

Article

Factors Influencing Urban Land Green Use Efficiency in China: A Meta-Analysis

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Abstract

China, the world's predominant carbon emitter, is instrumental in advancing green and low-carbon urban land development globally. Urban land green use efficiency (ULGUE) in China is shaped by a multifaceted array of economic and social factors. Given the incongruous results observed in prior research, a comprehensive evaluation of these factors is paramount. This study consolidates data from previous research that explored the determinants of ULGUE in China. Utilizing the IPAT model as a foundational framework, the influencing factors were classified, and meta-analysis was employed to quantify their overall impact. The results show the following: (1) Population agglomeration exhibits a nonlinear effect on ULGUE, with moderate density enhancing efficiency but excessive concentration yielding diminishing returns; (2) Economic development efficiency positively affects ULGUE, with both gross domestic product (GDP) per capita and industrial structure advancement showing significant positive associations; (3) Social development equity demonstrates a threshold effect, where excessive governmental intervention or disproportionate investment in science and education may constrain ULGUE; (4) Resource endowment sustainability, including per capita green space and road infrastructure, consistently enhances ULGUE; (5) The impacts of these factors vary across regions, highlighting the importance of context-specific strategies. These findings provide robust evidence for policymakers to design targeted interventions that account for nonlinearities, threshold effects, and regional heterogeneity, thereby supporting sustainable, green, and low-carbon urban land use in China.

Keywords: urban land green use efficiency; meta-analysis; IPAT model; China



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1. Introduction

Since the early 21st century, global economic development has been increasingly constrained by the challenges of climate change, resource depletion, and environmental pollution [1]. This has elevated the importance of green development in both economic and social discourse [2,3]. Green development, which is grounded in the principles of sustainable development, aims to achieve long-term economic and social prosperity by enhancing resource efficiency, reducing pollution emissions, and protecting ecological systems [4]. Urban land, a crucial resource in the processes of urbanization and economic advancement, plays a pivotal role in achieving these green development objectives [5]. Efficient green use of urban land not only optimizes resource utilization but also mitigates environmental degradation, thereby enhancing the ecological quality of urban environments [6]. Urban

land green use efficiency (ULGUE) reflects the capacity of urban land to generate economic and social benefits while minimizing environmental costs [7]. As such, it serves as a crucial indicator for assessing whether land development aligns with sustainable development trajectories. In the context of China's rapid urbanization and national commitments to high-quality and low-carbon development, enhancing ULGUE has become a strategic imperative for promoting sustainable urban transition.

With the increasing attention to the role of ULGUE in promoting green development, more and more studies have been conducted on this topic. The existing studies mainly focus on the definition of ULGUE [8,9], the measurement of ULGUE [10,11], and the identification of influencing factors of the ULGUE [12,13]. Among them, the study of the influencing factors has become a hotspot with the deepening of global green development. It is of great significance for improving the level of urban land use and promoting the realization of green development goals. The existing research on the factors influencing ULGUE can be divided into two categories: combined factors and single factors. The former studies can reflect the overall influence mechanism of various factors on the ULGUE and provide reference for the formulation of integrated strategies for sustainable urban development. Specifically, some studies constructed composite indices or integrative models to measure the comprehensive impacts of economic growth, ecological resources, policy system, and socio-economic conditions on the ULGUE [14,15]. The latter studies the impact of individual factors on ULGUE, such as the level of urbanization, population density, and economic development [16,17]. However, these prior studies have certain limitations. Many only focus on single regions or use limited timeframes, which may restrict the generalizability of their findings. Therefore, a meta-analysis that synthesizes evidence across regions and periods is necessary to provide a more comprehensive understanding of the driving factors of ULGUE.

Despite the significant contributions of existing studies, several gaps persist in the field. First, while there are various perspectives on the factors of ULGUE, there is a lack of comprehensive, systematic classifications that facilitate comparative analysis of these factors. Second, contradictory findings have emerged regarding the influence of certain factors on ULGUE. For example, some scholars believe that science and technology (S&T) expenditure has a positive impact on ULGUE [18,19], while others find that it has a negative impact [20,21]. These inconsistencies suggest that a systematic review of the association between each of these factors and ULGUE is needed. Meta-analysis is an appropriate method for this purpose, as it allows for the synthesis of results from multiple studies and the identification of common patterns. This study uses meta-analysis to provide a more precise understanding of the interaction between these factors, which may not be apparent from existing studies.

China, a country experiencing rapid urbanization and facing significant environmental challenges, has increasingly prioritized the enhancement of ULGUE. Given the substantial urban land area of China and its pivotal role in global sustainability initiatives, this nation offers a distinctive and invaluable context for investigating the determinants of ULGUE. Furthermore, given China's ongoing commitment to sustainable development, examining these factors within a Chinese context not only provides valuable insights into the efficacy of such interventions but also contributes crucial knowledge to global sustainability initiatives.

Based on the above analysis, this study uses meta-analysis to integrate the influencing factors of ULGUE in China and obtain valuable conclusions with global significance for the study of ULGUE. The IPAT model (Impact = Population, Affluence, Technology) is used as a basis to construct an analytical framework that divides the influencing factors into four dimensions: economic development efficiency, social development equity, population agglomeration, and sustainable resource endowment. Furthermore, the moderating effects

of sample characteristics and regional heterogeneity on ULGUE are examined. By resolving inconsistencies in previous studies, this study aims to provide more robust and dependable results, thereby enriching the meta-analysis and filling a critical research gap.

The rest of this paper study is structured as follows: Section 2 presents a comprehensive theoretical review and formulates the research hypotheses. Section 3 delineates the meta-analysis methodology employed in this study. Section 4 reports the results of empirical analyses derived from the analysis. Section 5 discusses the findings and their broader implications. Section 6 concludes the study, and addresses the policy implications drawn from the research outcomes.

2. Theoretical Framework and Research Hypothesis

2.1. Theoretical Framework

Efficiency, originally a concept from physics, refers to the relationship between output and input within a system [22]. Over time, the application of this concept has expanded across diverse disciplines, including ecology, economics, and management, where it has been utilized to address complex system dynamics and sustainability challenges. Urban land use, as an inherently complex system, encompasses a network of input-output relationships that not only reflect the efficiency of land resource allocation and utilization but also elucidate the intricate interplay between economic, social, and environmental factors within urban development [23,24]. Consequently, in response to urban expansion and land resource scarcity, scholars have proposed the concept of urban land use efficiency, aiming to enhance overall effectiveness of land utilization by optimizing resource allocation [25,26]. Amid rapid urban economic development and urbanization, scholars have increasingly integrated a broader range of economic and social factors into the exploration of urban land economic efficiency, emphasizing the need to balance economic returns with social equity [27,28]. In recent years, as environmental issues have intensified and sustainable development has gained prominence as a global priority, researchers have gradually incorporated environmental factors into the framework of urban land economic efficiency [29]. This evolution has given rise to the concept of ULGUE, underscoring the necessity of green development and the growing social demand for sustainable urban land use [30,31]. In summary, this study defines the concept of ULGUE as a holistic representation of urban energy factors, emphasizing the capacity of urban land use systems to generate social, economic, and environmental outputs while adhering to the constraints of pollutant and carbon emissions.

The IPAT model, which evaluates the impact of human activities on the environment, indicates that technological advancements are essential for alleviating environmental degradation [32]. The core formula of the IPAT model is expressed as I (Environmental Impact) = P (Population) $\times$ A (Affluence) $\times$ T (Technology) [33]. Building upon this concept and considering the current state of green urban land use, this study establishes an analytical framework based on the IPAT model. In addition to the traditional factors of population (P), affluence (A), and technology (T), this study incorporates the social development factor (S) and the resource endowment factor (R) as significant factors. Given that technology is intrinsically linked to social factors, this study frames government financial resources and expenditure on science and education as key indicators of social development equity. Consequently, the ULGUE impact model was structured around four primary components: population agglomeration (P), economic development efficiency (A), social development equity (S), and resource endowment sustainability (R), which together form the criterion layer. Factors relevant to these criteria were subsequently incorporated into the indicator layer, as depicted in Figure 1.

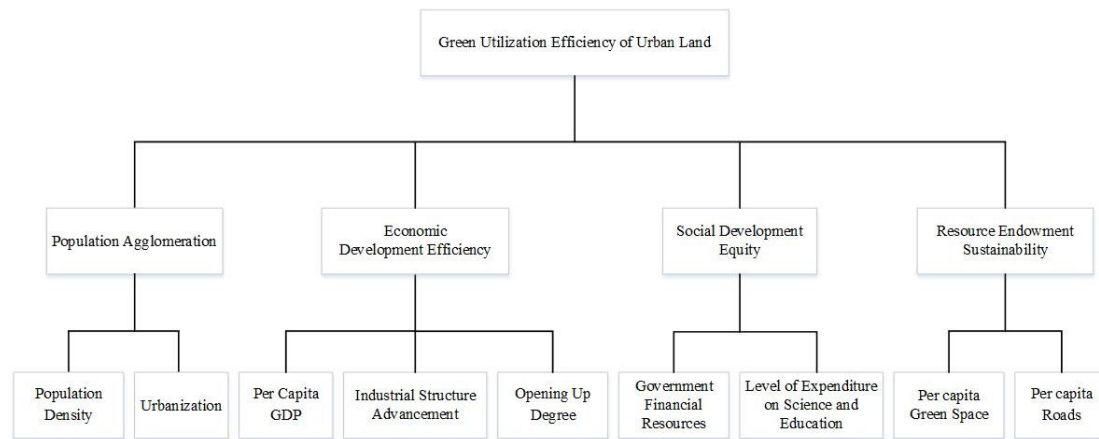


Figure 1. Framework of the Influencing Factors of ULGUE.

2.2. Population Agglomeration and ULGUE

Population agglomeration in this study primarily refers to population density and the level of urbanization. Classic urban economics, represented by Alonso and Fujita, highlights that agglomeration brings both positive and negative externalities. On one hand, the concentration of population facilitates economies of scale, improves public service efficiency, and promotes compact spatial development, thereby improving ULGUE [34]. On the other hand, excessive concentration may lead to congestion, environmental pollution, infrastructure overload, and inefficient expansion driven by speculative land development, which can hinder the green use of urban land [35].

Population density directly affects the allocation of land resources per unit of space, shaping spatial configuration and influencing green land use performance. Some studies indicate that moderate population density promotes efficient land utilization, while excessive density results in diminishing returns and ecological stress [36]. Urbanization, defined as the transformation of rural populations into urban residents, is theoretically expected to support better land use planning, industrial restructuring, and improved public services, generating positive effects on ULGUE [37,38].

The following hypotheses are proposed:

H1: *The impact of population agglomeration on ULGUE is nonlinear.*

H1a: *Population density positively affects ULGUE at moderate levels but exhibits diminishing returns at very high levels, implying an overall inverted U-shaped effect.*

H1b: *Urbanization positively affects ULGUE.*

2.3. Economic Development Efficiency and ULGUE

Economic development efficiency reflects a city's ability to transform factor inputs into high-quality green economic output. According to ecological modernization theory, improvements in industrial structure, technological progress, and economic regulation can enhance ULGUE by decoupling economic growth from environmental degradation [39,40]. In early stages of development, extensive industrialization or low-quality investment-driven growth may temporarily increase resource consumption and pollution, implying a potential nonlinear relationship between economic development and ULGUE [41].

GDP per capita serves as a proxy for overall economic productivity and urban land input intensity. Higher GDP per capita can attract advanced industries, encourage technological innovation, and promote efficient and green land use [42,43].

Industrial structure advancement, usually measured by the ratio of tertiary to secondary industry output, promotes the refinement of land use structures and the efficient allocation of urban land resources [44,45]. Higher shares of tertiary industry generally support improved ULGUE, as the service-oriented sector tends to require less intensive land use than heavy industry.

The degree of openness, measured by the ratio of foreign investment to GDP, can introduce capital and technology conducive to green development [46]. However, it may also have ambiguous effects if investment incentives lead to inefficient land expansion or relaxed environmental standards [47,48].

The following hypotheses are proposed:

H2: *Economic development efficiency positively affects ULGUE, potentially in a nonlinear manner.*

H2a: *GDP per capita positively influences ULGUE.*

H2b: *Industrial structure advancement positively affects ULGUE.*

H2c: *The degree of openness positively affects ULGUE.*

2.4. Social Development Equity and ULGUE

Within the green development framework, social development factors are essential determinants of urban land green use efficiency (ULGUE). This study focuses on government financial resources and expenditure on science and education as measurable indicators of social development equity. Investment in education cultivates high-quality human capital, which can enhance sustainable development capacity [49,50]. Similarly, government support for science and technology fosters technological innovation, providing the foundation for cleaner and more efficient production processes [51,52].

At the same time, government actions, particularly fiscal policies, shape urban land use decisions and can modify specific land use practices [53,54]. Fiscal policies enacted by governments significantly shape urban land use decisions and modify specific land use practices [55,56]. On the one hand, judicious fiscal expenditure can enhance ULGUE effectively. On the other hand, excessive intervention by local authorities may adversely affect the ecological environment, thereby inhibiting ULGUE [57,58].

The following hypotheses are proposed:

H3: *ULGUE is influenced by social development equity.*

H3a: *Government financial resources affect ULGUE in a nonlinear way, with moderate levels enhancing efficiency but very high levels potentially yielding diminishing returns.*

H3b: *Expenditure on science and education positively influences ULGUE.*

2.5. Resource Endowment Sustainability and ULGUE

Resource endowment sustainability constitutes a key determinant of urban land green use efficiency (ULGUE). Critical indicators include per capita green space and per capita road area. With the global emphasis on sustainable urban development, governments increasingly prioritize expanding urban green space and safeguarding ecological functions [59]. Simultaneously, industries with high energy consumption and pollution are encouraged to adopt cleaner production technologies [60,61]. The integration of innovative production methods enhances the efficient utilization of resources and contributes to decoupling economic activity from environmentally harmful practices [62].

Per capita road area reflects infrastructure development. While adequate infrastructure is essential for urban growth, excessive or poorly planned expansion may overconsume natural resources and diminish ULGUE [63]. Nevertheless, strategic infrastructure investments, particularly in road networks, can support more efficient land use and promote sustainable urban development [64,65].

The following hypotheses are proposed:

H4: *The sustainability of resource endowment positively affects ULGUE.*

H4a: *Per capita green space positively affects ULGUE.*

H4b: *Per capita road area positively affects ULGUE.*

3. Methods

Meta-analysis is a robust statistical technique employed to systematically synthesize and evaluate findings from multiple independent studies, with the aim of identifying consistent patterns and resolving discrepancies across research efforts, thereby generating more comprehensive and reliable conclusions [66]. In this study, meta-analysis is applied to integrate and weight empirical evidence on the influencing factors of ULGUE, enabling a clearer estimation of the overall effect size and its determinants. This approach helps to uncover the general trends and spatial heterogeneity associated with ULGUE development. The specific analytical steps are as follows.

3.1. Data Collection

A comprehensive literature search was conducted using the following databases: Web of Science, Elsevier Science Direct Online, and CNKI, covering publications from their inception to 31 August 2025. The search terms included “China”, “urban land”, “green”, “influence”, and “use efficiency”. These terms were organized into two groups: green-related terms and their alternatives, and land use efficiency-related terms and their alternatives. Keywords from both groups were searched in combination. The search was restricted to studies published in English and Chinese.

The inclusion criteria were established to align with the objectives of this study, focusing on identifying primary articles pertinent to the research question. Studies were included in the meta-analysis if they met the following criteria: (1) the study was published as a journal article, an unpublished master’s thesis, or a doctoral dissertation; (2) the study aimed to explore factors influencing ULGUE; (3) empirical methods were employed, excluding reviews articles and purely theoretical literature; (4) the study provided data on sample size, correlation coefficient (r) between independent variables and ULGUE, or other convertible statistics (e.g., β value, t value, p -value); (5) the study samples were independent.

To ensure the representativeness and rigor of the meta-analysis, this study focused on these three databases because they provide broad coverage of peer-reviewed studies across different regions in China. The search resulted in 1073 studies (Web of Science: 501; Elsevier Science Direct Online: 506; CNKI: 66). After removing 398 duplicates, 675 studies were screened for eligibility. Among these, 566 studies were excluded based on title and abstract screening. Subsequently, 109 studies underwent full-text evaluation, with 64 meeting the inclusion criteria. Exclusions were made for the following reasons: (1) absence of empirical analysis ($n = 22$); (2) incomplete data on impact levels or lack of reported correlation coefficients ($n = 35$). To ensure robustness in the subsequent analysis, independent variables appearing with a frequency of ≥ 3 were selected. In total, 118 independent variables, representing 45,663 independent samples, were included in the meta-analysis (Figure 2).

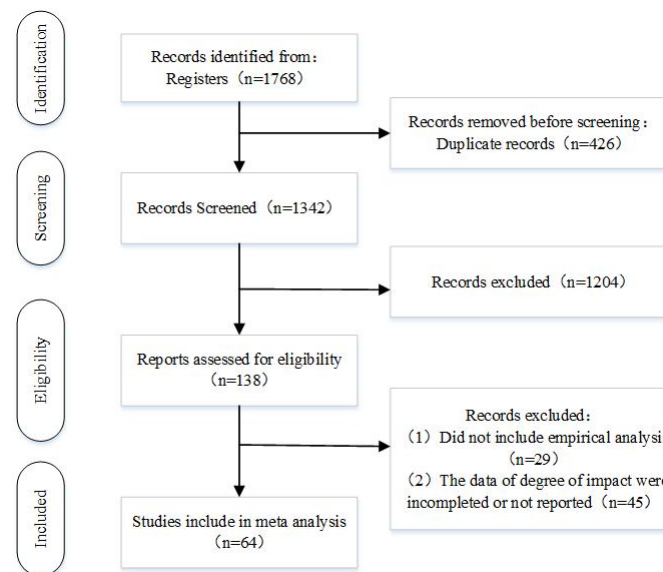


Figure 2. Search diagram with the numbers of records as a function of the stages of identification, screening, eligibility, and inclusion of studies.

3.2. Data Processing

ULGUE is generally measured using multi-dimensional evaluation frameworks that incorporate economic output, social welfare, and environmental performance. Due to variations in research design, indicator selection, and statistical modeling across studies, ULGUE is often reported in the form of correlation estimates or regression coefficients that reflect the strength and direction of relationships between influencing factors and ULGUE. Therefore, extracting and transforming such quantitative results allows effect sizes to be statistically comparable across studies and provides a feasible basis for meta-analysis. This process enables the integration of heterogeneous findings to determine the overall effect magnitude of each influencing factor and to explore sources of inconsistency among studies, such as differences in sample characteristics, indicator systems, and geographic contexts.

Following the methodology proposed by M.W. Lipsey and D.B. Wilson [67], the extraction of study sample data focused on both descriptive characteristics and effect-size statistics. Descriptive characteristics included details such as author, publication date, and title. Effect-size statistics encompassed numerical information such as sample size, regression coefficient (β), and correlation coefficient (r).

This study employed the Pearson correlation coefficient (r) as the effect size measure. Given that most studies did not report r values directly but provided regression coefficients (β) and t -values, the formula proposed by Peterson was applied to convert the standard regression coefficient (β) into the correlation coefficient (r): $r = \beta + 0.05\lambda$. This method enabled the calculation of the desired effect size while maximizing the retention of valid samples. Specifically, when $\beta \geq 0$, $\lambda = 1$; and when $\beta < 0$, $\lambda = 0$.

The issue of inconsistent naming for similar influencing factors was addressed during the coding process. By interpreting the conceptual connotations of these factors, similar factors were grouped and standardized through interpretation of their conceptual connotations. For example, the ratio of actual utilized foreign capital to regional GDP was consistently categorized as the “degree of openness.”

3.3. Data Analysis

After calculating effect sizes for all observations, the data were categorized to examine the influence of population development agglomeration, economic development efficiency, social development equity, and resource endowment sustainability on ULGUE. (1) Calcula-

lation of combined effect sizes: Correlation coefficients were transformed using Fisher's Z transformation, with the transformed correlation coefficient (Z_r) treated as the effect size. (2) Analysis of moderating effects: To ensure representativeness at each level of the moderating variable, consistent with established practices, the number of effects at each level was required to exceed two [68,69]. Heterogeneity among studies was assessed using Cochran's Q and I^2 statistics, and subgroup analyses were conducted based on sample size and region. Sensitivity analyses were performed by excluding each study individually and re-running the meta-analysis. To assess the risk of publication bias, funnel plots, Egger's test, and Begg's test ($\alpha = 0.05$) were employed.

There are two primary methods for estimating overall effect sizes: fixed-effects and random-effects models. The fixed-effects model posits that all studies share a common true effect size, attributing variations in observed results solely to random error. In contrast, the random-effects model accounts for variability in true effect sizes across studies, incorporating true value, systematic error, and random error, thereby recognizing that observed differences may stem from multiple factors [69].

Given the substantial heterogeneity among studies ($I^2 > 50\%$) and variability in sample sizes and regions, a Bayesian random-effects model was employed [70]. This approach offers key advantages: (1) it provides full posterior distributions, allowing direct probabilistic interpretation of uncertainty; (2) it incorporates theoretically informed priors (e.g., based on the IPAT expansion framework) to stabilize estimates across differing study-level covariates; and (3) it yields more robust estimates under high heterogeneity than frequentist methods, which rely on asymptotic approximations and may underestimate uncertainty. Together, these features justify its use to capture spatial and methodological variability in ULGUE across Chinese regions.

The p -value was used to evaluate heterogeneity in the meta-analysis. Specifically, if $p > 0.05$, a fixed-effects model was considered appropriate; otherwise, a random-effects model was applied. To further assess potential publication bias, a funnel plot was created and visually examined for asymmetry. In addition, we performed Classic Fail-Safe N analysis, which estimates the number of hypothetical null-effect studies required to reduce the overall effect to non-significance. This provides a quantitative measure of robustness against potential publication bias, complementing the visual inspection from the funnel plot and increasing confidence in the meta-analytic conclusions.

3.4. Limitation

Although meta-analysis enhances the robustness of conclusions by integrating evidence across studies, several inherent limitations remain. First, differences in research designs, variable definitions, and regional sampling frameworks may contribute to heterogeneity in the results. Second, as this meta-analysis is based on published literature, the possibility of publication bias cannot be completely ruled out. Third, although the number of included studies ($n = 64$) is substantial and provides sufficient statistical power for the primary analyses, it still places constraints on the comprehensiveness of moderator testing, particularly for less frequently examined variables. These limitations should be considered when interpreting the findings; however, they do not undermine the overall reliability of the observed patterns, which remain consistent across sensitivity and robustness checks.

4. Results

4.1. Quality Assessment

The reliability of the meta-analysis was assessed through a funnel plot and the Egger test (see Figure 3). The majority of studies were positioned at the upper part of the funnel plot, demonstrating a relatively even distribution around the mean effect sizes,

which indicates a low likelihood of publication bias. The results of the Egger test revealed *p*-values for the significance tests of the factors: population agglomeration (0.239), economic development efficiency (0.634), social development equity (0.863), and resource endowment sustainability (0.919). Since all *p*-values for these four factors were greater than 0.05, this suggests the absence of statistically significant publication bias in the analysis.

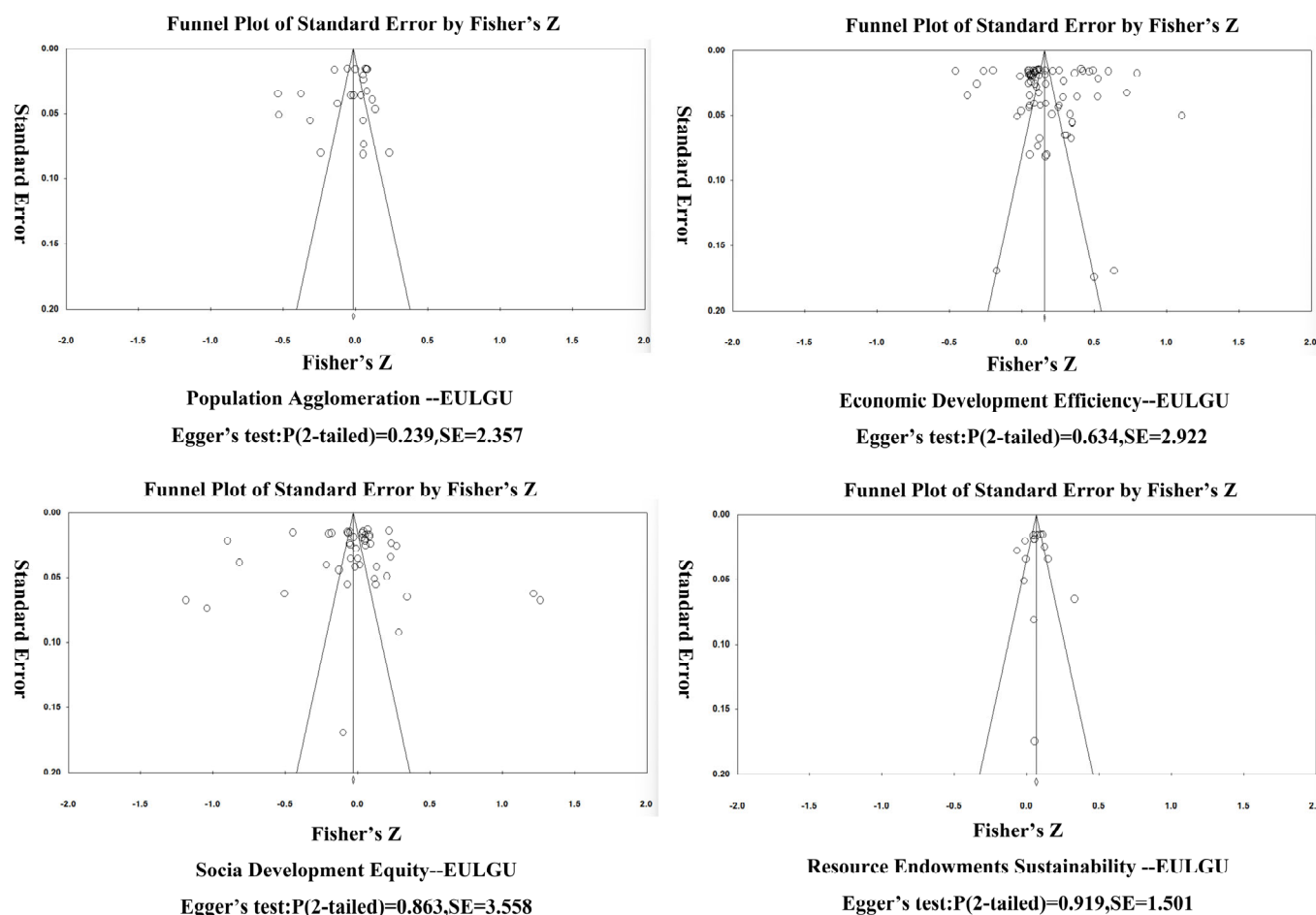


Figure 3. Funnel plot of publication bias.

Classic Fail-Safe N analyses were conducted to assess the robustness of the meta-analytic effects against potential publication bias. As shown in Table 1, all four dimensions produced Fail-Safe N values far exceeding the corresponding Rosenthal's recommended tolerance thresholds ($5k + 10$), suggesting that the observed effects are highly unlikely to be overturned by unpublished null-effect studies.

Table 1. Classic fail-safe N.

	Fail-Safe N	<i>p</i> -Value	Number of Observed Studies	Rosenthal's Recommended Threshold
Population Agglomeration	173	0.000	24	58
Economic Development Efficiency	224	0.000	44	138
Social Development Equity	114	0.000	25	60
Resource Endowment Sustainability	100	0.000	16	42

Specifically, the Fail-Safe N for Population Agglomeration was 173, surpassing its threshold of 58, indicating strong resistance to publication bias ($p < 0.001$). For Economic Development Efficiency, the Fail-Safe N reached 224 with a substantially higher observed study count ($k = 44$) compared to the threshold (138), further supporting the stability of this effect ($p < 0.001$). The Social Development Equity dimension yielded a Fail-Safe N of 114, again exceeding the tolerance level (60; $p < 0.001$), demonstrating that the results remain highly robust even in the presence of missing studies. Finally, the Fail-Safe N for Resource Endowment Sustainability was 100, also well above the threshold (42; $p < 0.001$), indicating adequate protection against publication bias.

Collectively, these findings confirm that a large number of hypothetically missing studies with null effects would be required to reduce the overall meta-analytic results to non-significance. Thus, the current findings exhibit strong robustness concerning potential publication bias.

4.2. Main Effects

The initial analysis aimed to examine the overall associations between ULGUE and four categories of variables: population agglomeration, economic development efficiency, social development equity, and resource endowment sustainability. Table 2 presents a comprehensive overview of the results, including effect sizes, sample sizes, correlation coefficients, 95% confidence intervals, Q-values, and results of heterogeneity tests. The Chi-square test for heterogeneity indicated statistical significance, with all effect values exhibiting significant Q-values and I^2 values exceeding 50%, which confirmed the presence of substantial heterogeneity. Therefore, a random-effects model was employed to analyze the relationships between each subfactor and overall ULGUE.

The overall correlation between population agglomeration and ULGUE was $r = -0.052$ (95% CI $[-0.111, 0.009]$), indicating no statistically significant linear relationship and thus not supporting a simple linear effect. However, the positive and significant quadratic term ($r = 0.043$, 95% CI $[-0.003, 0.089]$) suggests a nonlinear, threshold-dependent relationship, partially supporting H1. Subfactor analysis provides further clarity: population density exhibits a significant positive linear effect ($r = 0.054$, 95% CI $[0.038, 0.071]$) and a significant negative quadratic effect ($r = -0.043$, 95% CI $[-0.003, 0.089]$), consistent with an inverted U-shaped relationship and supporting H1a. This implies that moderate population density enhances ULGUE, whereas excessive concentration may lead to congestion and environmental stress, reducing efficiency. In contrast, urbanization does not show a significant linear effect on ULGUE under either fixed-effects or random-effects models ($r = 0.006$, 95% CI $[-0.007, 0.019]$; $r = -0.015$, 95% CI $[-0.090, 0.060]$), indicating that H1b is not supported at the national level. This may reflect China's urban expansion patterns, which often emphasize spatial growth over functional intensification, resulting in inefficient land conversion and lagged ecological performance.

The overall correlation between economic development efficiency and ULGUE was $r = 0.178$ (95% CI $[0.122, 0.232]$), indicating a statistically significant positive effect at the 95% confidence level and supporting the general hypothesis H2 that economic development efficiency enhances ULGUE. Examining subfactors, GDP per capita exhibits a significant positive association with ULGUE ($r = 0.234$, 95% CI $[0.171, 0.295]$, $p < 0.001$). Moreover, the positive and significant quadratic term for GDP per capita ($r = 0.117$, 95% CI $[0.063, 0.173]$, $p < 0.001$) suggests a nonlinear effect, with returns on ULGUE accelerating at higher GDP per capita levels, thereby supporting H2a. This finding indicates that higher economic productivity strengthens green land use efficiency. Industrial structure advancement also shows a positive relationship with ULGUE ($r = 0.131$, 95% CI $[0.003, 0.256]$, $p < 0.05$), consistent with H2b. This aligns with theoretical expectations that a greater share of

tertiary industry improves land use efficiency and contributes to sustainable urban land management. In contrast, the degree of openness does not show a statistically significant association with ULGUE ($r = 0.065$, 95% CI $[-0.098, 0.225]$, $p > 0.05$), indicating that H2c is not supported. This lack of significance may reflect the dual nature of openness, while foreign investment can introduce green technologies, it can also stimulate land-intensive speculative development, depending on regional policies and institutional contexts. Thus, although H2c is not confirmed, the result highlights the context-dependent effects of openness on ULGUE.

Table 2. Relationship between four types of factors and ULGUE.

ULGUE	Amount of Effect Size	Sample Size	Correlation Coefficient	95% Confidence Interval		Q-Value	I-Squared	Models
				Lower	Upper			
Population Agglomeration								
Population Density	20	18,335	0.054 ***	0.038	0.071	291.401 ***	97.255	Fixed
	20	18,335	0.141 **	0.026	0.251			Random
Population Density^2	20	18,335	−0.043 *	−0.003	0.089			Random
Urbanization	16	12,933	0.006	−0.007	0.019	412.643 ***	96.607	Fixed
	16	12,933	−0.015	−0.090	0.060			Random
Population Agglomeration	36	31,268	−0.014 ***	−0.024	−0.004	727.815 ***	96.840	Fixed
	36	31,268	−0.052	−0.111	0.009			Random
Population Agglomeration^2	36	31,268	0.043 *	−0.003	0.089			Random
Economic Development Efficiency								
Per Capita GDP	46	81,802	0.198 ***	0.191	0.204	3600.688 ***	98.916	Fixed
	46	81,802	0.234 ***	0.171	0.295			Random
Industrial Structure Advancement	14	41,649	0.196 ***	0.185	0.207	1481.500 ***	99.123	Fixed
	14	41,649	0.131 ***	0.003	0.256			Random
Opening Up Degree	14	49,039	0.010 *	−0.001	0.021	2549.810 ***	99.490	Fixed
	14	49,039	0.065	−0.098	0.225			Random
Economic Development Efficiency	74	172,535	0.156 ***	0.151	0.161	8920.584 ***	99.182	Fixed
	74	172,535	0.178 ***	0.122	0.232			Random
Economic Development Efficiency^2	74	172,535	0.096 ***	0.061	0.129			Random
Social Development Equity								
Government Financial Resources	28	74,321	0.023 ***	0.015	0.031	2485.235 ***	99.276	Fixed
	28	74,321	0.032	−0.062	0.125			Random
Government Financial Resources^2	28	74,321	−0.044 *	−0.007	0.095			Random
Level of Expenditure On Science and Education	17	29,231	−0.056 ***	−0.071	−0.042	921.282 ***	99.457	Fixed
	17	29,231	−0.034 ***	−0.048	−0.021			Random
Social Development Equity	45	103,552	−0.031 ***	−0.038	−0.024	3421.954 ***	99.299	Fixed
	45	103,552	−0.027 ***	−0.111	−0.057			Random
Resource Endowment Sustainability								
Per Capita Green Space	6	17,666	0.091 ***	0.039	0.142	22.992 ***	95.651	Fixed
	6	17,666	0.089 ***	0.057	0.120			Random
Per Capita Roads	10	12,731	0.046 *	−0.005	0.097	67.943 ***	91.318	Fixed
	10	12,731	0.053 **	0.008	0.098			Random
Resource Endowment Sustainability	16	30,397	0.083 ***	0.044	0.122	87.688 ***	82.677	Fixed
	16	30,397	0.098 *	−0.012	0.206			Random

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

The overall correlation between social development equity and ULGUE was $r = -0.030$ (95% CI $[-0.038, -0.024]$), indicating a statistically significant, though modest, negative

effect at the 95% confidence level. Examining subfactors reveals a more nuanced pattern. For government financial resources, the linear term was not significant ($r = 0.032$, 95% CI $[-0.062, 0.125]$), but the quadratic term was significantly negative ($r = -0.044^*$, 95% CI $[-0.007, 0.095]$), suggesting a nonlinear, inverted U-shaped relationship. This supports H3a: moderate levels of fiscal resources can enhance ULGUE, while excessively high levels may reduce efficiency, consistent with the diminishing returns predicted by theory. In contrast, expenditure on science and education showed a negative association with ULGUE ($r = -0.034^{***}$, 95% CI $[-0.048, -0.021]$), contrary to the original hypothesis H3b. This result indicates that disproportionate or misaligned investments in education and technology may not automatically improve urban land green-use efficiency, potentially due to resource misallocation, delayed effects, or implementation inefficiencies. Overall, these findings support H3a but not H3b, highlighting the importance of considering contextual and allocation factors when evaluating the influence of social development equity on ULGUE.

The overall correlation between resource endowment sustainability and ULGUE was $r = 0.065$ (95% CI $[0.034, 0.096]$), indicating a statistically significant positive effect at the 95% confidence level. This result supports hypothesis H4, confirming that greater sustainability of resource endowment is associated with higher urban land green-use efficiency. Examining subfactors further reinforces this conclusion. Per capita green space exhibited a positive correlation with ULGUE ($r = 0.089$, 95% CI $[0.057, 0.120]$), supporting hypothesis H4a, while per capita road area also showed a positive effect ($r = 0.053$, 95% CI $[0.008, 0.098]$), supporting hypothesis H4b. Overall, these findings confirm that improvements in resource endowment particularly through enhancing urban green space and infrastructure contribute to promoting efficient and sustainable urban land use.

4.3. Robustness Check

To evaluate the robustness of the meta-analytic findings, two complementary approaches were employed: sensitivity analyses and alternative effect size transformations using the Hunter and Schmidt method (see Table 3).

Sensitivity analyses were conducted by sequentially excluding individual studies and recalculating the overall effect sizes for each variable. The results showed that the effect estimates remained largely stable across all iterations. For instance, the correlation between population density and ULGUE was initially estimated at $r = -0.141$ (95% CI: $-0.251, -0.026$), and the recalculated effect sizes after removing each study did not materially deviate from this baseline. Similarly, for economic development efficiency, the overall effect remained robust ($r = 0.178$, 95% CI: $0.122, 0.232$), with subfactors such as per capita GDP ($r = 0.234$, 95% CI: $0.171, 0.295$) and industrial structure advancement ($r = 0.131$, 95% CI: $0.003, 0.256$) exhibiting consistent patterns.

Alternative effect size transformations were performed by converting regression coefficients to correlation coefficients following the Hunter and Schmidt approach. The transformed effect sizes were consistent with those obtained using the primary conversion method, further reinforcing the stability of the results. For example, after applying this alternative transformation, the correlation for population density shifted slightly to $r = -0.152$ (95% CI: $-0.274, -0.026$), while economic development efficiency increased to $r = 0.197$ (95% CI: $0.134, 0.259$), both remaining statistically significant. Similarly, the correlations for social development equity ($r = -0.033$, 95% CI: $-0.041, -0.025$) and resource endowment sustainability ($r = 0.098$, 95% CI: $-0.012, 0.206$) were consistent with the primary analyses, indicating that the main conclusions are not dependent on the choice of effect size transformation.

Overall, these robustness checks demonstrate that the meta-analytic findings are stable and not driven by individual studies or methodological choices. The consistency of results across both sensitivity analyses and alternative effect size transformations provides strong support for the reliability of the observed relationships between population agglomeration, economic development efficiency, social development equity, resource endowment sustainability, and ULGUE.

Table 3. Robustness Check.

ULGUE	Amount of Effect Size	Sample Size	Correlation Coefficient	95% Confidence Interval		Robustness Assessment
				Lower	Upper	
Population Agglomeration						
Population Density	20	18,335	−0.141 **	−0.251	−0.026	Sensitivity analyses Alternative effect size transformation
	20	18,335	−0.152 **	−0.274	−0.026	
Economic Development Efficiency						
Per Capita GDP	46	81,802	0.234 ***	0.171	0.295	Sensitivity analyses Alternative effect size transformation
	46	81,802	0.284 ***	0.201	0.362	
Industrial Structure Advancement	14	41,649	0.131 ***	0.003	0.256	Sensitivity analyses Alternative effect size transformation
	14	41,649	0.190 ***	0.061	0.312	
Economic Development Efficiency	74	172,535	0.178 ***	0.122	0.232	Sensitivity analyses Alternative effect size transformation
	74	172,535	0.197 ***	0.134	0.259	
Social Development Equity						
Level of Expenditure On Science and Education	17	29,231	−0.034 ***	−0.048	−0.021	Sensitivity analyses Alternative effect size transformation
	17	29,231	−0.047 ***	−0.061	−0.034	
Social Development Equity	45	103,552	−0.027 ***	−0.111	−0.057	Sensitivity analyses Alternative effect size transformation
	45	103,552	−0.033 ***	−0.041	−0.025	
Resource Endowment Sustainability						
Per Capita Green Space	6	17,666	0.089 ***	0.057	0.120	Sensitivity analyses Alternative effect size transformation
	6	17,666	0.089 ***	0.057	0.120	
Per Capita Roads	10	12,731	0.053 **	0.008	0.098	Sensitivity analyses Alternative effect size transformation
	10	12,731	0.049 *	−0.002	0.100	
Resource Endowment Sustainability	16	30,397	0.065 ***	0.034	0.096	Sensitivity analyses Alternative effect size transformation
	16	30,397	0.098 *	−0.012	0.206	

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

4.4. Moderator Analysis

Given the notable disparities in the effects of various factors on ULGUE, a further exploration of moderating effects was conducted. Since no significant relationship was identified between population development agglomeration and ULGUE, particular attention was directed to potential moderating factors affecting the relationships among economic development efficiency, social development equity, resource endowment sustainability, and ULGUE. This analysis seeks to elucidate the complexities of the interactions among these factors and their effect on ULGUE performance in diverse contexts.

Building on existing literature, this study primarily examines two dimensions: sample size and research area [71]. Regarding sample size, studies are classified into two groups: those with sizes ranging from 0 to 1000 and those exceeding 1000. In terms of research area, studies are categorized into three groups based on geographical, economic, and cultural factors: eastern, central, and western regions [72]. (see Figure 4)

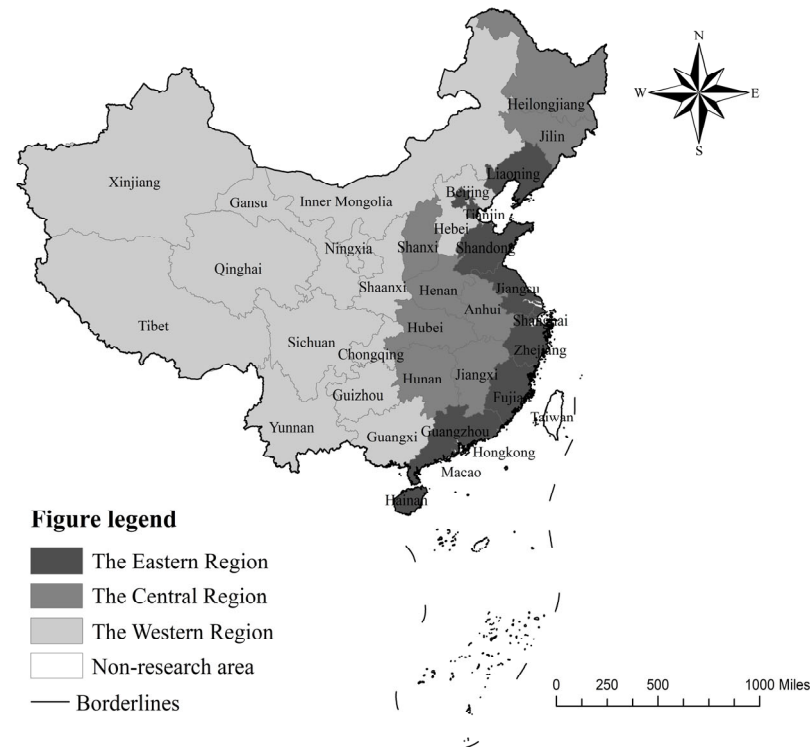


Figure 4. Regional Division Map of China.

According to Table 4, sample size demonstrates a significant moderating effect within the group of economic factors. Specifically, in subsamples with more than 1000 observations, the effect size is 0.140, while in those with fewer than 1000 observations, the effect increases to 0.231; both coefficients are statistically significant at the 1% level. This suggests that larger samples may attenuate the observed relationship between ULGUE and economic outcomes, whereas smaller samples may amplify it. However, for other factor categories, the moderating effect of sample size remains statistically insignificant ($p > 0.05$), indicating that the influence of sample size is primarily concentrated within economic contexts. Therefore, sample size should be considered a relevant moderating variable specifically in the analysis of economic-related effects.

Regarding the moderating role of the research area, significant subgroup differences were identified ($p < 0.05$). The correlation coefficients between the three types of factors and ULGUE are consistently higher in the eastern region than in other regions. Notably, the eastern region exhibits a stronger positive moderating effect on the relationship between economic development efficiency and ULGUE ($r = 0.377$), followed by the central region ($r = 0.227$), reflecting its advanced economic structure and stronger technological and institutional support. In contrast, the moderating effect of regional differences on the relationship between resource endowment sustainability and ULGUE remains weak across all areas.

Furthermore, the research time span also acts as a significant moderating variable. For economic development efficiency, the effect size increases from 0.041 in studies covering ≤ 10 years to 0.096 in those covering > 10 years (both $p < 0.001$), suggesting that

the green efficiency dividends of high-quality economic growth accumulate over longer periods. Similarly, social development equity shifts from an insignificant relationship in the ≤ 10 -year subgroup ($r = 0.078$) to a significantly positive relationship in the >10 -year subgroup ($r = 0.106$, $p < 0.001$), indicating that improvements in public services and inclusive development require time to translate into enhanced ULGUE. By contrast, resource endowment sustainability shows a declining effect over time (≤ 10 years: $r = 0.146$, $p < 0.10$; >10 years: $r = 0.053$, $p < 0.001$), implying diminishing marginal environmental benefits as resource-based advantages are gradually depleted.

Table 4. The moderator analysis of three factors and ULGUE.

Factors	Moderator	Subgroup Classification	Subgroup	Effect Value Quantity	Sample Size	Correlation Coefficient	95% Confidence Interval	
							Lower	Upper
Economic development efficiency	Sample size	0 = 0~1000 1 = 1000 above	0	32	6891	0.231 ***	0.133	0.323
			1	42	93,596	0.140 ***	0.068	0.210
Social development equity			0	20	8317	−0.008	−0.210	0.194
			1	25	84,211	−0.027	−0.111	0.057
Resource endowment sustainability			0	7	2078	0.095	−0.010	0.160
			1	9	20,395	0.065 ***	0.034	0.097
Economic development efficiency	Research area	1 = The Eastern Region 2 = The Central Region 3 = The Western Region	1	7	4148	0.377 ***	0.124	0.585
			2	6	1648	0.227 *	−0.023	0.450
			3	5	192	0.288 *	−0.026	0.551
Social development equity			1	10	3947	−0.393 *	−0.713	0.063
			2	7	5158	−0.235 ***	−0.376	−0.083
			3	2	-	-	-	-
Resource endowment sustainability			1	2	-	-	-	-
			2	1	-	-	-	-
			3	4	1696	0.073 ***	0.047	0.098
Economic development efficiency			1	21	42,008	0.041 ***	0.032	0.051
	Study period	1 = 0~10 2 = 10 above	2	36	77,623	0.096 ***	0.055	0.137
Social development equity			1	10	17,933	0.078	−0.058	0.212
			2	33	68,536	0.106 ***	0.072	0.140
Resource endowment sustainability			1	3	2250	0.146 *	−0.015	0.299
			2	9	19,815	0.053 ***	0.022	0.084

Note: *, and *** indicate significance at the 10%, and 1% levels, respectively.

Taken together, these findings reveal that the relationships between the three driving factors and ULGUE are shaped not only by spatial heterogeneity but also by temporal dynamics. Long-term institutional and technological progress strengthens the positive impacts of economic and social development, whereas the role of natural resource advantages weakens as development proceeds. Therefore, both data characteristics and spatiotemporal context must be considered when assessing ULGUE-driving mechanisms.

5. Discussion

This study analyzed 64 empirical studies to explore the factors influencing ULGUE in China, utilizing meta-analysis as the primary methodological approach. The findings

largely corroborated hypotheses H2, H3, and H4, revealing significant associations between economic development efficiency, social development equity, and resource endowment sustainability and ULGUE. Specifically, economic development efficiency was found to positively influence ULGUE, consistent with Sun [73], who indicated that urban economic growth could coexist with environmental protection. Moreover, the positive and significant quadratic term for GDP per capita suggests a nonlinear effect, indicating that returns on ULGUE accelerate at higher levels of economic development. Similarly, our results align with Wang et al., [74], and Ji et al., [75], showing that social development equity and resource endowment sustainability enhance green urban practices and land use efficiency. Importantly, government financial resources exhibit a nonlinear, inverted U-shaped relationship with ULGUE, where moderate levels enhance efficiency but excessively high levels may yield diminishing returns.

Although the linear relationship between population agglomeration and ULGUE is not statistically significant at the national level, the significance of the quadratic terms indicates a clear nonlinear mechanism behind this relationship. These results imply that the effects of agglomeration are not uniform but vary depending on the stage of urban development and city-specific conditions. Therefore, subgroup analyses based on urban hierarchy were conducted to further explore contextual differences.

In first-tier cities, the coefficient of population density on ULGUE is close to zero and statistically insignificant, suggesting that agglomeration economies have already reached saturation. Congestion externalities, infrastructure overload, and resource mismatches are likely to offset the efficiency gains from further clustering. This aligns with the compact city paradigm, which proposes that agglomeration benefits only exist within an optimal density threshold, beyond which marginal returns diminish or even turn negative. Conversely, in non-first-tier cities, population agglomeration still exerts a significantly positive effect on ULGUE, indicating that moderate clustering can continue to enhance urban land efficiency by promoting resource concentration, economic vitality, and improved provision of public services. This finding is consistent with the objectives of SDG-11, particularly Target 11.3, which emphasizes inclusive and sustainable urbanization and enhanced land use efficiency, as well as Target 11.1, which advocates strengthened urban–rural linkages. Collectively, these results underscore the context-dependent nature of population density effects on ULGUE and highlight the importance of differentiated urban strategies.

When comparing the influences of the three types of factors, economic development efficiency demonstrates a significantly greater impact on ULGUE than resource endowment sustainability. Several reasons may account for this outcome: (i) Economic development efficiency functions primarily as an exogenous factor, serving as a direct driver of changes in ULGUE. (ii) The weaker impact of resource endowment sustainability on ULGUE can be understood from an environmental protection perspective. Resource endowment mainly promotes green land use efficiency by improving the urban environment and increasing carbon sink capacity [76,77]. However, maintaining a sustainable resource endowment often incurs high costs, and the gradual nature of its effects may hinder the translation of environmental awareness into practice, especially when perceived costs outweigh benefits, leading to a diminished impact on ULGUE [78]. (iii) Furthermore, the lesser influence of resource endowment sustainability may be related to the stronger direct effects of modern technology on ULGUE.

While this study established a theoretical framework for the factors influencing ULGUE based on the IPAT model and synthesized existing evidence through meta-analysis, several limitations and directions for future research remain. First, although this study synthesized the most comprehensive set of empirical findings currently available, the overall body of literature on ULGUE in China remains limited in scope, and several potentially

relevant studies could not be included due to incomplete reporting of statistical indicators. This constraint not only narrows the empirical base of the meta-analysis but also introduces the possibility of subtle selection bias, as published studies tend to overrepresent statistically significant or theoretically expected results. To address this challenge, future research should broaden the potential sources of evidence, such as institutional reports, dissertations, and high-quality gray literature, but only insofar as these sources provide sufficient methodological detail to meet rigorous inclusion criteria. This is essential to avoid compromising the validity of meta-analytic estimates. At the same time, promoting standardized effect-size reporting practices across the field would enable a greater number of studies to become eligible for future syntheses, thereby reducing the risk of selection bias arising from the exclusion of otherwise informative work. Second, due to data availability, this study incorporated only a restricted set of moderators. Building on the reviewer's suggestions, future research should explore additional context-dependent moderators, particularly time periods and policy interventions associated with the evolution of China's environmental governance, such as the intensified regulatory measures implemented after 2012. The preliminary evidence of this study already indicates that time serves as an important contextual determinant of relationships between key factors and ULGUE. Third, the current literature has mainly investigated four separate categories of drivers, although their underlying mechanisms are highly interdependent. Future studies could employ structural equation modeling and multilevel meta-regression to uncover nonlinear, mediating, and moderating mechanisms, such as how economic openness influences the effect of resource endowment on green land use efficiency. Although such models are not feasible using the aggregated effect-size structure applied in meta-analysis, obtaining primary or panel data will allow testing of the latent interactions suggested by our findings.

In conclusion, extending the analytical framework toward dynamic policy effects and inter-factor coupling will contribute to a deeper understanding of ULGUE transition pathways and provide stronger decision-making guidance for sustainable land management and green urban transformation in China.

6. Conclusions and Implications

6.1. Conclusions

Guided by the global emphasis on green and low-carbon development, the pursuit of ULGUE has become increasingly central to government agendas worldwide [79]. This study systematically analyzed the factors influencing ULGUE through a meta-analysis, identifying population agglomeration, economic development efficiency, social development equity, and resource endowment sustainability as key determinants. The results demonstrate the critical role of these factors in shaping ULGUE, offering valuable insights for urban planners and policymakers aiming to foster sustainable development.

The results reveal nuanced effects in line with these hypotheses. At the national level, population agglomeration does not show a significant linear relationship with ULGUE; however, the significant quadratic term confirms H1, indicating a nonlinear, threshold-dependent effect. Population density exhibits an inverted U-shaped relationship with ULGUE, supporting H1a, while urbanization shows no significant linear effect, partially supporting H1b. Economic development efficiency shows a significant positive effect on ULGUE, supporting H2. GDP per capita (H2a) and industrial structure advancement (H2b) positively influence ULGUE, while the degree of openness (H2c) does not show a statistically significant effect, indicating context-dependent influences. Social development equity demonstrates a negative overall effect. Government financial resources exhibit a nonlinear relationship consistent with H3a, whereas expenditure on science and education (H3b) does not significantly enhance ULGUE, highlighting the importance of aligned

resource allocation. Finally, resource endowment sustainability positively affects ULGUE, confirming H4, with both per capita green space (H4a) and per capita road area (H4b) showing positive contributions.

The results of the moderator analysis indicate that regional differences play a significant role in explaining the heterogeneity observed within the sample, acting as moderators in the relationship between ULGUE and the key factors: economic development efficiency, social development equity, and resource endowment sustainability. These findings are consistent with the conclusions of He and Fu. In our study, the eastern region shows a significantly stronger moderating effect than other regions in the relationship between economic development efficiency, social development equity, and ULGUE. Several factors may explain this outcome: (i) The eastern region is at the forefront of efficient economic development in China, which enhances the comprehensive urban capacity and increases the quality of input factors per unit of land, thereby promoting ULGUE [80]. (ii) The eastern regions place a high priority on science, technology, and education, with significant investments in these areas, fostering rapid technological progress that directly influences ULGUE [81].

Although the analysis focuses on China, the mechanisms identified may provide guidance for sustainable urban land use in other rapidly urbanizing regions. For example, in European cities such as Warsaw, Poland, insights into balancing economic efficiency, social equity, and population density thresholds can inform compact city planning and resource allocation policies. In African cities such as Lagos, Nigeria, strategies that account for moderate density levels and optimize resource endowment can support resilient urban growth. These examples illustrate how our findings on nonlinear threshold effects of population agglomeration and density can be applied across different contexts. Cross-regional comparisons help distinguish universal factors, such as the critical role of economic efficiency in driving ULGUE, from context-specific factors shaped by local socio-economic and environmental conditions.

Linking these findings to ecological modernization theory highlights the complementary relationships among population agglomeration, economic development, social equity, and environmental protection, rather than treating them as conflicting goals. This perspective provides actionable insights for international frameworks such as the Paris Agreement, suggesting that local policies promoting green urban land use, improving energy efficiency, and advancing equitable development can adapt to regional realities while contributing to global climate targets.

Despite the robustness of the results, limitations remain. The scope of moderating variables is limited, regional heterogeneity is not fully captured, and empirical studies outside China are scarce. Future research should expand cross-regional sampling, incorporate additional moderators, and apply time-sensitive methods to examine dynamic changes in ULGUE mechanisms. In conclusion, sustainable optimization of ULGUE requires the integrated consideration of economic, social, and environmental factors. Efforts to enhance green land use are crucial for achieving high-quality urbanization and addressing environmental and resource challenges globally.

6.2. Implications

Guided by the empirical findings of this study, we propose actionable and evidence-based policy recommendations for enhancing ULGUE. The results indicate that population agglomeration, economic development efficiency, social development equity, and resource endowment sustainability play critical and differential roles in shaping ULGUE, with nonlinear or threshold effects observed for several factors. Accordingly, policy measures

should be tailored to regional conditions and grounded in quantitative targets to improve operability and effectiveness.

First, population agglomeration reveals a nonlinear relationship with ULGUE; moderate population density enhances efficiency, whereas excessive density diminishes it. Therefore, in non-first-tier cities, urban planning should promote moderate clustering through compact development, efficient public transportation, and controlled expansion to enhance land use efficiency. In contrast, in first-tier cities, where agglomeration benefits have plateaued, strategies should focus on optimizing existing urban spaces, reducing congestion, and implementing redevelopment or vertical expansion policies. Measurable targets, such as maintaining population density within the empirically identified optimal range, can provide concrete guidance.

Second, economic development efficiency is a primary driver of ULGUE. The significant positive coefficients for per capita GDP and industrial structure advancement imply that cities should continue promoting high-value, service-oriented industries and regulate industrial expansion to maintain sustainable land use gains. Scenario-based modeling can help quantify the expected impact of different investment levels in infrastructure, technology, and industrial upgrading on ULGUE, enabling evidence-based decision-making aligned with the 2035 carbon neutrality goals.

Third, social development equity requires nuanced consideration. Our results reveal a threshold effect for government financial resources and a potential negative association with excessive expenditure on science and education, indicating that indiscriminate or disproportionate investment may crowd out environmental efficiency. Targeted investments should prioritize interventions that directly enhance green land use efficiency, and modeling approaches can simulate policy outcomes under alternative funding allocations to guide resource prioritization.

Finally, resource endowment sustainability is crucial for green urban land use. Positive effects of per capita green space and road infrastructure highlight the importance of improving ecological conditions and infrastructure efficiency. Policies should establish quantitative targets for green space expansion and sustainable infrastructure development, tailored to regional contexts. Combining these measures with localized scenario simulations allows policymakers to evaluate trade-offs and optimize resource allocation to maximize ULGUE.

In summary, all policy measures should be aligned with long-term national targets, such as China's 2035 carbon neutrality roadmap. Cross-scenario modeling can help anticipate policy outcomes under different urban growth and investment scenarios, allowing governments to design region-specific strategies that maximize ULGUE improvements while contributing to global sustainability goals.

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