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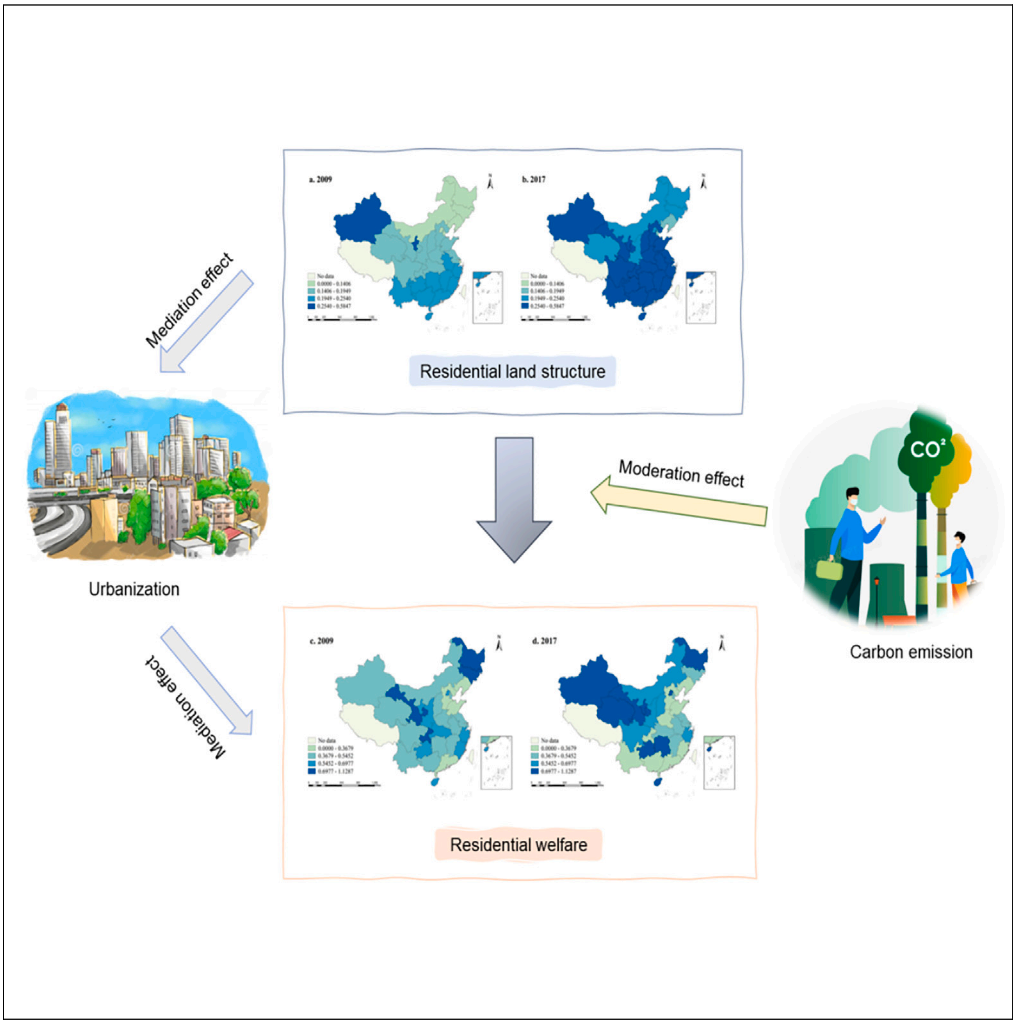

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Highlights

Orderly residential land structures enhance residential welfare

Residential land structure and residential welfare have a heterogeneous relationship

The mediating effect of urbanization is affected by the environment

The regulatory effect of carbon emissions functions partly through urbanization

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Residential land structure affects residential welfare: Linear and non-linear effects

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SUMMARY

The non-equilibrium phenomenon of residential land structure should be accorded particular importance when discussing residential welfare. Based on balanced panel data at the provincial level in China from 2009 to 2017, this study constructed an indicator to measure the residential welfare level using a multi-dimensional approach. It explored residential land structure's impact on residential welfare and its mechanism of action under carbon emissions and urbanization from both linear and non-linear perspectives. An orderly residential land structure was found to significantly positively affect residential welfare and this effect varies among provincial cities. Per the mechanism analysis, in the process of the residential land structure's impact on residential welfare, urbanization's mediating effect is influenced by the environment, whereas carbon emissions' moderating effect is partially influenced by urbanization. These insights contribute to the residential welfare literature and provide actionable recommendations for policy implementation in developing regions.

INTRODUCTION

Housing issues have gradually garnered increasing attention in various countries, with residential welfare becoming a focal point.[1] The United States—the world's largest economy—has integrated housing policies into its social welfare system. Measures such as low down payment loans and mortgage products have been implemented to lower the entry barriers to the housing market.[2] For instance, the Federal Housing Administration (FHA) provides mortgage insurance for loans issued by FHA-approved lenders, with down payments as low as 3.5%. In 2023, FHA-insured purchase transaction mortgages accounted for 79.44% of all FHA-insured endorsements. Singapore—renowned for its high welfare standards—achieves high coverage of public housing through efficient land acquisition and integrated housing construction models.[3] As of 2023, approximately 80% of Singapore's resident population lives in Housing and Development Board (HDB) flats, contributing to one of the highest homeownership rates globally, estimated at about 92%. As the largest developing country, China adopts a dual approach of government guidance and market regulation to strive for housing affordability and stability.[4] For example, since the 1990s, China has emphasized the development of a residential welfare framework compatible with a market economy under the dual housing system of "commercial housing + welfare housing." Specifically, the Economically Affordable Housing (ECH) and Public Rental Housing (PRH) programs have successfully constructed over 100 million units of affordable housing by the end of 2023, benefiting more than 230 million people. The aforementioned progress demonstrates the China's ongoing refinement of residential welfare. In summary, various countries actively enhance their residential welfare and quality of life (QoL) through numerous policy measures. While matching housing policies are necessary to improve residential welfare, focusing on the housing environment is equally important. Therefore, exploring the factors influencing residential welfare at the environmental level is crucial for its enhancement.

Residential welfare refers to the provision of adequate housing, high-quality living environments, and essential public services to meet residents' basic living needs, thereby enhancing their QoL and well-being. It encompasses multiple dimensions and constitutes a critical component of social welfare governance.[5] However, as global climate issues escalate, carbon emissions significantly affect the living environment's quality.[6] The increase in carbon emissions, as a clear indicator of environmental degradation, is also a crucial element in measuring residential welfare.[7] Common phenomena in urbanization processes, such as industrial activities, transportation, and energy consumption, contribute to the rise in carbon emissions. According to a report by the International Energy Agency (IEA), global energy-related carbon dioxide emissions increased by 1.1% in 2023, reaching a record 37.4 billion tonnes (Gt). This trend poses a severe challenge to residential welfare. Simultaneously, issues such as increased residential density and reduced green spaces owing to urbanization also negatively impact residential welfare.[8] According to a Statista report, China's urbanization rate reached 66.16% in 2023 and is expected to reach 75–80% by 2035.[9] The concentration of population and increased housing demand have precipitated a growing need for high-quality living environments and

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public services.[10] However, urbanization-related pollution and resource issues, such as traffic congestion, air pollution, and water shortages, further complicate the residential welfare landscape.[11] Therefore, when discussing residential welfare affected by environmental factors, considerations must include factors related to urbanization and carbon emissions.

Conversely, residential land's structure significantly affects residents' QoL, as indicated by existing research. Several countries use land structure adjustments as a means of housing regulation.[12] The residential land structure, encompassing the scale and arrangement of urban residential land, exerts a pivotal influence on the planning of urban functional zones.[13] In China, since 2004, the market-oriented allocation of operational land use rights has become part of the real estate market's macro-control.[14] As urban land becomes increasingly scarce, land transfer prices have risen rapidly, precipitating changes in residential land's structure.[14] According to the "China Statistical Yearbook," from 2009 to 2017, residential land in China increased from 81,548.17 ha to 87,087.28 ha, whereas the areas allocated for affordable housing and low-rent housing decreased by 1.78% and 29.40%, respectively, reflecting the irrationality in the residential land's internal structure to some extent. Further analysis reveals that in urban planning, owing to the limited total residential land area, preferences for certain types of residential land, such as high-end housing, decrease non-high-end residential land. Studies have indicated that the residential land structure's irrationality may exacerbate urban inequality and affect residential welfare's fairness.[15] Evidently, residential land structure's impact on residential welfare is increasingly drawing attention.

Furthermore, as an essential component of urban land use, residential land's structure is closely related to carbon emissions and urbanization.[16] In urban planning, different types of residential land exhibit significant differences in terms of carbon emissions. For example, high-density residential areas usually have higher energy utilization efficiency, whereas low-density residential areas require more infrastructure construction and maintenance, which may increase carbon emissions,[17] indicating that the imbalance in residential land structure significantly impacts the regional environment. Similarly, the urbanization process frequently accompanies diverse housing demands from various residents, precipitating changes in residential land structure.[18] However, an unreasonable residential land structure may exacerbate residential land wastage. Evidently, the residential land structure will be influenced by the urbanization process. In conclusion, scientific and reasonable planning of residential land structures requires considerations to reduce carbon emissions and accommodate urban development.

In summary, the structure of residential land use is likely to affect residential welfare. Accordingly, this study addresses the following questions.

- Does residential land's structure impact residential welfare?
- Is residential land structure's impact on residential welfare heterogeneous?
- What mechanisms explain how residential land structure impacts residential welfare amid carbon mitigation and urbanization?

A comparison with the existing literature clearly indicates that some research gaps remain. First, within the scope of research, studies primarily focus on residential land structure's impact on residents' QoL and environmental sustainability, with less attention paid to how the scale and composition of different types of residential land use affect residential welfare, particularly in the context of carbon reduction and urbanization. Moreover, residential welfare is a multidimensional and comprehensive concept,[19] and existing literature lacks a comprehensive and integrated definition of residential welfare. Second, concerning research methodology, linear studies with fewer nonlinear arguments dominate the literature on the structure of residential land and residential welfare. However, residential welfare's nonlinear characteristics are gradually attracting attention. Finally, from the argumentation perspective, existing studies on the mechanism of influence tend to focus on analyzing individual mediating or moderating variables separately, with limited analysis simultaneously incorporating them into mechanistic models.[20]

This study fills the gap in understanding the relationship between residential land structure and welfare in the context of rapid urbanization and carbon emission reduction. It investigates how residential land structure influences welfare both linearly and nonlinearly, analyzing variations across regions based on environmental regulations, economic development, and geographical location. Additionally, the study explores the mediating and moderating roles of urbanization and carbon emissions in this relationship. Utilizing panel data from 30 provinces in China between 2009 and 2017, the study initially employs a two-way fixed-effects model and validates the positive impact of residential land structure on welfare through robustness checks such as the System-Generalized Method of Moments (SYS-GMM). Semi-parametric estimation and quantile regression further validate the baseline impact and analyze regional welfare effects, revealing critical influencing factors. Finally, the study examines the mechanisms through which residential land structure affects welfare, highlighting the pivotal roles of urbanization and carbon emissions.

This study's specific contributions are as follows: First, grounded in the concept of residential welfare, this study formulates a holistic index system by integrating dimensions of economy, safety, health and well-being, infrastructure and accessibility, education, environment, and legal and rights aspects through the application of the entropy method. In comparison to existing literature, the selection of indicators in this study is broader and more inclusive, effectively addressing the gaps in the definition of residential welfare indicators within current research. Second, this study introduces methodological innovation by integrating linear and non-linear approaches to comprehensively assess the correlation between residential land structure and welfare. Through this approach, we fill a gap in the exploration of such dynamic relationships in prior studies, offering a fresh perspective to the existing literature. Thirdly, this study innovates upon conventional analyses of mediating and moderating effects by constructing an integrative model. Urbanization is posited as a mediator, and carbon emission intensity as a moderator, elucidating their respective and synergistic impacts on the nexus between residential land structure and welfare. This model refines the theoretical underpinnings of influence mechanisms and sheds light on how urban dynamics and environmental stewardship collectively sculpt residential well-being.

The remainder of this article is organized as follows: a review of the relevant literature is presented, followed by the formulation of research hypotheses. Next, the model, variable selection, and data sources are introduced. The results and discussion are then addressed. Finally, the article concludes with a summary and recommendations.

Literature review

Residential welfare

A universally agreed-upon the definition of residential welfare does not exist, and residential welfare systems' development requires amplification. However, the concept of residential welfare varies across studies. First, the Universal Declaration of Human Rights in 1948 proposed that residential welfare is a human right, and the current residential welfare still focuses solely on the right to housing. Second, a 1995 study suggested that the natural and human environment around housing, employment, education, healthcare, transportation, and other public resources contribute to residential welfare.[21] Subsequently, the 2005 Declaration on Residential Welfare in East Asia, which defines residential welfare as the condition wherein individuals have appropriate houses, maintain their dignity, and live safely and comfortably,[22] implies that residential welfare encompasses living conditions, the environment, and the right to housing. With social and economic progress, the concept of residential welfare continues to broaden, transforming into satisfaction with the economic, security, cultural, psychological, and developmental requirements of residents within their living spaces.[23–26]

Subsequently, studies have comprehensively defined residential welfare in terms of resident income, housing consumption, housing status, housing security, environment, health, and transportation.[27–29] This study concludes that the essence of residential welfare lies in ensuring the basic housing needs of residents, improving the quality of the living environment, and achieving housing equity and social stability. Therefore, this study defines residential welfare as a comprehensive social security system that fulfills residents' basic living needs and enhances their QoL and well-being by providing adequate housing, a high-quality living environment, and necessary public services. Regarding the measurement of residential welfare, some studies have drawn on Sen's capability approach,[30] which assesses the residential welfare level based on residents' economic status, housing conditions, and amenities.[31] Others have integrated indicators such as housing prices, quality, and the natural environment for a comprehensive assessment.[32] However, these studies did not comprehensively consider the aforementioned individual, economic, social, or environmental aspects. Consequently, the description of residential welfare was not sufficiently comprehensive.

Residential land structure

Urban residential land—a crucial component of urban construction land—integrates residential buildings, public facilities, green spaces, roads, and squares, providing space for residents' daily lives and social activities.[13] The residential land's structure, which refers to the scale and combination of different types of residential land, significantly impacts the spatial layout of urban functions, such as housing, transportation, services, and the environment.[33] An ideal residential land structure should follow the master plan and land use plan, demonstrating a high degree of orderliness. Per the "China Land Use Classification" (GB/T 21010-2007) and "China Land Resources Statistical Yearbook," residential land is divided into four categories (Table S1),[34] including land for general commercial housing, land for affordable housing, land for low-cost housing, and other land uses. Existing research on residential land has primarily focused on the following aspects: First, strictly regulating residential land frequently suppresses housing supply, precipitating rising housing prices and, consequently, causing market segmentation and inequality.[35] Second, studies have explored the impact of different types of residential land on the living environment and resource utilization. Moreover, residential land structure's influence on social equity has been confirmed. An over-reliance on high-profit commercial housing development may crowd out the supply of low-return affordable housing, further exacerbating housing inequality. Additionally, research has examined the relationship between residential land structure and housing prices,[36,37] industrial structure,[38] economic fluctuations,[39] and green development,[40] among other aspects. However, these studies have some limitations.

While most studies concentrate on specific regions or cities and, thus, lack extensive national-level data support and regional heterogeneity analysis, studies on residential land structures' long-term evolution are relatively few, rendering it difficult to comprehensively understand their dynamic impact. Currently, urban residential land supply in China is characterized by internal imbalances and spatial mismatches. However, relevant research on residential land structure's orderliness and balance, especially its internal composition, is lacking.

Noteworthily, changes in residential land structure are directly related to urban planning and land use.[41] A well-planned residential land structure improves land-use efficiency, thus promoting sustainable economic growth in cities. Moreover, optimizing residential land's structure promotes stability in the real estate market.[10] However, at the societal level, changes in residential land structure directly impact residential welfare's equitable distribution. Different types of residential land determine residents' living environments, community facilities, and public services.[42] By reasonably allocating various types of residential land, effectively addressing different social groups' housing needs is possible, which can provide more green spaces, cultural and entertainment facilities, and convenient transportation networks, thereby enhancing residents' welfare. However, current research on the impact of residential land structure primarily focuses on economic factors, such as housing prices and economic fluctuations, often overlooking its influence on the quality of daily life. Therefore, to achieve housing welfare, this study investigates the residential land structure's impact and mechanisms.

Research hypothesis

Relationship between residential land structure and welfare

Per the "Urban Land Classification and Construction Land Standards" (GB50137-2011), residential land should not exceed 40%. Urban planning suggests that residential land should occupy an appropriate proportion of urban construction land to ensure adequate and affordable living space.[43] In 2021, the Planning and Natural Resources Bureau of Shenzhen, China, issued "Several Measures for Further Increasing the Supply of Residential Land (Draft for Soliciting Opinions)," proposing to gradually increase residential and public facility land's scale and proportion. The goal is to ensure that by 2035, the per capita housing area for the permanent population in the city will reach more than 40 square meters, and the annual supply of residential land will, in principle, be no less than 30% of the total construction land supply. However, in some cities in China, the actual proportion of residential land supply falls below the recommended standards, precipitating a shortage in the total amount of residential land.

Additionally, commercial housing occupies a significant proportion of the residential supply and is closely linked to the local Chinese government's allocation of state-owned construction land use rights.[44] Local governments acquire fiscal revenues through land auctions and similar methods, with commercial housing development frequently being the primary target because of its potential for high profits. Owing to the high returns from commercial housing development, local governments tend to allocate more land to high-end residential projects, thereby limiting the supply of affordable and public housing. Specifically, the lack of an appropriate housing scale and internal structural imbalance precipitate the following problems: First, the insufficient housing supply in some areas exacerbates the rise in housing prices, increasing residents' housing burden.[45] Second, owing to the limited housing supply, the construction of high-profit commercial housing replaces the supply of low-return affordable housing, causing a severe imbalance in the residential land structure. Third, affordable housing's shortage deteriorates low-income groups' living conditions, exacerbating social inequality and potentially intensifying social conflicts.[46]

Regions with stringent environmental regulations may demonstrate a stronger correlation between orderly land structure and the enhancement of residential welfare, as sustainable development and environmental quality are prioritized in urban planning.[47] By contrast, areas with less stringent oversight may exhibit weaker associations, potentially owing to a focus on economic growth that could overshadow concerns for optimizing land use.[48] Furthermore, research has found that economic development further complicates this relationship. In economically advanced areas, the link between land structure and residential welfare may be more complex, stemming from various factors such as existing infrastructure, housing market dynamics, and social services, which already provide a high baseline for residential welfare. Conversely, economically underdeveloped regions may experience a more direct impact of residential land structure on residential welfare, as improvements in residential land allocation can translate into better living conditions and access to services.[49] Concurrently, considering the distinct geographical and cultural contexts of the eastern and non-eastern regions, the eastern regions may have reached a saturation point with their advanced urbanization and higher land scarcity. At this juncture, the marginal benefits of optimizing residential land structures for residential welfare are diminished. However, the non-eastern regions—with their potential for growth and development—may experience more significant improvements in residential welfare through better land-use planning. Therefore, the following hypothesis is proposed:

Hypothesis 1: An orderly residential land structure significantly positively impacts residential welfare; this impact exhibits significant heterogeneity across regions with varying intensities of environmental regulation, economic development levels, and geographical locations.

Relationship between residential land structure, residential welfare, and urbanization

The urbanization process manifests spatially as the evolution of urban form and structure.[50] The residential land structure in a region often directly reflects urban living spaces' rationality and sustainability, serving as an essential indicator of residents' QoL and urban development level.[51] Multiple factors drive the supply of regional residential land and significantly impact the urbanization process.[52] As urbanization progresses, the residential land structure tends to negatively impact urbanization, primarily in the following aspects: First, with the acceleration of urbanization, the planning and allocation of residential land have failed to keep pace with population growth and housing demand, precipitating insufficient supply or uneven distribution. This mismatch creates housing space shortages and environmental degradation, thereby affecting residential welfare. Second, the residential land structure is increasingly imbalanced. To accelerate urbanization, local governments may exhibit biases in residential land planning, causing an unbalanced housing supply system and further exacerbating the imbalance in the urban residential land structure.

Furthermore, urbanization significantly impacts factors such as the environment, culture, and residents' health,[53] thereby influencing residential welfare. Urbanization trends exert a complex impact on the residential welfare level. A certain degree of urbanization increases employment opportunities, raises household income, enhances the social security level, and improves the living environment, thus contributing to the overall residential welfare level. However, excessive urbanization without corresponding improvements in residential land structure can lead to land mismatch and social problems counterproductive to welfare. Therefore, the following hypothesis is proposed:

Hypothesis 2: An organized residential land structure discourages urbanization, thereby promoting residential welfare.

Relationship between residential land structure, residential welfare, and carbon emissions

The residential land structure significantly impacts carbon emissions during the urbanization process. By improving land use efficiency, rational planning of residential land can reduce energy consumption and carbon emissions, thereby improving environmental quality and enhancing residential welfare. For example, high-density residential areas can achieve improved energy efficiency and reduced carbon emissions by optimizing public transportation and infrastructure layouts. Additionally, promoting green buildings and eco-friendly communities,

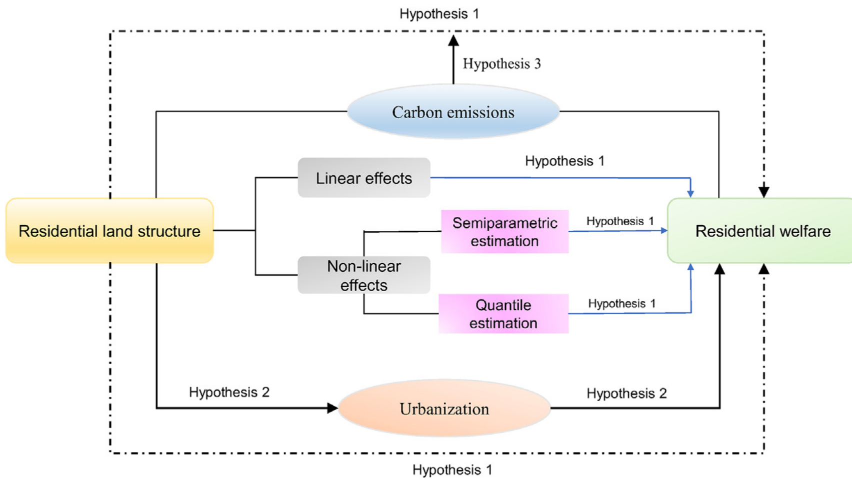

Figure 1. Research hypothesis diagram

Hypothesis 1: Under both linear and nonlinear analyses, the structure of residential land use has a significant positive effect on residential welfare. **Hypothesis 2:** An organized structure of residential land use can mitigate urbanization, thereby promoting residential welfare. **Hypothesis 3:** Carbon emissions positively moderate the effect of residential land use structure on residential welfare.

as well as adopting green building standards and energy-saving technologies, can further reduce building energy consumption and improve living quality.

Given the current imbalance in China's residential land structure, which adversely affects carbon emission efficiency and indirectly impacts residential welfare, optimizing this structure is crucial for achieving dual carbon goals and enhancing welfare.[54] When formulating housing policies, local governments should consider the interplay of carbon emissions and land use, striving for a balance between economic growth and environmental sustainability.[55] Accordingly, the following hypothesis is proposed:

Hypothesis 3: Carbon emissions exert a positive moderating effect on residential land structure's impact on residential welfare.

Figure 1 summarizes the research hypotheses.

Materials and methods

Methodology

Basic measurement models. To accurately examine residential land structure's effect on residential welfare and consider the possible unobserved heterogeneity of individual and temporal differences in the sample and their impact on the regression results, the two-way fixed-effects model was used as the underlying measurement model.[56] The model was constructed as follows:

$$Score_{it} = \alpha_0 + \alpha_1 \, Inf_{it} + \beta_0 Controls_{it} + \phi_i + \gamma_t + \varepsilon_{it} \quad \text{(Equation 1)}$$

$Score_{it}$ denotes the residential welfare effect in province i in year t. The main independent variable is the residential land structure (inf) obtained by information entropy, denoted as Inf_{it}, which represents the residential land structure of the province i in year t. α_1 denotes the effect of residential land structure on the level of residential welfare and $Controls_{it}$ denotes the control variables. ϕ_i and γ_t denote individual and year-fixed effects, respectively, and ε_{it} denotes random interference term.

This study employed a system-generalized method of moments (SYS-GMM) to construct a dynamic panel regression model for robustness testing primarily because while fixed-effects models can handle some missing variable issues, they are not entirely adequate. Additionally, considering residential development's long-term nature and its lagged impact on regional residential welfare, the explanatory variables' lagged terms were included in the model to reduce bias.[57]

$$Score_{it} = \alpha_0 + \phi Score_{it-1} + \alpha_1 \, Inf_{it} + \gamma \, Inf_{it-1} + \sum \beta_0 Controls_{it} + \varepsilon_{it} \quad \text{(Equation 2)}$$

In Equation 2, $Score_{it-1}$ represents the lagged term of the explained residential welfare variable. Inf_{it-1} denotes the lagged term for the residential land structure. ϕ and γ represent the coefficients of the variables, while the remaining variables are the same as in Equation 1.

Nonlinear econometric model

Semi-parametric estimation model. This study adopts a semi-parametric estimation method for regression analysis to address purely parametric or non-parametric approaches' limitations. The former depends heavily on model assumptions, which can lead to biased results if the assumptions are incorrect.[58] Conversely, the latter requires large sample sizes to achieve reliable estimates.[59] Semi-parametric estimation combines the strengths of both methods, enabling flexible modeling of complex relationships without requiring large sample sizes.[60]

This method effectively handles both linear and non-linear components of the model, making it suitable for robustly examining the relationship between residential land structure and residential welfare, especially with smaller datasets like the 30 provincial-level datasets used in this study. The model is as follows:

$$Score_{it} = \beta\, inf'_{it} + \lambda(z_i) + \varepsilon_{it} \quad \text{(Equation 3)}$$

where $Score_{it}$ represents the response variable, inf'_{it} denotes the explanatory variable, and z represents a covariate. $\lambda(z_i)$ is a non-parametric component represented as an unknown function. $\beta\, inf'_{it}$ represents the linear parameter component of this study, with the coefficient β being known. ε_{it} is the error term, typically assumed to follow a normal distribution.

Quantile estimation model. To comprehensively understand the study subjects' distributional characteristics, particularly in the presence of heterogeneity, the subsequent sections employ quantile regression for a deeper and more thorough analysis. Unlike the standard regression that focuses on the mean mentioned above, quantile regression is better suited to the data distribution. It provides insights into the impact of explanatory variables across different quantiles.[61] This is particularly useful for understanding the effects of extreme values and heterogeneity within the data, precipitating more nuanced result interpretations. The quantile regression model is presented in (Equation 4).

$$Score_{it} = \beta\, inf'_{it} + \epsilon_{it} + \phi_i + \gamma_t \quad \text{(Equation 4)}$$

where $Score_{it}$ represents the dependent variable value of the individual *i* at time *t*; inf'_{it} is the independent variable vector of the individual *i* at time *t*; β is the regression coefficient vector; and the remaining variables are the same as in Equation 1.

Variable selection

Dependent variable. In previous studies, single indicators or narrow-range composite indicators were frequently used to measure the residential welfare level. With the increasing complexity of the real factors affecting residential welfare, indicators are now more commonly used to comprehensively assess residential welfare.[62] Therefore, based on existing research, this study selected nine indicators—namely, economic access, residential consumption, residential security, health, transportation, security, education, carbon emissions, and residential rights.[63–66] These indicators encompass multiple dimensions, such as economic, social, environmental, and security aspects. Among them, economic access and residential consumption reflect residential welfare's financial aspect, while health and education indicate the social dimension. Security, residential security, and residential rights cover legal and safety aspects, and transportation and carbon emissions are related to environmental factors. We used the entropy method to calculate each indicator's weights and construct a composite index to measure residential welfare levels. The entropy method objectively assigns weights based on indicator values' variability, avoiding biases introduced by subjective factors.[67] Table S2 presents the specific index construction and calculation process.

Independent variable. The independent variable selected herein is the residential land structure, represented by information entropy, owing to the following reasons: First, the theoretical foundation of information entropy is derived from the work of Claude Shannon in 1948, who utilized thermodynamic principles to quantify the uncertainty of information sources.[68] This theory offers a fresh perspective on studying urban land-use structures, allowing researchers to explore the orderliness and diversity of these structures in greater depth.[69] Second, information entropy can quantify the dynamics and orderliness of a system, aligning with residential land structures' natural and historical complexity. Furthermore, information entropy provides an objective measure of residential land structures' orderliness by quantifying the distribution and proportion of different land uses. This method is particularly suitable for capturing the complexity and diversity of residential land structures. Information entropy demonstrates higher objectivity, comprehensiveness, and comparability than traditional subjective evaluation methods.[70] Ultimately, the entropy value effectively maps the orderliness of regional residential land structures and their efficiency across various residential land-use patterns. Variations in the entropy of urban residential land structures provide a quantitative basis for assessing their orderliness. Consequently, this study employs entropy as the preferred metric for quantifying residential land structures' orderliness. The calculation method is as follows:

S represents the total area of residential land in an area, and *m* represents the structure type. If the area of each type is S_i, then

$$S = \sum_{i=1}^{m} S_i(1, 2, ..., m) \quad \text{(Equation 5)}$$

The proportion of each category to the total area of residential land is:

$$P_t = \frac{S_i}{S} \quad \text{(Equation 6)}$$

where $\sum_{i=1}^{m} P_i = 1$, then the information entropy of the residential land structure can be expressed as follows:

$$H = -\sum_{i=1}^{m} P_t \cdot Ln\, P_i \quad \text{(Equation 7)}$$

The unit of information entropy is Nat, which measures the quantity of residential land and the uniformity of various land type distributions.

When $S_1 = S_2 = ... = S_m$, the information entropy H reaches its maximum value H_{max}, at this point:

$$H_{max} = Lnm \tag{Equation 8}$$

indicating that regional residential development is mature and the land type distribution is stable.

Conversely, when the information entropy H reaches its minimum value $H_{min} = 0$, it indicates that the region is in a developmental state.

As the number of land-use categories increases and the area differences among types decrease, the system's orderliness increases, leading to higher information entropy.

Control variable. In this study, control variables were selected at the economic and social levels to mitigate other factors' potential impact. Specifically, the following items were included: First, industrial structure (ind) is represented by the ratio of secondary output to GDP. On the one hand, the misallocation of land resources is an essential factor constraining the upgrading of China's industrial structure,[71] which, consequently, is related to all aspects of housing, thus affecting the level of residential welfare. On the other hand, the secondary industry, which includes manufacturing and construction, is typically a primary driver of economic growth and employment, directly influencing economic accessibility and residential consumption in communities. Although the primary and tertiary industries also play crucial roles, this study selects the proportion of the secondary industry to GDP as a control variable because of its more direct and measurable impact on the dependent variable.

Second, the fiscal gap (fin) is expressed as the ratio of fiscal expenditure to fiscal revenue; widening the fiscal gap slows the improvement in the residential welfare level.[49] Third, residential investment plays a crucial role in shaping supply and demand dynamics in the market, which directly impacts the demand and configuration of land use and consequently influences residential welfare.[72] In this study, the ratio of the amount of residential investment to the total investment in real estate development was chosen to represent residential investment (inv). Fourth, differences in population density (peo) between regions directly impact the residential structure. For example, high population density often precipitates a compact layout of residential land structures, driving the demand for vertical construction and high-rise buildings with a corresponding impact on residential welfare.[73]

Other variables. Mediating variables. The urbanization level significantly impacts residential land allocation. Simultaneously, the urbanization process largely reflects the trend of improving living conditions and development.[14] In this study, the urbanization rate (urb) was selected as a mediating variable to investigate residential land structure's indirect influence on residential welfare.

Moderating variables. Carbon emissions can represent the environmental pollution level in a province, and environmental advantages and disadvantages impact transport and consumption in a certain area. In this study, carbon emissions (ei) were selected as indicators to test the regulatory effects—expressed through carbon intensity. Carbon intensity is calculated as the ratio of urban carbon emissions to urban areas. The carbon emissions of cities and towns are calculated according to the "2022 China Building Energy Consumption and Carbon Emission Research Report," and its formula is $BCE = \sum BE_i EF_i$, where BCE represents the carbon emissions, BE_i is the consumption of the i th type of energy in the building operation process, and EF_i is the carbon emission factor of the i th type of energy.

Substitution of independent variables. The robustness test replaced the core independent variable in the original regression with the degree of equilibrium (equ) of the residential land structure, whereas the other variables were treated in the same manner as in the basic regression owing to the following reasons: Information entropy and equilibrium, as indicators of the degree of order and concentration of urban land use, have the same sign reflecting the order of the land use structure. Generally, the more ideal the equilibrium state of the land-use structure, the greater the information entropy of the residential land structure and the higher the degree of equilibrium is.[74] Therefore, the equilibrium degree of residential land structure was selected as the replacement independent variable to enhance this study's credibility. The specific calculations are as follows:

$$J = \frac{H}{H_{max}} = -\frac{\sum_{i=1}^{m} P_i \ln P_i}{\ln m} \tag{Equation 9}$$

where J∈[0,1] denotes the degree of equilibrium of the structure for residential land, and the rest of the variables have the same meaning as in Equation 7.

Table 1 presents the indicator system for all variables.

Data sources

Considering the latest data from the "China Statistical Yearbook of Land and Resources" from 2017, this study focused on the supply of residential land in 31 provinces and cities in China from 2009 to 2017. As some indicators lacked data for Tibet, the Tibetan region was excluded, resulting in a total sample size of 30 provincial cities. The relevant data for this study was sourced from the "China Statistical Yearbook of Land and Resources," "China National Statistical Yearbook," and "China Statistical Yearbook of Urban Construction" for these years. Logarithms were applied to absolute variable data to mitigate issues related to heteroscedasticity. The vector boundary and building land data for urban agglomerations were obtained from the Data Center for Resource and Environmental Sciences of the Chinese Academy of Sciences (http://www.resdc.cn, accessed on November 15, 2023). Carbon emissions-related data were obtained from the "China Energy Statistics Yearbook," "China Statistics Yearbook," and "China Urban and Rural Construction Statistics Yearbook" in previous years.

Table 1. Variables' definitions

Variable Type	Variable	Variable Symbols	Variable Meaning
Dependent variables	Residential welfare	Score	The Comprehensive Residential Welfare Index is calculated using the Entropy Method based on nine indicators—namely, Economic Accessibility, Housing Expenditure, Housing Security, Health, Transportation, Safety, Education, Carbon Emissions, and Housing Tenure
Independent variable	Residential land structure	Inf	Residential Land Structure Index Based on Information Entropy
Control variables	Fiscal deficit	Fin	Government expenditure/government revenue
	Industrial structure	Ind	Secondary industry output/Gross Domestic Product (GDP)
	Residential investment	Inv	Residential investment/real estate development investment total
	Population density	Peo	Population/Area, Logarithm of Population Density Value
Alternative independent variable	Residential land structure equilibrium	Equ	Residential Land Structure Information Entropy/Maximum Residential Land Structure Information Entropy
Intermediary variables	Urbanization rate	Urb	Urban Population/Total Population
Adjustable variable	Carbon emissions	Ei	Urban Carbon Emissions/Urban Area

Stationarity test

Table 2 presents the variables' descriptive statistics. To avoid "spurious regression" and ensure the validity of the estimation results, the LLC,[75] Hadri LM,[76] and Fisher-ADF[77] test methods were used to check the variables' stationarity. The Kao co-integration method was employed to estimate the long-term relationships among the panel variables. All variables passed the stationarity tests at the 1% significance level (Table 3), indicating the absence of unit roots. Additionally, the t-statistics in the co-integration tests were significant at the 1% level (Table 4), suggesting a long-term equilibrium relationship among the variables.

RESULTS

Residential land structure and spatial and temporal changes in residential welfare

Panels a and b in Figure 2 depict the spatial evolution of residential land structures among China's 30 provinces from 2009 to 2017. In 2009, the national average for the orderliness of residential land use was 0.433563, indicating a moderate diversity level. Xinjiang and Ningxia had the highest entropy values, suggesting a dynamic development phase with balanced land type distribution. By 2017, the national average orderliness increased to 0.539411, reflecting a trend toward more diversified and evenly distributed residential land, with all provinces except Xinjiang and Ningxia showing an increase in entropy values.

Panels c and d in Figure 2 illustrate the spatial evolution of residential welfare over the same period. While the national welfare index was generally low in 2009, with higher levels in Heilongjiang, Jilin, Gansu, and Chongqing, by 2017, a general improvement in living standards was observed, despite declines in Guangdong, Liaoning, Shandong, Hebei, Chongqing, Yunnan, Guangxi, Fujian, and Henan. The national welfare index rose from 0.193467 to 0.295307, indicating an overall enhancement in living standards.

Table 2. Summary statistics

Variable Type	Variable	Variable Symbols	Mean	S.D.	Min.	Median.	Max.
Dependent variables	Residential welfare	Score	0.257	0.0910	0.0888	0.249	0.585
Independent variable	Residential land structure	inf	0.605	0.237	0.0717	0.602	1.188
Control variables	Fiscal deficit	fin	2.285	0.999	1.074	2.162	6.745
	Industrial structure	ind	0.460	0.0830	0.190	0.477	0.591
	Residential investment	inv	0.170	0.0655	0.0534	0.158	0.415
	Population density	peo	7.852	0.430	6.639	7.858	8.669
Intermediary variables	Urbanization rate	urb	0.553	0.130	0.299	0.533	0.896
Adjustable variable	Carbon emissions	ei	1.478	0.348	0.480	1.535	2.016

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Table 3. Panel unit root tests

Variables		LLC	ADF	Hardri LM
Score	Level	−9.5086***	−4.3441***	6.4282***
inf	Level	−15.6194***	−6.1336***	4.3394***
ind	Level	−10.6246***	−4.6564***	5.3542***
inv	Level	−14.4762***	−4.1176***	4.7497***
peo	Level	−8.4116***	−4.3450***	5.2615***
fin	Level	−15.4106***	−4.8118***	2.8733***

Note: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively.

The parallel upward trends in both residential land orderliness and welfare suggest a potential correlation. High entropy values, indicative of diverse and evenly distributed land types, may contribute to welfare by offering a broader range of housing options and community amenities. However, the relationship between land diversity and welfare is multifaceted and influenced by urbanization.

To address urbanization's impact on the correlation between residential welfare and the orderliness of residential land structure, this study considers urbanization's dual role as a mediator and as a factor influenced by residential land planning in the subsequent analysis. Although urbanization itself can enhance the orderliness of residential land structure and the level of residential welfare, its mediating role and its interaction with carbon emissions will be explicitly examined in Section 6.3. These analyses will help to isolate the specific impacts of residential land structure on welfare by considering urbanization's complex effects.

The synchronized growth of entropy and welfare over time may indicate a synergistic effect, where enhancements in the orderliness of residential land structure could foster improvements in residential welfare. Further research, including the detailed mediation and moderation analyses presented later in this study, is needed to unpack the complex dynamics at play and understand how the orderliness of residential land use impacts residential welfare.

Benchmark regression results

Table 5 presents the baseline regression analysis results, illustrating the relationship between the residential land structure (inf) and residential welfare (Score). Column (1), without control variables, presents a positive effect of residential land structure on the residential welfare level, with a coefficient of 0.0196 at a 5% level of significance. Column (2) of the regression results includes the control variables to enhance the regression's precision. The regression coefficient was 0.0225, which is statistically significant at the 1% level. In summary, Hypothesis 1 received partial support, regardless of the presence of control variables. That is, the organization of residential land structure significantly contributes to the welfare of residents.

For the control variables selected in the regression, the correlation coefficient of residential investment (inv) was positive and significant ($p < 0.01$), indicating that an organized residential land structure promotes residential investment growth, thereby substantially enhancing residential welfare. The coefficient of the fiscal gap (fin) was −0.0138 and significant at the 10% level, indicating that an organized residential land structure can help close the fiscal gap and, consequently, enhance residential welfare. The coefficient for the population density (peo) was −0.0122 but not significant, and the coefficient for the industrial structure (ind) was 0.0257 but also not significant. This indicates that, compared to the orderly nature of the residential land structure, the relationship between population density and industrial structure and residential welfare is more complex, potentially involving the influence of multiple mediating variables and long-term effects, with a less pronounced direct or immediate impact on residential welfare. Population density may indirectly affect welfare by influencing housing demand and the stress on urban infrastructure. Furthermore, the industrial structure could indirectly impact welfare levels by providing employment opportunities and promoting economic growth.

Robustness test

The following robustness tests were conducted to ensure the findings' reliability. If the results were not robust, it would indicate potential model misspecification, data issues, or omitted variable bias, which could undermine the conclusions' validity.

Table 4. Panel cointegration test

	Statistic	*p*-values
Modified Dickey–Fuller t	3.4642	0.0003
Dickey–Fuller t	2.9294	0.0017
Augmented Dickey–Fuller t	3.2641	0.0005
Unadjusted modified Dickey–Fuller t	−3.1038	0.0010
Unadjusted Dickey–Fuller t	−3.3701	0.0004

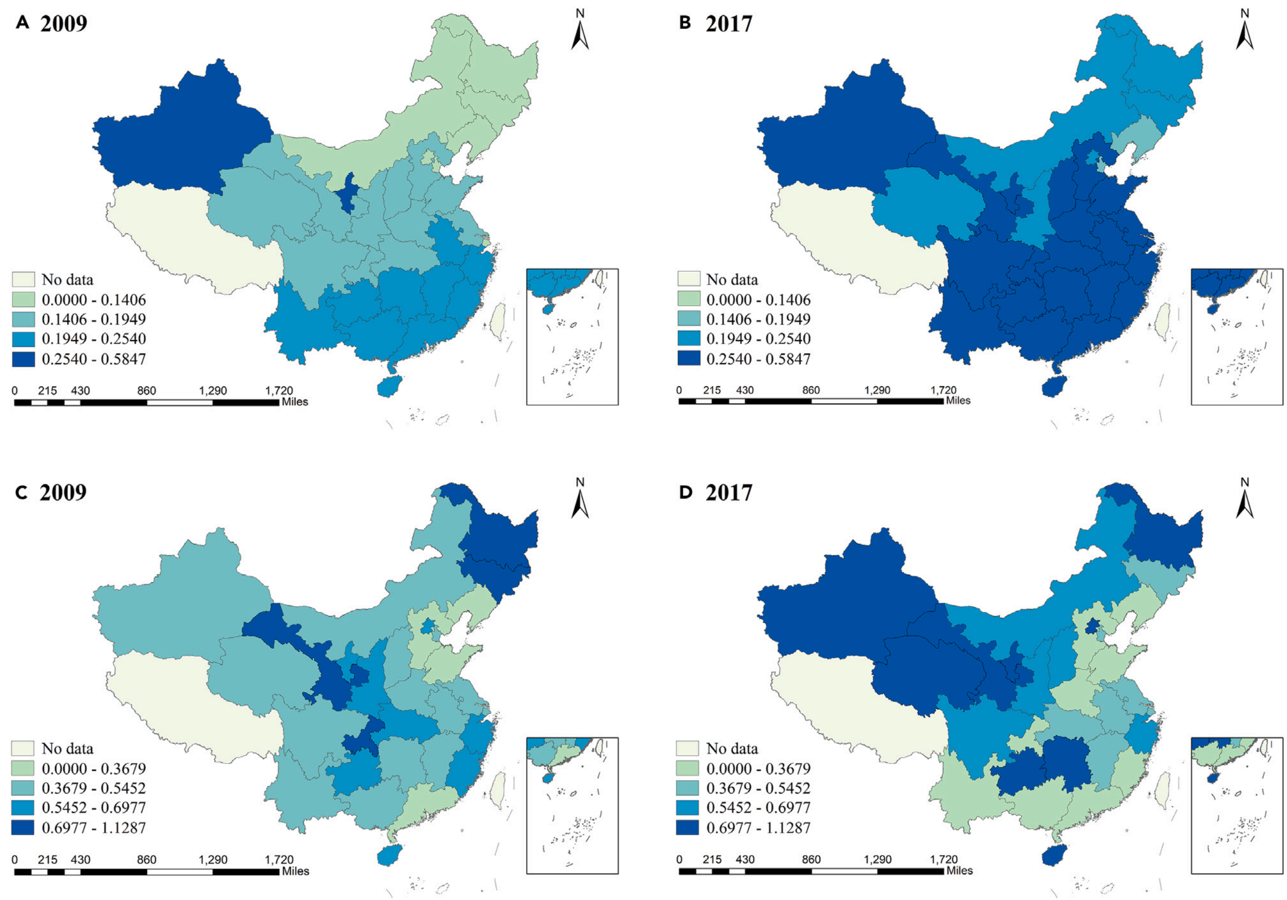

Figure 2. Spatial evolution of residential land structure and residential welfare

Panels (A and B) in Figure 2 depict the spatial evolution of residential land structures among China's 30 provinces from 2009 to 2017. Panels (C and D) display the spatial evolution of resident welfare from 2009 to 2017.

Removing outliers from the sample

In this study, outliers for all variables were handled by removing the top and bottom 1% of values. The estimation results, shown in Column (1) of Table 6, indicate that the ordered residential land structure continues to contribute significantly to the residential welfare level.

Dynamic panel regression

Dynamic panel regression analysis was conducted using the System Generalized Method of Moments (SYS-GMM). Columns (2) and (3) of Table 6 present the results. Column (2) displays the regression results without control variables, with the residential welfare significantly positive at the 10% level. Column (3) includes control variables, and the *Score* coefficient remains positive and significant at the 1% level. However, noteworthily, in Column (3), while the main explanatory variable remains significant, the control variables do not exhibit statistical significance. This may be attributed to the current model specification, which may not fully capture the complexity and interaction effects of the control variables. The Hansen test *p*-value is above 0.100, and the AR(2) and AR(3) test *p*-values indicate the presence of only first-order serial correlation, ensuring the results' robustness. The significant positive correlation between lagged residential welfare and current residential welfare suggests that residential welfare exhibits dynamic continuity and impacts subsequent levels.

Replacement of independent variables

The dependent variable was replaced with the equilibrium of the residential land structure for re-estimation. Columns (4) and (5) present the regression results. Column (4) presents results without control variables, with a coefficient of 0.0272, significant at the 5% level. Column (5) includes control variables, with a coefficient of 0.0312, significant at the 1% level. These tests reaffirm that an organized residential land structure significantly positively impacts residential welfare.

Overall, the robustness tests confirm that the findings are consistent and reliable. The confirmation of robustness across various tests strengthens the study's findings and supports part of Hypothesis 1, suggesting that an organized residential land structure significantly enhances residential welfare.

Table 5. Regression results of residential land structure's impact on residential welfare

Variables	(1)	(2)
inf	0.0196**	0.0225***
	(0.0087)	(0.0087)
ind		0.0257
		(0.0539)
fin		−0.0138*
		(0.0073)
inv		0.1642***
		(0.0553)
peo		−0.0122
		(0.0084)
Constant	0.1829***	0.2700***
	(0.0057)	(0.0762)
Year fixed effect	Yes	Yes
City fixed effect	Yes	Yes
Observations	270	270
R-squared	0.8298	0.8402
Number of id	30	30

Note: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

Further research

Considering the potential nonlinear effects of residential land structure on residential welfare, this study extends beyond linear analysis by employing semiparametric estimation and quantile regression to examine panel data further.

Nonlinear regression analysis

Semiparametric estimation. First, we compared the parametric and non-parametric regressions. Among these, non-parametric regression uses kernel density, k-nearest neighbor, and Lowess regressions. Figure 3 shows a comparison of the scatterplot, linear regression with kernel density regression, k-nearest neighbor regression, and Lowess regression. The results of each of the above non-parametric regressions were notably close to each other, with the scatter being more concentrated in the middle of the inf and more diffuse on both sides. Compared to linear regression, nonparametric regression can fit the data better at the cost of sacrificing part of the smoothness. A non-linear relationship was observed between the impact of residential land structure on residential welfare.

Second, this study adopts a semiparametric estimation to test further the relationship between residential land structure and residential welfare. Figure 4 shows the kernel regression prediction of residential land structure for residential welfare. When the residential land structure has low orderliness, it negatively impacts residential welfare. However, as the orderliness of the structure reaches a certain level, the level of residential welfare increases with an improvement in structural order—consistent with the basic regression results in Table 5.

Quantile regression. Table 7 presents the panel data quantile regression estimation results at the 0.1, 0.3, 0.5, 0.7, and 0.9 quantile points. The parameter estimates for the impact of residential land structure (inf) on residential welfare (Score) are consistently positive and significant at the 0.1, 0.3, 0.5, and 0.9 quantile points but not significant at the 0.7 quantile point, thereby validating the effectiveness of the model proposed in this study. An orderly residential land structure can significantly enhance residential welfare.

Concerning control variables, the coefficient for fiscal gap (fin) is negative and significant at the 0.9 quantile point, indicating that a higher fiscal deficit has a more pronounced adverse effect on welfare in areas with higher levels of residential welfare. The coefficient for residential investment (inv) is positive and significant across most quantile points, suggesting that increased residential investment generally leads to improved welfare. However, the coefficient for population density (peo) is negative and significant at the 0.1 and 0.7 quantile points, implying that high population density primarily negatively impacts welfare in areas with lower and higher levels of residential welfare. The coefficient for industrial structure (ind) is not significant at any quantile point, which may be related to the more indirect influence of industrial structure on welfare, not manifesting as a significant change in the data.

Analysis of regional heterogeneity

Houses are stationary; they have typical regional characteristics and exhibit varying urbanization levels, economic development, and social development across regions. Therefore, further sub-sampling was conducted for heterogeneity analysis, which divides regions according

Table 6. Robustness tests

Variables	Dependent variable: Score (1)	(2)	Dependent variable: equ (3)	(4)	(5)
L.Score		1.0034***	0.8796***		
		(0.0148)	(0.0560)		
Inf	0.0213**	0.0310**	0.1279***		
	(0.0086)	(0.0116)	(0.0433)		
L.inf		−0.0358***	−0.0838**		
		(0.0121)	(0.0341)		
equ				0.0272**	0.0312***
				(0.0120)	(0.0120)
ind	0.0218		−0.0339		0.0257
	(0.0535)		(0.0544)		(0.0539)
fin	−0.0149**		−0.0043		−0.0138*
	(0.0074)		(0.0037)		(0.0073)
inv	0.1594***		−0.0246		0.1642***
	(0.0543)		(0.0893)		(0.0553)
peo	−0.0098		0.0080		−0.0122
	(0.0084)		(0.0346)		(0.0084)
Constant	0.2581***	0.0148***	−0.0172	0.1829***	0.2700***
	(0.0763)	(0.0035)	(0.2556)	(0.0057)	(0.0762)
Year fixed effect	Yes			Yes	Yes
City fixed effect	Yes			Yes	Yes
Hansen *p*-value		0.722	0.859		
ar1 *p*-value		0.001	0.001		
ar2 *p*-value		0.848	0.620		
Observations	270	240	240	270	270

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

to different characteristics, including environmental regulatory intensity, the Heihe-Tengchong Line, and the eastern and non-eastern regions.

Zoning based on the intensity of environmental regulation. The land spatial structure is closely related to carbon emissions, whereas environmental regulation has an inverted U-shaped relationship with carbon emissions.[78] The primary goal of environmental regulations is to regulate and control businesses' emission practices, enabling them to minimize carbon emissions and other forms of environmental pollution during their production processes. Generally, regions with greater environmental regulation intensity have more balanced industrial and commercial land use and a more orderly residential land structure than regions with less intensity. To investigate the heterogeneous relationship between residential land structure and welfare under different environmental regulation intensities, this study divided the sample into strong and weak environmental regulation groups based on the median value of environmental regulation intensities in the 30 provinces for benchmark regression analysis. Specifically, regions with environmental regulation intensity above the median are classified as the strong environmental regulation group, while those below the median are classified as the weak environmental regulation group.

Regression to baseline. Table 8 presents the empirical results, with Columns (1) and (2) showing the regression results for the strong and weak environmental regulation groups, respectively. In the group with stringent environmental regulations, the residential land structure of the area significantly positively impacted the level of residential welfare, whereas no significant relationship was observed between the two in areas with less stringent environmental regulations. This difference exemplifies the regional heterogeneity and corroborates Hypothesis 1. For the results, we derive the following analysis: In regions with strict environmental regulations, the interplay of regulatory oversight and market mechanisms, exemplified by carbon trading markets that offer economic incentives for emission reduction, effectively promotes the optimization of residential land structures. This optimization, in turn, precipitates a comprehensive enhancement of residential welfare. Conversely, in regions where environmental regulations are less stringent, the impact of residential land structure optimization on welfare improvement may not be as pronounced. This diminished effect could stem from a deficiency in policy support and resource allocation,

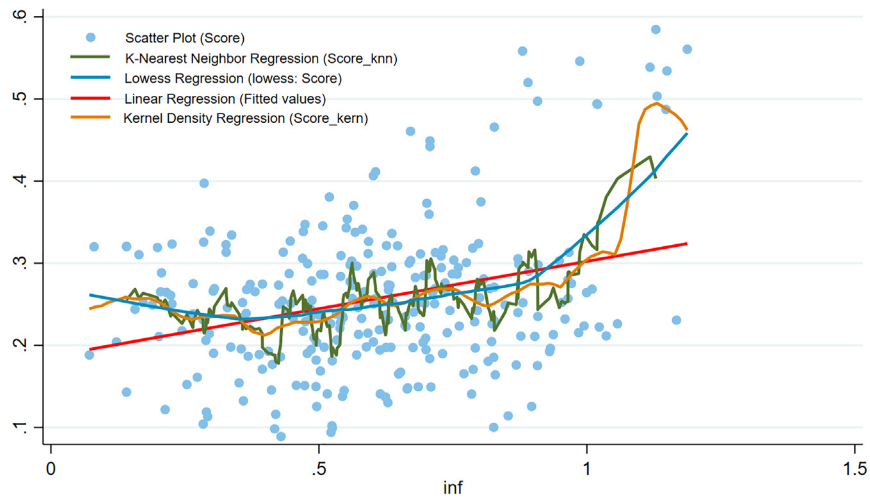

Figure 3. Comparison of non-parametric regressions

Comparison of scatterplots, linear regression, kernel density regression, k-nearest neighbor regression, and Lowess regression.

resulting in lingering environmental challenges and a failure of residential land use planning to adequately address the genuine needs of residents.

Quantile regression. Tables 9 and 10 present the quantile regression results for areas with strong and weak environmental regulations, respectively. Overall, these two types of areas exhibited significant differences in the relationship between residential land structure and residential welfare levels. Specifically, in areas with strong environmental regulations, the residential land structure had a positive and significant impact on residential welfare levels across most quantiles. However, in areas with weak environmental regulations, residential land structure did not significantly affect residential welfare levels across most quantiles. This finding aligns with the results of the basic regression analysis of heterogeneity (Table 8). These results suggest that the effective management and allocation of residential land under strict environmental regulations can improve residential welfare levels. In this context, governments should prioritize the effective utilization of land resources and environmental protection to ensure residents' QoL and environmental sustainability.

Zoning based on the Heihe-Tengchong Line divisions. The Heihe-Tengchong Line is a geographic demarcation line proposed by Chinese geographer Hu Huanyong in 1935, dividing the southeast and northwest parts of China. In the southeastern region, 36% of the land supports 96% of China's population, whereas, in the northwestern region, 64% of the land supports only 4%. The southeastern region is characterized by high population density, advanced urbanization, and a developed transportation network. By contrast, the northwestern region has slower urban growth, a sparse population, and a complex natural environment. Meanwhile, these regions differ significantly in industrial structure, residential investment, and population density. Therefore, this study divided the 30 provinces per the Heihe-Tengchong Line.

Regression to baseline. Column (1) in Table 11 displays the regression outcomes for the southeastern region, indicating that the structure of residential land does not significantly affect the level of residential welfare in these provinces. By contrast, Column (2) reveals that the *inf* coefficient is 0.0549—significant at the 10% level, reflecting that in the northwestern region, orderly planning of residential land structure has a significantly positive impact on residential welfare. This aligns with the content of Hypothesis 1, which posits that the relationship between residential land structure and welfare exhibits heterogeneity influenced by geographical factors.

Furthermore, the results from Table 11 suggest that owing to the economic maturity and high urbanization level in the southeastern region, residential welfare is influenced by a multitude of factors, thus limiting the impact of adjustments in residential land structure. Conversely, orderly residential land planning plays a more significant role in enhancing residential welfare in the relatively underdeveloped northwestern region, characterized by low population density, lower urbanization, and abundant land resources. Such regional disparities highlight the need for land use policies to consider the economic development levels of different regions to maximize improvements in residential welfare.

Quantile regression. Tables 12 and 13 present the quantile regression results for the southeastern and northwestern regions, respectively—consistent with the results of the basic regression analysis of heterogeneity (Table 11). Specifically, the results for the southeastern region indicated no relationship between residential land structure and the level of residential welfare under the rest of the quantile tests, except for a weakly significant relationship at the two extreme quantile points.

By contrast, in the northwestern region, the importance of planning residential land structures for residents' welfare is further emphasized. Notably, a negative relationship was observed at the 0.1 decile in the Northwest Territories—attributable to a combination of the unequal

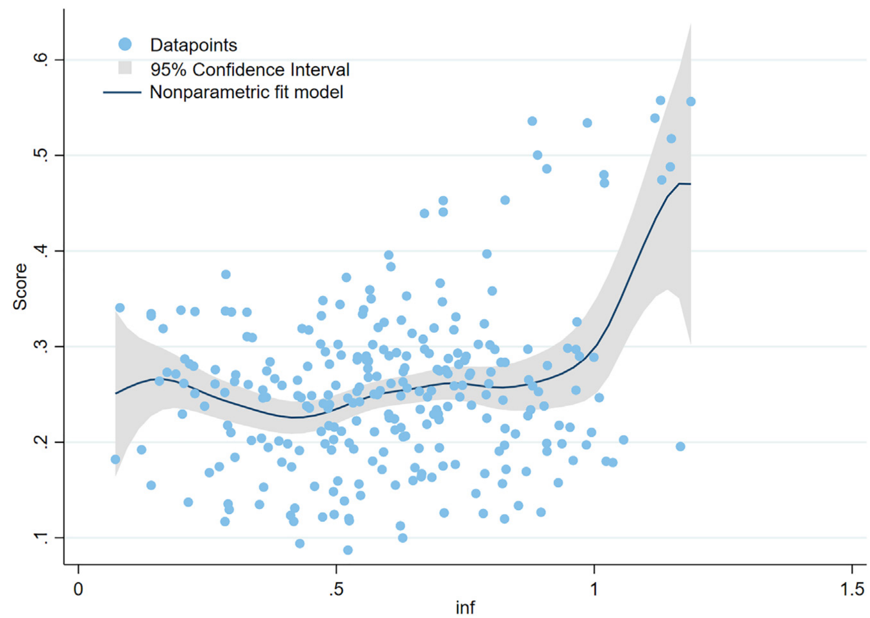

Figure 4. Semi-parametric panel linear prediction plot
Comparison between linear regression and semi-parametric regression.

distribution of resources, insufficient social service facilities, and income distribution effects. For example, in more resource-poor areas, changes in the residential land structure may result in fewer people enjoying limited resources, thus reducing the welfare of residential in the lower quartiles.[79] In summary, planning for residential land structures is particularly important in the Northwest Territories (NWT) to enhance the welfare of residents.

Analysis of eastern and non-eastern heterogeneity. China has implemented a coordinated regional development strategy. In 2022, the combined GDP of the nine cities in the eastern region, namely Beijing-Tianjin-Hebei, the Yangtze River Delta, and Guangdong-Hong

Table 7. Quantile regression estimates

	(1)	(3)	(4)	(5)	(6)
Variables	Q10	Q30	Q50	Q70	Q90
inf	0.0209***	0.0254**	0.0308***	0.0144	0.0163***
	(0.0063)	(0.0108)	(0.0102)	(0.0099)	(0.0061)
ind	0.0560	0.0097	0.0708	0.0663	0.0395
	(0.0391)	(0.0673)	(0.0632)	(0.0618)	(0.0378)
fin	−0.0005	−0.0129	−0.0075	−0.0130	−0.0153***
	(0.0053)	(0.0091)	(0.0085)	(0.0083)	(0.0051)
inv	0.1131***	0.0904	0.1623**	0.0969	0.1434***
	(0.0401)	(0.0691)	(0.0649)	(0.0634)	(0.0388)
peo	−0.0141**	−0.0049	−0.0143	−0.0195**	−0.0089
	(0.0061)	(0.0105)	(0.0098)	(0.0096)	(0.0059)
Year fixed effect	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes
Constant	0.1384***	0.1171	0.1532**	0.2423***	0.1698***
	(0.0474)	(0.0817)	(0.0766)	(0.0749)	(0.0458)
Observations	270	270	270	270	270

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

Table 8. Heterogeneity regression results for environmental regulation sub-regions

Variables	(1)	(2)
inf	0.0305**	0.0163
	(0.0127)	(0.0127)
ind	0.0357	−0.0850
	(0.0654)	(0.1117)
fin	−0.0068	−0.0266**
	(0.0093)	(0.0133)
inv	0.1308	0.0986
	(0.0804)	(0.0949)
peo	−0.0143	−0.0077
	(0.0095)	(0.0213)
Constant	0.2628***	0.3299**
	(0.0917)	(0.1621)
Year fixed effect	Yes	Yes
City fixed effect	Yes	Yes
Observations	135	135
R-squared	0.8283	0.8723
Number of id	15	15

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

Kong-Macao-Greater Bay Area reached 49.5 trillion yuan, exceeding 40 percent of the GDP, playing a dominant role in China's economy. However, significant economic differences exist between the eastern and non-eastern regions. These differences are reflected in the level of economic development and further affect the social structure and livelihood conditions. Per the regional division criteria in the "China Statistical Yearbook," the 30 provinces and cities are classified into eastern and non-eastern regions.

Regression to baseline. Column (1) of Table 14 represents the results for the eastern region, where the coefficient for *inf* is not significant, indicating that residential land structure does not significantly impact residential welfare. Column (2) shows the regression results for the non-eastern region, where the coefficient for *inf* is 0.0219 ($p < 0.1$), suggesting that a more organized residential land structure enhances residential welfare in non-eastern provinces. This is similar to the conclusion in Section 6.2.2. Specifically, in economically mature regions with high levels of urbanization, the impact of residential welfare influenced by residential land structure is relatively limited. By contrast, in economically underdeveloped regions with low urbanization levels, the impact of residential welfare influenced by residential land structure is significant. The possible reasons for this phenomenon are as follows: Significant differences exist between the eastern and non-eastern regions in terms of economic development and urbanization processes. The eastern region, owing to its coastal location, has historically been a center for economic and trade activities. This region has a large economic scale and faces more stringent land-use restrictions and regulatory measures. The urbanization process in the eastern region started earlier, precipitating a relatively stable residential land structure, which may not significantly enhance residential welfare compared to other factors.

By contrast, the non-eastern regions have a relatively delayed urbanization process and more flexible land-use policies. Governments in these regions have greater leeway in land planning and optimizing residential land structure, rendering the impact of residential land structure on residential welfare more pronounced. The mature infrastructure and social services in the eastern region may reduce the marginal effects of changes in residential land structure on residential welfare, whereas in the non-eastern regions, optimizing land use can more directly improve residents' welfare levels. The conclusions drawn in this section further substantiate Hypothesis 1.

Quantile regression. Tables 15 and 16 present the regression results for eastern and non-eastern regions, respectively. In the eastern region, no significant relationship was observed between residential land structure and residential welfare levels across most quantiles. By contrast, in the non-eastern region, residential land structure significantly positively impacted residential welfare levels across most quantiles—consistent with the results of the basic regression analysis of heterogeneity presented in Table 14, which further underscores the differences in the relationship between residential land structure and residential welfare levels in eastern and non-eastern regions.

DISCUSSION

In the preceding research, we found that an orderly residential land structure can significantly enhance residential welfare, with this effect exhibiting heterogeneity. However, these studies have primarily focused on the direct impact of residential land structure on residential

Table 9. Regression results for regions with strong environmental regulatory intensity

	(1)	(3)	(4)	(5)	(6)
Variables	Q10	Q30	Q50	Q70	Q90
inf	0.0259***	0.0201	0.0415***	0.0340**	0.0125
	(0.0064)	(0.0156)	(0.0134)	(0.0143)	(0.0081)
ind	0.1899***	0.1077	0.0441	0.0254	0.0191
	(0.0375)	(0.0918)	(0.0788)	(0.0840)	(0.0476)
fin	0.0088*	−0.0150	−0.0098	−0.0125	−0.0211***
	(0.0048)	(0.0117)	(0.0100)	(0.0107)	(0.0061)
inv	0.1336***	−0.0022	0.0223	−0.0097	−0.0395
	(0.0484)	(0.1184)	(0.1017)	(0.1083)	(0.0614)
peo	−0.0137***	−0.0231**	−0.0243**	−0.0358***	−0.0185***
	(0.0048)	(0.0117)	(0.0100)	(0.0107)	(0.0060)
Constant	0.1151***	0.2723***	0.2594***	0.3626***	0.2781***
	(0.0391)	(0.0957)	(0.0822)	(0.0876)	(0.0496)
Year fixed effect	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	135	135	135	135	135

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

welfare and have paid little attention to the constraints imposed by external factors. We recognize that relying solely on direct effects may not fully capture the complexity of this relationship, particularly in the context of rapid urbanization and the impact of carbon emissions in China. Therefore, this study aims to discuss the roles of urbanization as a mediator and carbon emissions as a moderator, exploring their independent and interactive effects in the relationship between residential land structure and residential welfare.

Mediation analysis

Table 17 presents the mediation analyses' results. In Column (1), the coefficient for the influence of residential land structure(inf) was 0.0225 ($p < 0.01$), indicating that an orderly residential land structure significantly contributes to the improvement of the level of residential welfare. In Column (2), the coefficient of influence of inf was −0.0162 ($p < 0.05$), indicating that an orderly residential land structure relatively inhibits urbanization. The negative correlation may be attributed to the fact that an orderly residential land structure leads to increased land scarcity and property value inflation, which in turn suppresses urban expansion. This implies that the aspiration for well-organized residential areas might come at the cost of constraining available land for new urban development, thereby relatively decelerating the pace of urbanization. In Column (3), the coefficients of urbanization (urb) and the influence of inf were both significant and had opposite signs. Urbanization is indeed a partially mediating variable between residential land structure and residential welfare, thus verifying Hypothesis 2. Urb demonstrates a significant negative coefficient (−0.1517), indicating a detrimental effect on residential welfare. While urbanization offers economic benefits, it may also introduce challenges such as increased living costs, overcrowding, and environmental degradation, which, when combined, could erode the QoL for residents. In summary, although an orderly residential land structure may to some extent suppress the rapid development of urbanization, its overall enhancing effect on residential welfare remains significant.

Moderation analysis

This study employed a two-way fixed-effects model to examine the moderation of carbon emissions on the promotion of residential welfare through residential land structures. To mitigate multicollinearity in the Equations, each variable was decentered.

In Table 18, it can be observed that in Columns (1) and (2), the coefficients for inf and ei are both significantly correlated, indicating a baseline positive correlation between residential land structure and welfare, as well as a direct negative impact of carbon emissions. Notably, in Column (3), the interaction term inf*ei exhibits a coefficient of 0.0418, which is significant at the 5% level, thereby confirming the moderating effect of carbon intensity and validating Hypothesis 3. This suggests that carbon emissions intensify the positive influence of a well-organized residential land structure on welfare. The mechanism behind this moderating effect is related to the direct impact of carbon emissions on environmental quality and the potential influence of declining environmental quality on public health. Specifically, disordered residential land structures are associated with higher carbon emissions, which can exacerbate environmental pollution and health issues, potentially diminishing welfare.

Table 10. Regression results for regions with weak environmental regulations

	(1)	(3)	(4)	(5)	(6)
Variables	Q10	Q30	Q50	Q70	Q90
inf	0.0145**	0.0043	0.0078	0.0162	0.0333***
	(0.0060)	(0.0123)	(0.0150)	(0.0146)	(0.0048)
ind	0.1933***	−0.0644	−0.0772	−0.1086	−0.0325
	(0.0486)	(0.0999)	(0.1220)	(0.1184)	(0.0390)
fin	−0.0182***	−0.0297**	−0.0036	−0.0037	−0.0093*
	(0.0059)	(0.0121)	(0.0148)	(0.0144)	(0.0047)
inv	0.1408***	0.1845**	0.0754	0.1002	0.1308***
	(0.0405)	(0.0833)	(0.1017)	(0.0987)	(0.0326)
peo	0.0372***	0.0252	0.0111	0.0140	−0.0104
	(0.0095)	(0.0195)	(0.0238)	(0.0231)	(0.0076)
Constant	−0.2248***	−0.0700	0.0437	0.0281	0.1723***
	(0.0678)	(0.1394)	(0.1702)	(0.1651)	(0.0545)
Year fixed effect	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	135	135	135	135	135

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

Mixed effect

This study continued to test the mechanisms in studies with both mediating and moderating variables. This subsection uses Ordinary Least Squares (OLS) benchmark regression to construct a mediated moderation model, a mediated effect model with moderation, and a mixed model combining both approaches with the same variable treatment, as described in the previous section. Only the mixed model analysis is presented here; the remainder is provided in the Supplement. For the mixed model constructed in this study, the testing procedure proposed by Yeh and Wen was adopted, as the relevant tests of Edwards and Lambert are mainly for the mediated mediation model with moderation.[80]

Table 11. Heterogeneity regression results for southeastern and northwestern provinces

Variables	(1)	(2)
inf	0.0100	0.0549*
	(0.0090)	(0.0318)
ind	−0.0045	0.0145
	(0.0558)	(0.1954)
fin	−0.0200**	−0.0146
	(0.0087)	(0.0173)
inv	0.1067*	0.3190
	(0.0550)	(0.2599)
peo	−0.0109	−0.0219
	(0.0096)	(0.0192)
Constant	0.2903***	0.3815**
	(0.0890)	(0.1802)
Year fixed effect	Yes	Yes
City fixed effect	Yes	Yes
Observations	225	45
Number of id	25	5
R-squared	0.8683	0.8448

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

Table 12. Quartile regression results for the southeast region

Variables	(1) Q10	(3) Q30	(4) Q50	(5) Q70	(6) Q90
inf	0.0161***	0.0183	0.0148	0.0030	0.0083*
	(0.0055)	(0.0115)	(0.0091)	(0.0106)	(0.0049)
ind	0.0580*	0.0326	0.0609	0.0707	0.0112
	(0.0345)	(0.0718)	(0.0563)	(0.0660)	(0.0308)
fin	−0.0032	−0.0020	−0.0081	−0.0193*	−0.0208***
	(0.0054)	(0.0112)	(0.0088)	(0.0103)	(0.0048)
inv	0.0700**	0.0953	0.1331**	0.0581	0.0672**
	(0.0340)	(0.0707)	(0.0555)	(0.0650)	(0.0303)
peo	−0.0128**	−0.0122	−0.0120	−0.0191*	−0.0117**
	(0.0059)	(0.0123)	(0.0097)	(0.0113)	(0.0053)
Constant	0.1533***	0.1537	0.1623**	0.2688***	0.2293***
	(0.0474)	(0.0987)	(0.0775)	(0.0907)	(0.0423)
Year fixed effect	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	225	225	225	225	225

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

Table 19 presents the regression results. In Columns 1 and 3, the coefficient for inf is positive ($p < 0.01$), strongly confirming its positive correlation with residential welfare. Additionally, Columns (1) to (3) demonstrate the combined effect of urbanization and carbon emissions. Firstly, regression analysis was conducted with residential welfare (Score) regressed on inf, ei, and their interaction term (inf*ei) (Model 1). The results indicate that the coefficient for ei and its interaction with inf*ei is significant, demonstrating that carbon emissions moderate the positive effect of residential land structure on residential welfare, reaffirming the moderating role of carbon emissions. Secondly, the study examined the regression of urb on inf, ei, and inf*ei (Model 2). The negative coefficient for inf*ei (−2.7457) suggests that urbanization may limit the optimization potential of residential land structures while promoting environmental protection and the use of clean energy, thereby reducing

Table 13. Quartile regression results for the northwest region

Variables	(1) Q10	(3) Q30	(4) Q50	(5) Q70	(6) Q90
inf	−0.0047***	0.0310	0.0763***	0.0685*	0.0598***
	(0.0000)	(0.0260)	(0.0248)	(0.0345)	(0.0000)
ind	−0.1753***	0.0453	0.1176	−0.0844	−0.3194***
	(0.0000)	(0.1597)	(0.1527)	(0.2122)	(0.0000)
fin	−0.0262***	−0.0145	−0.0110	−0.0286	−0.0240***
	(0.0000)	(0.0141)	(0.0135)	(0.0188)	(0.0000)
inv	0.7236***	0.4315*	0.1149	0.0987	0.1599***
	(0.0000)	(0.2124)	(0.2030)	(0.2823)	(0.0000)
peo	−0.0051***	−0.0193	−0.0152	−0.0353	−0.0278***
	(0.0000)	(0.0157)	(0.0150)	(0.0208)	(0.0000)
Constant	0.1988***	0.1691	0.1103	0.3998**	0.4596***
	(0.0000)	(0.1384)	(0.1323)	(0.1840)	(0.0000)
Year fixed effect	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	45	45	45	45	45

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

Table 14. Heterogeneity regression results for eastern and non-eastern provinces

Variables	(1)	(2)
inf	0.0101	0.0219*
	(0.0130)	(0.0114)
ind	−0.0626	−0.0108
	(0.1250)	(0.0639)
fin	0.0209	−0.0137
	(0.0221)	(0.0087)
inv	0.2242**	0.1645**
	(0.0948)	(0.0754)
peo	−0.0315	−0.0150
	(0.0218)	(0.0096)
Constant	0.3646**	0.3272***
	(0.1713)	(0.0920)
Year fixed effect	Yes	Yes
City fixed effect	Yes	Yes
Observations	90	180
Number of id	10	20
R-squared	0.9126	0.8217

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

carbon emissions. Finally, Model 3 tested the regression of Score on inf, urb, and the interaction terms inf*ei and ei*urb. The results show that the coefficient for ei*urb is significantly positive, indicating a substantial impact of their interaction on residential welfare. The coefficient for inf*ei, at 0.5895, is significant at the 1% level, suggesting that the intensity of carbon emissions remains a positive moderator of the relationship between residential land structure and residential welfare, even after accounting for urbanization factors. This may imply that orderly residential land structure can still enhance residential welfare by reducing carbon emissions, despite the challenges posed by urbanization.

Overall, our mixed model analysis has shed light on the complex relationships between residential welfare, residential land structure, urbanization, and carbon emissions. Figure 5 depicts the residential land structure's impact on welfare, influenced by both carbon emissions and urbanization. Although urbanization is a key aspect of optimizing land structure, it may paradoxically erode certain aspects of residential welfare. On the contrary, carbon emissions play a positive moderating role in this dynamic. The moderating effect of carbon emissions appears to be mediated, at least in part, through urbanization, which in turn facilitates the promotion of orderly land structures conducive to enhanced welfare. The interplay between urbanization and carbon emissions is critical, with carbon emissions playing a pivotal moderating role in the complex relationship between residential welfare and urbanization.

Conclusions

This study constructs a comprehensive evaluation index system for residential welfare levels and explores the impact and mechanism of residential land structure on residential welfare from both linear and nonlinear perspectives under the dual-carbon background. The main findings are as follows: (1) An orderly residential land structure can significantly enhance the level of residential welfare, particularly influenced by the notable impact of fiscal gaps and residential investment. In contrast, the influence of population density and industrial structure on welfare levels is not as significant as anticipated. Furthermore, the dynamic nature of residential welfare indicates its important impact on future welfare levels. (2) This effect exhibits significant heterogeneity across different regions. In areas with strong environmental regulations, abundant land resources but low population density, slow urban development, and underdeveloped economies, an orderly residential land structure significantly positively impacts residents' welfare levels. Conversely, in regions characterized by lenient environmental regulations, scarce land resources, rapid urban development, and developed economies, the residential land structure shows no significant impact on residential welfare. (3) Urbanization plays a partial mediating role in the impact of residential land structure on residential welfare. Although an orderly residential land structure may to some extent suppress the rapid development of urbanization, its overall effect on enhancing residential welfare remains significant. (4) Carbon emissions play a significant moderating role in the relationship between residential land structure and residential welfare, further enhancing their positive correlation. An orderly residential land structure can reduce carbon emissions while enhancing the level of residential welfare. (5) Residential land structure's impact on residents' welfare is influenced by the joint effects of urbanization and carbon emissions. Urbanization partially mediates this impact, but its effectiveness is influenced by carbon emissions. Concurrently, carbon emissions indirectly enhance the positive effect of orderly residential land structure on residents' welfare through urbanization.

Table 15. Quartile regression results for the eastern region

	(1)	(2)	(3)	(4)	(5)
Variables	Q10	Q30	Q50	Q70	Q90
inf	0.0131***	0.0116	0.0170	0.0290	0.0141***
	(0.0013)	(0.0146)	(0.0192)	(0.0182)	(0.0030)
ind	−0.0417***	−0.1243	−0.0699	0.1007	0.1892***
	(0.0122)	(0.1398)	(0.1841)	(0.1749)	(0.0285)
fin	0.0293***	0.0391	0.0457	0.0424	−0.0081
	(0.0022)	(0.0248)	(0.0326)	(0.0310)	(0.0051)
inv	0.2846***	0.1737	0.1913	0.2123	0.2044***
	(0.0092)	(0.1060)	(0.1397)	(0.1327)	(0.0217)
peo	0.0002	−0.0521**	−0.0626*	−0.0351	−0.0235***
	(0.0021)	(0.0243)	(0.0320)	(0.0304)	(0.0050)
Constant	0.0061	0.4258**	0.4771**	0.2416	0.2187***
	(0.0149)	(0.1715)	(0.2259)	(0.2146)	(0.0350)
Year fixed effect	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	90	90	90	90	90

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

Accordingly, the study proposes the following policy recommendations: First, the government should optimize the planning of residential land structures. By reasonably allocating the proportion of residential land and ensuring the supply of affordable housing and public rental housing, residents' QoL and happiness can be enhanced. Furthermore, the government should take measures to optimize the structure of fiscal revenues and expenditures, reduce fiscal deficits, and prevent negative impacts on residential welfare. Concurrently, increased investment in the residential sector should be encouraged, particularly in providing affordable and public rental housing to meet the housing needs of residents across different income levels and promote the overall improvement of social welfare.

Second, considering the differentiated impact of residential land structure on residential welfare, local governments should adjust incentive measures in accordance with specific local conditions. In regions with stringent environmental regulations, non-eastern areas, and those with underdeveloped economies, there should be an emphasis on strengthening the rational allocation of residential land structure to support sustainable economic development and enhance welfare. Conversely, in areas where previous research has indicated that the impact of residential land structure on welfare is not significant, local policies should focus on a broader range of interventions. These may include reinforcing the social safety net, promoting equitable access to public services, and implementing policies that alleviate the cost of living for residents, thereby improving living welfare without relying solely on adjustments to residential land allocation.

Third, the government should actively guide the urbanization process and develop differentiated strategies according to the specific conditions of different regions. By reasonably controlling the pace of urban expansion, the high-density living conditions and resource pressures brought about by rapid urbanization can be avoided. Specific measures include promoting the construction of small towns, enhancing the public service levels of small and medium-sized cities, reducing the resource pressures on large cities, and optimizing the living environments for residents. For instance, in the eastern regions, where the level of urbanization is relatively high and land resources are relatively scarce, policies should focus on improving urban land use efficiency and encouraging sustainable compact urban development.

Fourth, enhancing the regulation and control of carbon emissions is of paramount importance. By advocating for green buildings and eco-friendly communities, as well as the adoption of energy-saving and environmentally friendly technologies, we can reduce building energy consumption and carbon emissions, thereby improving environmental quality and residential welfare. Governments can establish green building standards, offer financial subsidies and tax incentives, and motivate developers and residents to adopt energy-saving and environmentally friendly measures. To further refine these efforts, policies should take into account regional disparities, particularly in terms of economic development. In economically advanced regions with well-developed infrastructure, specific regional green building initiatives and policy frameworks tailored to local climate and resource conditions can further enhance energy efficiency and promote long-term improvements in residential welfare.

Limitations of the study

This study systematically investigates the relationship between residential land structure and residential welfare, making an important contribution to related research and providing policy guidance for improving the welfare of residents in developing regions. However, the study has certain limitations that need to be addressed. Firstly, due to the lack of land and resource statistics in China after 2018, recent changes in

Table 16. Quartile regression results for non-eastern region

	(1)	(2)	(3)	(4)	(5)
Variables	Q10	Q30	Q50	Q70	Q90
inf	0.0275***	0.0247**	0.0181	−0.0026	−0.0040
	(0.0053)	(0.0112)	(0.0177)	(0.0145)	(0.0063)
ind	0.0193	−0.0725	−0.0213	0.0654	0.0722**
	(0.0295)	(0.0628)	(0.0996)	(0.0812)	(0.0354)
fin	0.0053	−0.0179**	−0.0070	−0.0091	−0.0016
	(0.0040)	(0.0085)	(0.0135)	(0.0110)	(0.0048)
inv	0.1688***	0.1252*	0.1985*	0.1485	0.1213***
	(0.0348)	(0.0741)	(0.1175)	(0.0958)	(0.0417)
peo	−0.0285***	−0.0172*	−0.0204	−0.0076	−0.0033
	(0.0044)	(0.0094)	(0.0150)	(0.0122)	(0.0053)
Constant	0.3105***	0.3292***	0.2980**	0.1962*	0.1581***
	(0.0426)	(0.0908)	(0.1440)	(0.1174)	(0.0512)
Year fixed effect	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	180	180	180	180	180

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

residential land are unclear, and long-term trends are not reflected. Recently, China has implemented urban renewal and stock reconstruction, strengthening the construction of guaranteed housing. This may enhance the rationality of residential land structure in certain regions or cities, thereby increasing its impact on residential welfare. Secondly, the indicators used in the study may still not comprehensively cover all factors affecting residential welfare. Future research can further expand the data scope and consider more influencing factors to gain a more comprehensive understanding of the complex relationship between residential land structure and residential welfare. Thirdly, while this study

Table 17. Regression results of mediating effects of urbanization

	(1)	(2)	(3)
Variables	Score	urb	Score
inf	0.0225***	−0.0162**	0.0201**
	(0.0087)	(0.0064)	(0.0088)
urb			−0.1517*
			(0.0893)
ind	0.0257	0.1131***	0.0429
	(0.0539)	(0.0399)	(0.0546)
fin	−0.0138*	−0.0085	−0.0151**
	(0.0073)	(0.0054)	(0.0073)
inv	0.1642***	−0.1696***	0.1385**
	(0.0553)	(0.0410)	(0.0572)
peo	−0.0122	−0.0170***	−0.0148*
	(0.0084)	(0.0062)	(0.0085)
Constant	0.2700***	0.6361***	0.3665***
	(0.0762)	(0.0564)	(0.0948)
Observations	270	270	270
R-squared	0.8402	0.8723	0.8422
Number of id	30	30	30

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

Table 18. Regression results of the moderating effect of carbon intensity

Variables	(1)	(2)	(3)
inf	0.0225***	0.0189**	0.0200**
	(0.0087)	(0.0085)	(0.0085)
ei		−0.0595***	−0.0608***
		(0.0177)	(0.0176)
inf*ei			0.0418**
			(0.0212)
ind	0.0257	0.0059	0.0065
	(0.0539)	(0.0531)	(0.0527)
fin	−0.0138*	−0.0152**	−0.0163**
	(0.0073)	(0.0071)	(0.0071)
inv	0.1642***	0.1618***	0.1724***
	(0.0553)	(0.0541)	(0.0541)
peo	−0.0122	−0.0104	−0.0108
	(0.0084)	(0.0082)	(0.0082)
Constant	0.2700***	0.3620***	0.3663***
	(0.0762)	(0.0794)	(0.0790)
Observations	270	270	270
R-squared	0.8402	0.8478	0.8504
Number of id	30	30	30

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

has delved into the heterogeneity of the relationship between residential land structure and welfare, constraints such as space have limited our ability to conduct an in-depth analysis of the differences in mechanisms. Specifically, the differentiated mechanisms under the conditions of regional disparities, environmental regulations, and economic development merit further exploration. Future research endeavors will incorporate these dimensions of heterogeneity, aiming to provide a more comprehensive understanding through in-depth analysis. Finally, to gain a deeper understanding of the impact of environmental regulation intensity on the orderliness of residential land structure, more detailed regional surveys and data verification are required. For instance, in areas with weaker environmental regulations, there may be a tendency toward disorder in the residential land structure. Such disorder could lead to inefficient land use and a decline in the QoL environment in these areas, thereby indirectly affecting residential welfare. Therefore, it is vital to strengthen environmental regulations and enhance policies for residential welfare in areas with weak environmental regulations. A detailed analysis will be further discussed in subsequent research.

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources should be directed to the lead contact, Lei Gan(ganlei@cqut.edu.cn).

Materials availability

This study did not generate any new unique reagents.

Data and code availability

- The basic data are available in supplemental information, and the detailed data associated with the article is available from the lead contact on reasonable request.
- This article does not report original code.
- Any additional information required to reanalyze the data reported in this article is available from the lead contact upon request.

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Table 19. Regression results of Mixed model

	(1)	(2)	(3)
Variables	Score	urb	Score
inf	0.1049***	−0.2256***	0.0749***
	(0.0229)	(0.0706)	(0.0216)
urb			−0.2466***
			(0.0639)
ei	−0.3052***	−0.9098***	−0.5947***
	(0.0431)	(0.1330)	(0.0972)
inf*ei	0.9396***	−2.7457***	0.5895***
	(0.2037)	(0.6286)	(0.1956)
ei*urb			1.0907**
			(0.5241)
ind	−0.1239*	−0.2254	−0.1578**
	(0.0661)	(0.2040)	(0.0614)
inv	−0.1099	0.1056	−0.1202
	(0.0877)	(0.2706)	(0.0820)
fin	0.0104*	−0.1937***	−0.0206***
	(0.0056)	(0.0172)	(0.0074)
peo	−0.0257**	0.2662***	0.0104
	(0.0113)	(0.0349)	(0.0118)
Constant	−0.0053	0.0154	0.0155
	(0.0048)	(0.0147)	(0.0101)
Observations	270	270	270

Notes: ***, **, and * represent significance at the levels of 1%, 5%, and 10%, respectively. The data in parentheses represent the t-statistic.

AUTHOR CONTRIBUTIONS

Jiao Li: Writing – review and editing, writing – original draft, conceptualization, funding acquisition, methodology, resources, and supervision. **Xueying Zhang:** writing – review and editing, writing – original draft, data curation, formal analysis, investigation, methodology, software, validation, and visualization. **Lei Gan:** Writing – review and editing, formal analysis, investigation, methodology, project administration, supervision, and visualization.

DECLARATION OF INTERESTS

The authors have declared that no competing interest exists.

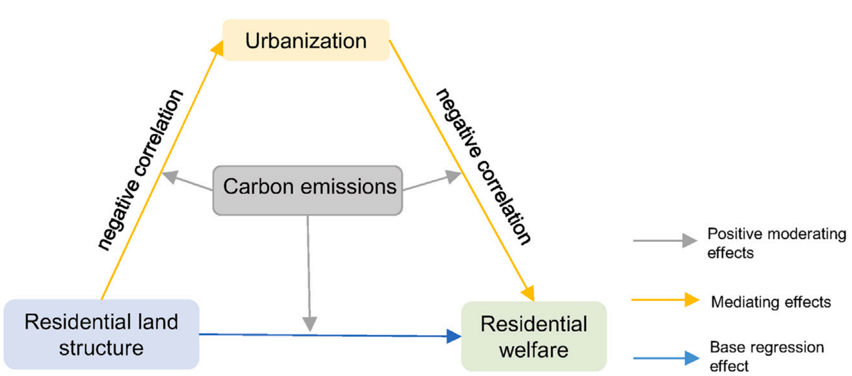

Figure 5. Path diagram of hybrid model

Diagrams of baseline regression effects, mediation effects, and moderation effects. Yellow arrows represent mediation effect paths. Blue arrows represent baseline regression effect paths. Gray arrows indicate moderation effect paths.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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  - Heterogeneity regional impact difference analysis
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SUPPLEMENTAL INFORMATION

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Software and algorithms		
Stata17	Stata 17 is a statistical analysis software provided by StataCorp LP. It can be obtained through the official website of StataCorp LP or from authorized distributors.	

METHOD DETAILS

Data description

Residential welfare data is synthesized from nine pivotal indicators: economic access, residential consumption, residential security, health, transportation, security, education, carbon emissions, and residential rights. The data primarily stem from the "China Financial Yearbook," "China Statistical Yearbook," and various local statistical yearbooks. Specifically, the economic access indicator is calculated as the ratio of per capita disposable income to per capita regional GDP; the residential consumption indicator is measured by the ratio of per capita comprehensive residential expenditure to per capita annual consumer expenditure; the residential security indicator is determined by the proportion of housing security expenditure to general fiscal budget expenditure; the health indicator is computed by the ratio of medical and health expenditure to general fiscal budget expenditure; the transportation indicator is established by the ratio of transportation expenditure to general fiscal budget expenditure; the security indicator is the ratio of public safety expenditure to general fiscal budget expenditure; the education indicator is calculated by the ratio of educational expenditure to general fiscal budget expenditure; the carbon emissions indicator is measured by the ratio of carbon emissions to energy consumption; and the residential rights indicator is the ratio of commercial housing sales area to residential sales area.

The residential land structure indicator is represented by information entropy, incorporating four categories of land use: commercial housing land, affordable housing land, low-rent housing land, and other land types, as sourced from the "China Land and Resources Statistical Yearbook." Information entropy serves as a quantitative tool for measuring the diversity and balance of the residential land structure. By calculating the proportion of each land type's area relative to the total residential land area, the information entropy is computed using the formula $H = -\sum_{i=1}^{m} P_t \cdot Ln\, P_i$, where P_i denotes the proportion of the i-th land type, and n represents the total number of land categories. This indicator reflects the evenness of the residential land distribution and the diversity of land types. When the areas of each land type are equal, the information entropy reaches its maximum value, indicating the most balanced and mature residential land structure. Conversely, if one land type significantly exceeds others in area, the information entropy decreases, suggesting a potential imbalance in the residential land structure.

TWFE (two-way fixed-Effects model

The two-way fixed effects model, by controlling for both individual province and time-year fixed effects, effectively addresses potential omitted variable bias and endogeneity issues inherent in time-series data. This study employs the two-way fixed effects model to explore the impact of residential land structure on residential welfare levels. Initially, we establish the basic framework of the model, incorporating residential land structure as the primary explanatory variable, alongside a range of control variables such as industrial structure, fiscal gaps, residential investment, and population density to ensure the model's comprehensiveness and explanatory power.

The model construction is based on balanced panel data from 30 provincial regions in China from 2009 to 2017. We utilized entropy methods to quantify the orderliness of residential land structure and employed composite indicators to measure residential welfare levels. The model is represented as:

$$Score_{it} = \alpha_0 + \alpha_1\, Inf_{it} + \beta_0 Controls_{it} + \phi_i + \gamma_t + \varepsilon_{it}$$

In this model, α_1 represents the coefficient of the impact of residential land structure on residential welfare levels, while β_0 denotes the coefficients for the control variables. The individual fixed effects ϕ_i and time fixed effects γ_t capture province-specific effects and time trend effects, respectively.

To validate the robustness of the model, we employed the System Generalized Method of Moments (SYS-GMM) approach to address potential endogeneity issues in dynamic panel data. By incorporating lagged terms as instrumental variables, the SYS-GMM method effectively estimates model parameters while accounting for the long-term effects of residential land structure on residential welfare. Additionally, a series of robustness checks were conducted, including the exclusion of outliers and the replacement of core explanatory variables, to ensure the reliability of the research findings.

Nonlinear model analysis

In this study, the application of nonlinear models is primarily achieved through semi-parametric estimation and quantile regression, which possess advantages in capturing and analyzing the nonlinear characteristics of data.

Semi-parametric estimation method

The semi-parametric estimation method allows the model to maintain a certain degree of parametric structure while also incorporating non-parametric features, thus providing a more flexible fit to the data. In this study, kernel smoothing techniques were employed to estimate the relationship between residential land structure and residential welfare. This technique involves selecting an appropriate bandwidth to perform a weighted average of the local area around the data points, thereby smoothing out potential nonlinear trends. The choice of kernel function (such as Gaussian kernel, triangular kernel) and the setting of bandwidth directly affect the estimation results, so careful selection is necessary during implementation. Specific applications include the Nadaraya-Watson estimator or local linear regression methods to assess the varying impacts of residential land structure on welfare under different regional and conditional contexts.

Quantile regression analysis

Quantile regression provides a method for evaluating the impact of variables on different quantiles of the dependent variable. Unlike traditional mean regression, quantile regression can reveal the influence of residential land structure under different conditions of the data distribution, offering a richer perspective for understanding effects at various levels. In this study, by setting different quantile points (such as 0.1, 0.3, 0.5, 0.7, and 0.9), researchers were able to observe the specific impact of residential land structure on residential welfare at different conditional quantiles. The parameter estimation of the quantile regression model is carried out by minimizing the quantile loss function, a method robust to outliers that provides a comprehensive understanding of changes in data distribution.

Heterogeneity regional impact difference analysis

Regional division criteria

The regional division in this study is based on a set of multi-dimensional standards, including the level of economic development, the intensity of environmental regulation, and geographical location. For environmental regulation intensity, a median split method is applied, classifying the sample regions into those with strong and weak environmental regulations based on the median value of the environmental regulation index across the 30 provincial regions. This approach provides an objective measure of the relative stringency of environmental regulations across different areas. The sample is also bifurcated into eastern and non-eastern regions based on economic development levels, with the eastern regions generally exhibiting higher GDP and rates of urbanization. Additionally, the He-Teng Line is utilized to delineate geographical disparities between the eastern and western parts of China, historically indicative of the uneven distribution of population and economic activities.

Heterogeneity analysis techniques

The study utilizes benchmark regression and quantile regression analyses to uncover regional heterogeneity. Benchmark regression offers a comprehensive view of how residential land structure impacts residential welfare, whereas quantile regression enhances this perspective by exposing variations in impact across different regions and levels of residential welfare. The importance of conducting heterogeneity analysis is to identify critical factors for policy formulation and land planning strategies within specific regional contexts. The merits of this approach include offering more nuanced and targeted insights, which contribute to the development of more precise regional strategies.

Mediation and moderation mechanism

Mediation effect analysis

The mediation effect analysis aims to explore whether the impact of residential land structure on residential welfare is realized through certain mediating variables. In this study, urbanization was selected as the mediating variable for analysis, as it is considered a key pathway through which residential land structure affects residential welfare.

Baron and Kenny's mediation effect analysis method was employed to construct the model and validate the mediation effect. The specific steps include: (1) introducing the direct impact of residential land structure on residential welfare in the model; (2) incorporating the impact of residential land structure on the mediating variable; and (3) assessing the influence of the mediating variable in the relationship between residential land structure and residential welfare. By comparing the fit of different models, the existence of a mediation effect can be evaluated. The results indicate that urbanization exhibits a significant partial mediation effect.

Moderation effect analysis

The moderation effect analysis examines whether the impact of residential land structure on residential welfare varies under different conditions. The primary focus is on carbon emission intensity as the moderating variable, which may adjust the strength and direction of the impact of residential land structure on residential welfare.

An interaction model was used to test the moderation effect. Specifically, the model included interaction terms between residential land structure and the moderating variable to investigate whether the moderating variable significantly alters the impact of residential land structure on residential welfare. This approach enables the identification of conditions under which the impact of residential land structure is more pronounced or less significant.

Mixed Effects Analysis

The mixed effect analysis in this study is used to comprehensively examine both mediation and moderation effects, providing a more holistic framework to understand the combined influence of urbanization and carbon emissions on the relationship between residential land structure and residential welfare. This approach allows for the simultaneous analysis of the mediating role of urbanization and the moderating role of carbon emissions, revealing how they jointly shape the impact of residential land structure on residential welfare. The advantage of the mixed effect model lies in its ability to uncover the complex interactions between variables, offering deeper insights for policymakers. The following details the specific steps involved.

Model construction. Ordinary Least Squares (OLS) was employed as the baseline regression method to construct a mixed model that includes both mediating and moderating variables. The model considers residential land structure (inf), urbanization (urb), carbon emissions (ei), and their interaction terms.

Mediation effect examination. In the model, urbanization (urb) serves as a mediating variable to test its role in the relationship between residential land structure (inf) and residential welfare (Score). Through regression analysis, the relationship between urb, inf, ei, and their interaction term (inf*ei) was examined to assess the limiting effect of urbanization on the optimization potential of residential land structure.

Moderation effect examination. By introducing the interaction term (inf*ei), the study tests whether carbon emissions moderate the positive impact of residential land structure on residential welfare. The significant interaction term coefficient indicates that the intensity of carbon emissions enhances the positive effect of residential land structure.

Mixed model analysis. The mixed model (Model 3) incorporates residential land structure, urbanization, carbon emissions, and their interaction terms to evaluate the combined effects of urbanization and carbon emissions. The significance of the interaction terms in the model indicates the complex role that urbanization and carbon emissions play in the relationship between residential land structure and residential welfare.

The regression results show that the coefficient for residential land structure (inf) is significantly positive, strongly confirming its positive correlation with residential welfare. The significantly positive coefficient for the interaction term inf*ei suggests that, even after accounting for urbanization, the intensity of carbon emissions continues to positively moderate the relationship between residential land structure and residential welfare.

QUANTIFICATION AND STATISTICAL ANALYSIS

All regression analyses were conducted using Stata 17. Figures 1, 5, S1, and S2 were created using Microsoft PowerPoint, while Figure 2 was generated in ArcGIS 10.8.