clustering. Vertical integration reduces transaction costs for GTCI-related technologies, as seen in the Yangtze River urban agglomeration where transportation distances are notably lower, enhancing the scale effect’s reach (Philip, 2019; Fanghu *et al.*, 2024). Conversely, despite substantial scale in the northeast and northwest, a “scale trap” ensues due to resource disparities (Gao *et al.*, 2021). Second, the positive impact of asset scale and regulatory intensity reflects a spatio-temporal coupling threshold. Asset scale peaks in the Yangtze River Delta and Pearl River Delta, declining westward, emphasizing the need for a mature green capital market to foster development. Although western provinces exhibit moderate regulatory intensity, weak green financial systems inflate compliance costs, leading to a “regulatory void” and nominal compliance (Jingbo *et al.*, 2022; Song *et al.*, 2020). These findings contradict the oversimplified conclusions from global models and underscore that the effectiveness of both market forces (scale) and government intervention (regulation) is intrinsically tied to local context. Notably, the northeast’s ownership structure shows a negative core value, highlighting the weakest inhibitory effect linked to state-owned enterprises. Recent initiatives in Liaoning and Jilin, integrating “green building proportions” in evaluations, offset institutional challenges with political incentives. Moreover, repurposing existing infrastructure in old industrial bases reduces the marginal cost of green investments, alleviating property-rights-related constraints. These findings, enabled by the GWR framework, fundamentally challenge the paradigm of uniform drivers and emphasize the intricate, location-specific interplay of “scale-governance-regulation” as a fundamental constraint shaping China’s GTCI (Hoddy *et al.*, 2025; Zhang *et al.*, 2025).

5.2 Theoretical implication

This study yields significant theoretical contributions that extend beyond the Chinese context, offering new perspectives on the spatiotemporal dynamics of sustainability transitions in the construction sector. The empirical findings challenge established paradigms and provide a theoretical foundation for analyzing green transitions in geographically diverse countries:

- Establish a dynamic trajectory framework that captures the non-linear nature of sustainability transitions. The identified pattern of “continuous rise-stage differentiation-explosive leap”, coupled with KDE evidence demonstrating simultaneous national advancement and provincial divergence, reveals the co-evolution of aggregate progress and regional disparity as an inherent characteristic of large-scale transitions. This finding offers valuable insights for understanding transition pathways in other major economies facing similar regional heterogeneity challenges.
- Advance theoretical understanding of spatial structures in sustainability transitions. Through spatial autocorrelation analysis, the study demonstrates both the persistence and dynamism of spatial clustering patterns. While stable “high-high” and “low-low” agglomerations reflect the enduring nature of regional path dependence, the observed reconfiguration of provincial positions reveals the potential for strategic intervention to alter established pathways. This empirical evidence contributes to addressing the development gaps between Global North and South regions within international sustainability frameworks.
- Challenge the theoretical premise of universal driver effects in sustainability transitions. GWR results provide evidence that the impacts of key transition drivers vary substantially across geographical contexts. This finding shows effective transition governance requires spatially differentiated approaches that account for regional specificities in economic structure, resource endowment and institutional capacity.
- Beyond China, the proposed framework also offers theoretical value for countries with similar development trajectories. The identified spatiotemporal patterns – regional divergence shaped by long-term structural factors and short-term policy accelerations – are most applicable to rapidly urbanising emerging economies such as India, Indonesia, Vietnam and Brazil, where construction sectors face comparable institutional and capacity asymmetries. These contexts share key features that allow the “policy–market–technology–institution” mechanism to function similarly. At the same time, the generalizability of our framework is conditioned by several China-specific characteristics, including strong multi-level governance, the significant presence of state-owned enterprises and highly coordinated national carbon policies. In countries with more decentralised regulation, market-driven upgrading or sizeable informal construction activity, the mechanism may operate differently, requiring adjustments in the indicators of governance capacity or industry structure. Thus, while the theoretical insights possess cross-country relevance, their application necessitates contextual calibration.

5.3 Policy implications

Based on the above findings, this study proposes a set of differentiated and targeted policy recommendations for Chinese policymakers:

- Implement differentiated fiscal and technology strategies tailored to regional roles. Eastern regions, as innovation hubs, should receive performance-based rewards for breakthrough innovations in high-end green building technologies. Central and western regions should be supported through technology diffusion policies, such as

subsidies for adopting mature prefabricated and energy-saving technologies, to lower cost barriers and accelerate catch-up.

- Establish a tiered green financing system linked to emission reduction performance. The allocation of green funds and loan interest rates should be dynamically adjusted based on verified carbon reduction outcomes. In addition, a cross-regional green transition compensation fund should be created, where developed eastern provinces support less developed western ones, specifically to subsidize financing costs for SMEs and enhance local technical capacity.
- Enforce spatially targeted environmental regulations and governance reforms. In the eastern and central regions with stronger regulatory effects, policy should focus on refining market-based mechanisms like the construction sector carbon emission trading system. In the western and northeastern regions, policy should prioritize strengthening the enforcement of mandatory standards while providing parallel technical and financial support to ensure effective compliance and avoid a “regulatory void”.
- Leverage ownership structure reforms in specific regions to unlock transition potential. Particularly in Northeast China, the evaluation system for SOE executives should integrate key performance indicators for green building proportions and carbon reduction. This can transform the inherent attributes of SOEs from a potential inhibitory factor into a proactive driver of the green transition.
- Foster cross-regional collaborative platforms to facilitate knowledge and technology spillover. The government should incentivize the formation of green development alliances between eastern and western provinces. A national digital platform for sharing green patents and management experience should be established to provide low-cost access for enterprises in underdeveloped regions, thereby breaking down technological barriers.

6. Conclusions

This study meticulously traced China’s GTCI evolutionary trajectory and regional disparities, using models like CRITIC–TOPSIS to uncover key characteristics and influencing factors driving the transition process. Findings reveal that from 2011 to 2021, China’s GTCI displayed an overall upward trajectory, notably accelerating post the introduction of the “dual carbon” policy in 2021. Despite this progress, GTCI development was marred by pronounced regional imbalances. Provincial disparities exhibited a widening trend, fueled by increasing divergence both between and within regions. Analysis confirmed significant spatial autocorrelation in GTCI, evident through distinct clustering patterns. Coastal regions, particularly the Yangtze River Delta and Pearl River Delta, formed high-high clustering zones, while the northwest and northeast regions predominantly constituted low-low clusters. This spatial distribution remained relatively stable throughout the study period, influenced by a confluence of driving mechanisms encapsulated by the “scale-governance-regulation” framework.

References

- Ade, T., Pirooznezhad, L., Ravanshadnia, M. and Tajaddini, A. (2021), “Global policies on green building construction from 1990 to 2019: a scientometric study”, *J Green Build*, Vol. 16, pp. 227-245.
- Bai, W., Wang, J. and Yu, X. (2025), “Measurement and spatiotemporal evolution of the green resilience index of the construction industry in Chinese provinces”, *Engineering, Construction and Architectural Management*, pp. 1-31.

- Beamond, M.T., Farndale, E. and HÄRTEL, C.E.J. (2016), "MNE translation of corporate talent management strategies to subsidiaries in emerging economies", *Journal of World Business*, Vol. 51 No. 4, pp. 499-510.
- Bleichwitz, R., Yang, M., Huang, B., Xu, X., Zhou, J., Mcdowall, W., Andrews, P., Liu, Z. and Yong, G. (2022), "The circular economy in China: achievements, challenges and potential implications for decarbonisation", *Resources, Conservation and Recycling*, Vol. 183, p. 106350.
- Chan, L.L.M., Shaffer, M.A. and Snape, E. (2004), "In search of sustained competitive advantage: the impact of organizational culture, competitive strategy and human resource management practices on firm performance", *The International Journal of Human Resource Management*, Vol. 15 No. 1, pp. 17-35.
- Chang, R.-D., Soebarto, V., Zhao, Z.-Y. and Zillante, G. (2016), "Facilitating the transition to sustainable construction: China's policies", *Journal of Cleaner Production*, Vol. 131, pp. 534-544.
- Change, I. (2021), *Climate Change 2021 – The Physical Science Basis*, Chemistry International, Vol. 43 No. 4, pp. 22-23.
- Chen, Z. and Xie, J. (2025), "The impact of informal environmental regulation on total-factor carbon emission performance", *Scientific Reports*, Vol. 15 No. 1, pp. 1-14.
- Chen, Z., Yuan, C., Xiaodong, L. and Mingyang, S. (2022), "Factors influencing embodied carbon emissions of China's building sector: an analysis based on extended STIRPAT modeling", *Energy and Buildings*, p. 255.
- Chuanwang, S., Xu, Z. and Zheng, H. (2023), "Green transformation of the building industry and the government policy effects: policy simulation based on the DSGE model", *Energy*, Vol. 268, p. 126721.
- Costantini, V., Crespi, F. and Palma, A. (2017), "Characterizing the policy mix and its impact on eco-innovation: a patent analysis of energy-efficient technologies", *Research Policy*, Vol. 46 No. 4, pp. 799-819.
- Cuiyun, C. and Chazhong, G. (2020), "Green development assessment for countries along the belt and road", *Journal of Environmental Management*, Vol. 263 No. C, p. 110344.
- Darko, A., Chan, A.P.C., Huo, X. and Owusu-Manu, D.-G. (2019), "A scientometric analysis and visualization of global green building research", *Building and Environment*, Vol. 149, pp. 501-511.
- Dhayal, K.S., Agrawal, S., Agrawal, R., Kumar, A. and Giri, A.K. (2024), "Green energy innovation initiatives for environmental sustainability: current state and future research directions", *Environmental Science and Pollution Research*, Vol. 31 No. 22, pp. 31752-31770.
- Fanghu, L., Yinnan, H. and Biao, W. (2024), "Analysis of logistics capacity, influencing factors and spatial spillover effect in Yangtze river economic belt", *Plos One*, Vol. 19 No. 5, p. e0303200-e.
- Feng, Q., Chen, H., Shi, X. and Wei, J. (2020), "Stakeholder games in the evolution and development of green buildings in China: Government-led perspective", *Journal of Cleaner Production*, Vol. 275, p. 122895.
- Gan, X., Xiang, S., Shuang, H. and Wen, T. (2025a), "Towards sustainable rural development: characteristics and influencing factors of spatial correlation network of China's rural digitalization development", *Sustainable Futures*, Vol. 10, p. 100901.
- Gan, X., Xiang, S., Zhan, Y., Zhang, H., Cai, C. and Shuang, H. (2025b), "Dynamic spatial-temporal evolution of the construction industry's sustainable development in China based on the coupling coordination model", *Journal of Green Building*, Vol. 20 No. 2, pp. 265-290.
- Gao, X., Wang, S., Ahmad, F., Chandio, A.A., Ahmad, M. and Xue, D. (2021), "The nexus between misallocation of land resources and green technological innovation: a novel investigation of Chinese cities", *Clean Technologies and Environmental Policy*, Vol. 23 No. 7, pp. 1-15.
- Geels, F.W. (2012), "A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies", *Journal of Transport Geography*, Vol. 24, pp. 471-482.

- Guo, K., Li, Q., Zhang, L. and Wu, X. (2021), "BIM-based green building evaluation and optimization: a case study", *Journal of Cleaner Production*, Vol. 320, pp. 1-16.
- Guo, Y., Tong Z, Wang, Z., Xu, Z. and Yao, Y. (2025), "Evolutionary characteristics and influencing mechanisms of green development efficiency in Chinese urban agglomerations: Analysis of the Yangtze river Delta urban agglomeration", *Journal of Environmental Management*, Vol. 375, p. 124236.
- Gyimah, S., Owusu-Manu, D., Edwards, D., Buerter, J. and Danso, A. (2025), "Exploring the contributions of circular businessmodels towards the transition of green economyin the Ghanaian construction industry", *Smart and Sustainable Built Environment*, Vol. 14 No. 3, pp. 859-880.
- Hoddy, E., Halliday, S., Ensor, J., Macome, A., Wamsler, C. and Boyd, E. (2025), "A socio-legal perspective on land market informality and accountability in urban land governance", *World Development*, Vol. 195, p. 107110.
- Hossain, M., A.s, M., Yu, H., Kim, J.-T. and Jung, H.-J. (2019), "Towards digitizing the construction industry: State-of-the-art of construction 4.0 in the industry", *Proceedings of International Structural Engineering and Construction*, Vol. 6 No. 1.
- Humaidan, O., Almazam, K., Agboola, O., Oladokun, O. and Dodo, Y.A. (2025), "A review on the strategies for green building construction: the role of nanomaterials in green buildings for a sustainable future", *Journal of Building Engineering*, Vol. 114.
- Ibishova, B., Misund, B. and Tveterås, R. (2024), "Driving green: financial benefits of carbon emission reduction in companies", *International Review of Financial Analysis*, Vol. 96, p. 103757.
- Jaber, S., Matloub, H. and Mehmood, K. (2019), "Green and sustainable practices in the construction industry: a confirmatory factor analysis approach", *Engineering, Construction and Architectural Management*, Vol. 26 No. 6, pp. 1063-1086.
- Jiankun, H., Zheng, L., Xiliang, Z., Hailin, W., Wenjuan, D., Ershun, D., Shiyun, C., Xunmin, O., Siyue, G., Zhiyu, T., Alun, G., Fei, T., Bin, H., Xiu, Y., Siyuan, C., Mingtao, Y., Zhiyi, Y., Li, Z. and Danwei, Z. (2021), "Towards carbon neutrality: a study on China's long-term low-carbon transition pathways and strategies", *Environmental Science and Ecotechnology*, Vol. 9, p. 100134.
- Jingbo, C., Jing, D., Zhenxuan, W. and Xiande, Z. (2022), "Does environmental regulation induce green innovation? A panel study of Chinese listed firms", *Technological Forecasting and Social Change*, p. 176.
- Juan, L., Mei, S. and Lixin, T. (2025), "Carbon emissions and regional differences of Chinese urban buildings under multi-dimensional key influencing factor identification", *Environment, Development and Sustainability*.
- Lai, X., Liu, J., Shi, Q., Georgiev, G. and Wu, G. (2017), "Driving forces for low carbon technology innovation in the building industry: a critical review", *Renewable and Sustainable Energy Reviews*, Vol. 74, pp. 299-315.
- Lan, Y., Yuan, Z., Tang, R., Hsu, S.-C. and Wei, H.-H. (2025), "Green innovation and the ESG disconnect: Evidence from green patenting in the construction industry in China", *Journal of Management in Engineering*, Vol. 41 No. 1.
- Lee, J. and Li, S. (2017), "Extending Moran's index for measuring spatiotemporal clustering of geographic events", *Geographical Analysis*, Vol. 49 No. 1, pp. 36-57.
- Li, X., Yao, Y. and Shen, Q. (2025), "From dilemma to breakthrough: fuzzy-set qualitative comparative analysis of green development behavior pathways in construction materials enterprises", *Humanities and Social Sciences Communications*, Vol. 12 No. 1.
- Li, N., Dong, S. and Zhang, Y. (2025), "Can mixed-ownership reform in state-owned enterprises promote urban green transformation? Evidence from Chinese cities", *Journal of Cleaner Production*, Vol. 519, p. 145923.
- Li, C., Li, F., Wu, Z. and Cheng, J. (2017), "Exploring spatially varying and scale-dependent relationships between soil contamination and landscape patterns using geographically weighted regression", *Applied Geography*, Vol. 82, pp. 101-114.

- Li, L., Yi, Z., Jiang, F., Zhang, S. and Zhou, J. (2023), "Exploring the mechanism of digital transformation empowering green innovation in construction enterprises", *Developments in the Built Environment*, Vol. 15.
- Li, H., Peng, X., Zhang, J., Perez, P.B., Philbin, S.P., Li, Z., Tang, X. and Cheng, J. (2023), "Enabling the green total factor productivity of the construction industry with the prospect of digital transformation", *Environment, Development and Sustainability*, Vol. 27 No. 7, pp. 1-28.
- Li, D., Zhao, Y., Zhou, S., Yu, L., Wang, W., Wu, Y. and Dong, X. (2024), "Spatial spillover effects and correlation network analysis of green construction development efficiency in China", *Journal of Cleaner Production*, Vol. 474, p. 143627.
- Liu, G., Shi, P., Hai, F., Zhang, Y. and Li, X. (2018), "Study on measurement of green productivity of tourism in the Yangtze river economic zone, China", *Sustainability*, Vol. 10 No. 8, p. 2786.
- Manasseh Moses, E., Rengasamy, M., Lakshmana Prabu, S., and Venkatesan, G. (2025), "Environmental sustainability and green technology: a new approach[M]/KIRAN", *Sustainable Green Technologies: Bioremediation of Environmental Pollution*, Cham; Springer Nature Switzerland., pp. 1-27.
- Martínez, A.A. (2015), "Lessons from the past for sustainability transitions? A meta-analysis of socio-technical studies", *Global Environmental Change*, Vol. 44, pp. 125-143.
- Mlybari, E.A. (2025), "Smart sustainability in construction: an integrated LCA-MCDM framework for Climate-Adaptive material selection in educational buildings", *Sustainability*, Vol. 17 No. 21, p. 9650.
- Nelson, R. and Winter, S.G. (1985), "An evolutionary theory of economic change".
- Philip, L. (2019), "Global supply chains, firm scope and vertical integration: evidence from China", *Journal of Economic Geography*, Vol. 19 No. 1, pp. 173-198.
- Poortinga, W., Spence, A., Demski, C. and Pidgeon, N.F. (2012), "Individual-motivational factors in the acceptability of demand-side and supply-side measures to reduce carbon emissions", *Energy Policy*, Vol. 48, pp. 812-819.
- Porter, M.E. and Linde, C.V.D. (1995), "Toward a new conception of the environment competitiveness relationship", *Journal of Economic Perspectives*, Vol. 9 No. 4, pp. 97-118.
- Qidan, H., Jin, X., Rongsheng, L., Geoffrey, Q.S. and Feng, X. (2023), "Green building policies in China: a policy review and analysis", *Energy and Buildings*, p. 278.
- Rachel, F. and Gillard, R. (2022), "Policy entrepreneurs in green building transitions: the role of interurban coalitions", *Environmental Innovation and Societal Transitions*, Vol. 43, pp. 160-172.
- Salimi, H. and Sheikhzeinoddin, A. (2025), "Nonlinear dynamics of environmental performance in Asia: the role of economic complexity, renewable energy, and green technologies", *Environmental and Sustainability Indicators*, Vol. 28, p. 100938.
- Shen, L., Tam, V., Tam, L. and Ji, Y. (2010), "Project feasibility study: the key to successful implementation of sustainable and socially responsible construction management practice", *Journal of Cleaner Production*, Vol. 18 No. 3, pp. 254-259.
- Shi, Q., Yu, T. and Zuo, J. (2015), "What leads to low-carbon buildings? A China study", *Renewable and Sustainable Energy Reviews*, Vol. 50, pp. 726-734.
- Shuoran, X., Ting, W. and Yao, Z. (2020), "The spatial-temporal variation and convergence of green innovation efficiency in the Yangtze river economic belt in China", *Environmental Science and Pollution Research International*, Vol. 27 No. pp. 1-14.
- Siche, J.R., Agostinho, F., Ortega, E. and Romeiro, A. (2007), "Sustainability of nations by indices: comparative study between environmental sustainability index, ecological footprint and the energy performance indices", *Ecological Economics*, Vol. 66 No. 4, pp. 628-637.
- Singh, R.K., Murty, H.R., Gupta, S.K. and Dikshit, A.K. (2011), "An overview of sustainability assessment methodologies", *Ecological Indicators*, Vol. 15 No. 1, pp. 281-299.

- Song, M., Zhao, X., Shang, Y. and Chen, B. (2020), "Realization of green transition based on the anti-driving mechanism: an analysis of environmental regulation from the perspective of resource dependence in China", *Science of The Total Environment*, Vol. 698, p. 134317.
- Teng, Y., Li, K., Pan, W. and Ng, T. (2018), "Reducing building life cycle carbon emissions through prefabrication: evidence from and gaps in empirical studies", *Building and Environment*, Vol. 132, pp. 125-136.
- Teng, Y.C. (2019), "Quantifying the green efficiency of the construction industry in China", proceedings of the International Conference on Construction and Real Estate Management 2019, Reston, F, VA: *American Society of Civil Engineers*.
- Tan, Y., Luo, T., Xue, X., Shen, G.Q., Zhang, G. and Hou, L. (2021), "An empirical study of green retrofit technologies and policies for aged residential buildings in Hong Kong", *Journal of Building Engineering*, Vol. 39.
- Tengfei, H., Yuling, M., Linbo X, W.F. and Weiguang, C. (2022), "Carbon emissions in China's urban residential building sector through 2060: a dynamic scenario simulation", *Energy*, p. 254.
- Wackernagel, M. (2014), "Comment on "ecological footprint policy? Land use as an environmental indicator", *Journal of Industrial Ecology*, Vol. 18 No. 1, pp. 20-23.
- Wang, X. and Li, X. (2025), "Towards a green world: how new urbanization affects green total factor carbon productivity", *Frontiers in Environmental Science*, Vol. 12, p. 1522259.
- Wang, Y. and Gao, X. (2024), "Mineral resource dependence and green transformation: the impact and challenges of green finance in Chinese cities", *Humanities and Social Sciences Communications*, Vol. 11 No. 1, p. 1450.
- Wang, L., Song, X. and Song, X. (2021), "Research on the measurement and spatial-temporal difference analysis of energy efficiency in China's construction industry based on a game cross-efficiency model", *Journal of Cleaner Production*, Vol. 278, p. 123918.
- Wang, Z., Qin, F., Liu, J. and Jin, X. (2025), "Evolution trajectory and driving mechanism of the synergistic effect on construction waste and carbon reduction: Evidence from China", *Waste Management (New York, NY)*, Vol. 203, p. 114891.
- Wang, Z., Hu, T., Liu, J., Xia, B. and Chileshe, N. (2024), "Spatial differences, evolutionary characteristics and driving factors on economic resilience of the construction industry: evidence from China available to purchase", *Engineering, Construction and Architectural Management*, Vol. 32 No. 10.
- Wang, Y.J., Li, S.S., Gu, X., Sun, Q.Q., Zhang, N.R. and Chen, Y.F. (2024), "Spatio-temporal evolution and multi-subject influencing factors of urban green development efficiency in China: under the carbon neutral vision constraint", *Ecological Indicators*, Vol. 167, p. 112580.
- Wang, Z., Hu, T., Liu, J., Xia B, Bao, Z. and Zhao, N. (2025), "The spatial correlation network and driving factors of economic resilience in the construction sector: evidence from China", *Construction Management and Economics*, Vol. 43 No. 11, pp. 961-982.
- Wen, Q., Chen, Y., Hong, J., Chen, Y., Ni, D. and Shen, Q. (2020), "Spillover effect of technological innovation on CO 2 emissions in China's construction industry", *Building and Environment*, Vol. 171, p. 106653.
- Xingwei, L., Xiang, L., Yicheng, H., Jingru, L., Jinrong, H. and Jiachi, D. (2024), "Evolutionary mechanism of green innovation behavior in construction enterprises: evidence from the construction industry", *Engineering, Construction and Architectural Management*, Vol. 31 No. 1, pp. 159-178.
- Xu, J., Cheng, M. and Sun, A. (2025), "Assessing sustainable practices in architecture: a data-driven analysis of LEED certification adoption and impact in top firms from 2000 to 2023", *Frontiers of Architectural Research*, Vol. 14 No. 3, pp. 784-796.
- Ya-Ju, C. and Demi, Z. (2021), "Water security of the megacities in the Yangtze river basin: comparative assessment and policy implications", *Journal of Cleaner Production*, p. 290.

- Yang, S., Jie, S., Xiaopeng, D., Kun, L., Zeru, L. and Baoquan, C. (2024), "Digital economy revolutionizing green total factor productivity in construction industry", *Technological Forecasting and Social Change*, Vol. 206, p. 123564.
- Yang, Z., Yan, D., Hu, S. and Guo, S. (2019), "Modelling of energy consumption and carbon emission from the building construction sector in China, a process-based LCA approach", *Energy Policy*, Vol. 134, p. 110949.
- Yao, W.W.T.Z.X.W.T.Y.R.D. (2020), "The influencing factors of China's green building development: an analysis using RBF-WINGS method", *Building and Environment*, p. 107425.
- Yao, H., Xu, P., Wang, Y. and Chen, R. (2023), "Exploring the low-carbon transition pathway of China's construction industry under carbon-neutral target: a socio-technical system transition theory perspective", *Journal of Environmental Management*, Vol. 327, p. 116879.
- Yi, S., Huolong, B., and Yi, Q. (2022), "Green total factor productivity of China's construction industry: based on the SBM-GML model", in *proceedings of the 2022 2nd International Conference on Management Science and Software Engineering (ICMSSE 2022)*.
- Yin, K., Zhang, R., Jin, X. and Yu, L. (2022), "Research and optimization of the coupling and coordination of environmental regulation, technological innovation, and green development", *Sustainability*, Vol. 14 No. 1.
- Yu, Z., Guo, T., Song, X., Zhang, L., Cai, L., Zhang, X. and Zhao, A. (2024), "Green transition assessment, spatial correlation, and obstacles identification: evidence from urban governance data of 288 cities in China", *Land*, Vol. 13 No. 3.
- Zeng, S.H., Gu, Y.X., Su, B. and Li, T.F. (2025), "Energy consumption transition and green total factor productivity in Chinese prefecture-level cities", *Energ Econ*, p. 142.
- Zhai, Q.X., An, F.Y., Shi, P.X. and Liu, X. (2022), "Measurement of green transition and its driving factors: Evidence from China", *Journal of Cleaner Production*, Vol. 335, p. 130292.
- Zhang, J. (2020), "Environmental regulation and green productivity of the construction industry in China", *Proceedings of the Institution of Civil Engineers - Engineering Sustainability*, Vol. 174 No. 2, pp. 1-8.
- Zhang, S., Cai, W., Zheng, X., Lv, X., An, K., Cao, Y., Cheng, H.S., Dai, J., Dong, X., Fan, S., Gao, Y., Gong, Z., Guan, Y., Hong, C., Li, J., Li, M., Li, Y., Liang, S., Liao, W., Ma, Z., Ren, Y., Shen, J., Shi, X., Su, Y., Sun, J., Xia, C., Xu, J., Ye, W., Zhang, L., Zhang, S., Zhang, T., Zhen, Z., Zhong, H., Wang, C. and He, K. (2025), "Global readiness for carbon neutrality: from targets to action", *Environmental Science and Ecotechnology*, Vol. 25, p. 100546.
- Zhou, Y., Jin, H., Li, C. and Ding, L. (2024), "Spatio-temporal patterns and impact mechanisms of CO₂ emissions from China's construction industry under urbanization", *Sustainable Cities and Society*, Vol. 106, p. 105353.
- Zhou, Y., Liu W, Lv, X., Chen, X. and Shen, M. (2019), "Investigating interior driving factors and cross-industrial linkages of carbon emission efficiency in China's construction industry: based on Super-SBM DEA and GVAR model", *Journal of Cleaner Production*, Vol. 241, p. 118322.
- Zou, Y., Zhao, W. and Zhong, R. (2017), "The spatial distribution of green buildings in China: regional imbalance, economic fundamentals, and policy incentives", *Applied Geography*, Vol. 88, pp. 38-47.

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