

From Community to City: Challenges and Research Progress in Cross-Scale Sustainability Assessment

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Abstract

Global urbanization is accelerating in the 21st century, and the United Nations projects that the urban population will reach 6.5 billion by 2050, positioning cities as the primary arena for implementing SDG 11. However, existing research on urban sustainability assessment remains largely confined to either the city or community scales, exhibiting considerable fragmentation, and neglecting dynamic cross-scale interactions leads to policy mismatches. This study conducts a systematic review of literature published between 2015 and 2025 in the Web of Science and Scopus databases, following the PRISMA guidelines. After excluding single-scale and non-urban studies, 14 core papers were identified. The results reveal three dominant pathways for cross-scale city–community assessment: top-down, bottom-up, and hybrid approaches. Methods predominantly involve computational modeling and spatial analysis (GIS), indicating a trend toward methodological integration. Indicators commonly demonstrate cross-dimensional coupling and cross-scale nesting structures. However, persistent challenges remain, including data barriers, insufficient coverage of sociocultural dimensions, and high technical thresholds. Future efforts should prioritize enhancing data integration, refining multidimensional indicator frameworks, and reducing application barriers to advance cross-scale assessment and achieve the coordinated, sustainable development of cities and communities.

Keywords: urban sustainability, cross-scale assessment, evaluation methods, SDGs, systematic review

1. Introduction

1.1 Urbanization Context and Limitations of Single-Scale Assessment

The 21st century is increasingly recognized as the “urban century,” with global urbanization advancing at an unprecedented pace and cities becoming the main arena of human development. According to UN projections, 4.8 billion people will live in urban areas by 2025 (Statistics, 2025), and this figure will reach 6.5 billion by 2050, roughly two-thirds of the global population (United Nations Development Programme). As Acuto et al. (2018) point out, cities are engines of global growth, driving nearly 75% of global GDP, yet they also account for the largest shares of energy, consumption, carbon emissions, and pollution. The Habitat Progress Report (Habitat, 2023) further indicates that achieving up to 65% of the Sustainable Development Goals (SDGs) depends directly on the effective implementation of urban initiatives. Building on this, the effective resolution of a series of “urban challenges” has become one of the most pressing global issues of the century (Acuto et al., 2018). In this context, the United Nation (2015) noted that guiding cities towards inclusive, safe, resilient, and sustainable development has become the core target of Sustainable Development Goal 11 (SDG 11) within the 2030 Agenda for Sustainable Development.

Cities are inherently open and complex multiscale systems encompassing hierarchical levels from households and communities to cities and regions (Bai et al., 2016; Purvis et al., 2022). In recent years, scholars have developed numerous indicator frameworks, evaluation systems, modeling approaches, and assessment tools to incorporate sustainability into urban planning (Aly et al., 2022; Kaur & Garg, 2019), and most studies still focus on either the urban or community level in isolation. This fragmentation makes it difficult to address the systemic complexity of urban sustainability. As Elmqvist et al. (2019) observed, existing research often remains confined within single scales, while few have successfully bridged interactions among spatial levels (Furlan et al., 2025; Zheng et al., 2020). Küfeoğlu (2022) similarly highlighted that such single-scale approaches often neglect the inherent multiscale characteristics of SDG 11.7 and its cross-linkages with other goals. A systematic review of models supporting SDG implementation between 2015 and 2021 conducted by Aly et al. (2022), found that only about 5%

of these models addressed cross-scale issues, revealing a lack of integrated assessment methods connecting the urban and community scales—two distinct yet interdependent governance and ecological units.

1.2 Significance and Core Issues of Multi-Scale Assessment

Neglecting these cross-scale dynamics results in a lack of alignment between local practices and urban strategies, sometimes triggering governance dilemmas in which local optimization leads to system imbalances and aggravates regional disparities (Yang & Zhang, 2025). Therefore, cross-scale sustainability assessment is essential for overcoming the limitations of fragmented, single-scale approaches. As Contestabile (2018) emphasized, sustainable urban systems depend on the integration of structure and process. Building on the multiscale and open characteristics of urban systems (Cash et al., 2006), researchers are increasingly adopting interdisciplinary approaches to deal with scale mismatches and enhance collaborative knowledge between scholars and practitioners.

Accordingly, this paper conducts a systematic literature review to examine the progress and challenges in global city-community cross-scale sustainability assessment over the past decade. It addresses three key questions: (1) What methods are predominantly used in cross-scale assessment? (2) How do sustainability indicators exhibit coupling and nesting characteristics across scales? (3) What major challenges hinder the advancement of cross-scale assessment?

Addressing these questions holds significant value: clarifying assessment methods can address methodological deficiencies in scale integration; preventing policy one-size-fits-all approaches or imbalanced local optimization; elucidating indicator characteristics ensures assessment systems align with governance needs. Furthermore, identifying existing challenges can guide future research, promoting more coherent implementation of cross-scale assessments to support SDG 11. This study ultimately seeks to deepen understanding of multiscale interactions, elucidate governance insights, and explore strategies to enhance the collaborative sustainability between cities and communities.

2. Theoretical Framework

2.1 Scale

“Scale” is a crucial concept and a fundamental analytical tool in numerous fields, including the study of urban sustainable development (Cash et al., 2006). Gibson et al. (2000) defined “scale” as the spatial, temporal, quantitative, or analytical dimensions through which phenomena are examined. Among these, spatial scale is closely related to jurisdictional scale, which refers to a hierarchical political organization of administrative units—such as towns, districts, counties, and cities—structured through institutional norms and nested governance arrangements (Allen et al., 2023). This concept provides a theoretical foundation for understanding cross-scale interactions between the micro level of communities and the macro level of cities. Within urban sustainability assessments, these two spatial levels differ markedly in their demands, socioeconomic conditions, environmental contexts, institutional structures, and evaluation mechanisms (Sharifi & Murayama, 2015). Therefore, the interactions and interdependencies across scales not only generate complex governance challenges but also provide research opportunities for advancing sustainable urban development.

2.1.1 Urban Scale

As micro-units of complex systems composed of blocks and neighborhoods (Nuisl et al., 2009), cities need to be measured in a systematic way across economic, social, and environmental dimensions to evaluate their sustainability performance (Coulson et al., 2020). However, the extensive data demands and sensitivities of sustainability metrics give rise to several limitations, including a weak alignment between indicator frameworks and local priorities (Lee & Huang, 2007), as well as limited accuracy in long-term trend predictions.

Existing urban sustainability assessments generally follow four major stages (Liu, 2024): defining indicator frameworks, constructing evaluation systems, integrating SDG dimensions into quantitative models, and formulating policy strategies. Commonly used methods exhibit complementary strengths: system dynamics models effectively predict long-term trends through causal feedback loops, but need complete historical datasets (Aly et al., 2022); agent-based models capture the macro-level effects of micro-level behavior, but confront problems with deviations from the rational agent assumption; and Bayesian networks are adept at handling uncertainty but depend heavily on prior knowledge of network structures.

At the practical level, cities adopt a variety of approaches depending on their institutional settings and data contexts. For example, Jining City, China, built a multi-indicator evaluation framework for urban sustainability (Li et al., 2009); a Brazilian study combined data envelopment analysis (DEA) with neural networks to enhance resource allocation efficiency (Furlan et al., 2025); and in Turkey, researchers established an urban sustainability index based on fuzzy analytic hierarchy process (AHP) techniques (Kusakci et al., 2022). Collectively, these studies show

the importance of aligning methods with local governance capacity and contextual knowledge. However, persistent challenges remain, including the masking of community heterogeneity by city-level aggregation and limited cross-national comparability of assessment outcomes.

2.1.2 Community Scale

Communities are the basic units of cities (Searfoss, 2011). Although limited in spatial extent, they can provide a comprehensive reflection of social reality, environmental quality, and service conditions at the micro level. Therefore, communities are units for recognizing and practicing sustainability, and are the optimal starting point for achieving urban sustainable development (Sharifi & Murayama, 2013). Within a cross-scale sustainability framework, the community scale constitutes not only the logical starting point for bottom-up analysis but also a crucial bridge linking individual behaviors with city-level outcomes.

With the acceleration of urbanization, Neighborhood Sustainability Assessment (NSA) tools have been developed, offering quantitative support for cross-scale research (Dawodu et al., 2022). These tools are generally divided into two categories: Derivative Tools (e.g., LEED-ND), which are developed from standardized indicators, and thus can be used for cross-regional comparisons but often lack sensitivity to local contexts; and Planning-Embedded Tools (e.g., HQE2R), which are tailored to local conditions and planning needs but are less suitable for horizontal comparisons (Berardi, 2013; Sharifi & Murayama, 2013). Together, these two types of tools complement each other in striking a balance between standardization and differentiation.

There are two mainstream methodological approaches commonly adopted for community-scale sustainability assessment (Wang et al., 2022): the Comprehensive indicator approach integrates multi-dimensional information for holistic evaluation and is applicable for diagnostic analysis, but it often ignores local heterogeneity (Valderrey et al., 2023); In contrast, the Single-Dimensional Approach focuses on specific aspects—such as environmental quality or social equity—for in-depth research, though it struggles to reflect the overall balance (Shirazi et al., 2022). Therefore, the method selection should align with the objectives of the evaluation assessment, data availability, and the analytical scale. The methodological and conceptual distinctions between urban- and community-scale evaluations, and their core characteristics, are summarized in Table 1.

Table 1. Comparison of Core Characteristics in Sustainability Assessment at Urban and Community Scales

Comparative Dimension	Urban Scale	Community Scale
Policy Focus	Housing, transportation, regional economy, and macro-environmental policies	Public services, residents' demands, and micro-environment
Assessment Tools/Methods	System Dynamics, DEA (Data Envelopment Analysis), Fuzzy AHP (Analytic Hierarchy Process), Comprehensive Polygon Graph Method	LEED-ND, HQE2R, Comprehensive Indicator Method, Single-Dimension Method
Applicable Scenarios	Overall urban sustainability diagnosis, cross-regional urban comparison	Precise community planning, local problem optimization
Core Limitations	Overshadows community heterogeneity, leading to “one-size-fits-all” policies	Difficulties in horizontal comparison, inability to support the formulation of overall urban strategies

2.2 Cross-Scale

Cross-scale interactions refer to the mutual influence and feedback that occur between different spatial or governance levels (Allen et al., 2023). Stevens (2018) emphasizes that integrating multiple spatial, jurisdictional, and temporal scales is a critical prerequisite for effective governance. Foundational studies before 2015 established the theoretical and methodological groundwork in this field. Cash et al. (2006) proposed the theory of scale and cross-scale dynamics, clarifying the governance logic and information transmission mechanisms in multi-level systems. Bourdic et al. (2012) developed a system of cross-scale spatial indicators, providing an early case of exploring cross-scale spatial indicators, demonstrating feasible ways to quantify the sustainability of cities at different levels. Based on these foundational studies, existing research on urban sustainability indicators, urban renewal, and smart cities has made substantial progress, including the development of methodological frameworks and tools to implement the SDGs (Allen et al., 2023).

Despite these advancements, most existing studies remain confined to a single analytical scale. Some studies focus

on micro-level elements, such as buildings, landscapes, or communities, while others construct macro-level indicator systems for cities, regions, or nations (Yigitcanlar et al., 2015). This fragmented assessment method often ignores the dynamic coupling and feedback mechanisms across different scales. And cities and communities are inherently nested complex systems. Communities are embedded within urban systems, and interactions occur vertically across these scales (Wang et al., 2022). Local interactions within community subsystems take specific forms. These forms include residents' behavioral choices and demographic structures. Through nonlinear processes, these local interactions manifest as macro-level urban characteristics (Keddie & Tonkiss, 2010). Different scales operate within specific spatial and environmental constraints. Thus, adopting a cross-scale perspective is essential in urban sustainability research (Huang et al., 2015).

Cross-scale research serves two important purposes. First, it is essential to understand the transformation of urban governance. Second, it offers a practical approach to promote multi-scale coordination. Cross-scale sustainability assessment addresses the limitations of single-scale methods. It accomplishes this through hierarchical decomposition, revealing underlying mismatches and providing a scientific foundation for collaborative governance between cities and communities. Within the framework of SDG 11 (“Sustainable Cities and Communities”), specific targets articulate clear requirements. For example, Target 11.3 explicitly advocates for the establishment of hierarchical linkage mechanisms and participatory planning processes that connect community-level engagement with city-level strategies (Küfeoğlu, 2022; United Nation 2025). International organizations have similarly underscored the importance of multi-scale coordination: The Committee on Sustainable Urban Systems of the National Science Foundation (National Science, 2022) emphasizes the importance of cross-scale coordination; likewise, Asian urban research practices (Asian Development, 2021) and Latin American studies (CEPAL, 2022) echo this sentiment. These cases reflect a global consensus on the importance of this issue.

3. Methodology

This study aims to synthesize and evaluate global progress, methodological innovations, and existing challenges in urban sustainability research, with a particular focus on cross-scale sustainability assessment methods linking cities and communities. This study adopted a systematic literature review (SLR) approach, following a clearly defined search logic, screening process, and evaluation protocol. The main procedural steps are outlined below.

3.1 Literature Search Strategy

The literature search was conducted using two major academic databases: Web of Science (WoS) and Scopus. The WoS Core Collection—including SCI-EXPANDED, SSCI, A&HCI, CPCI-S, and CPCI-SSH—served as the main data source. At the same time, Scopus was used as a supplementary source to ensure comprehensive coverage and academic credibility. The search period was restricted to 2015–2025, aligning with the decade following the adoption of the UN 2030 Agenda for Sustainable Development, during which research on sustainable cities and cross-scale governance rapidly expanded.

Boolean operators (“AND”, “OR”) were used to combine keywords such as: Urban sustainability, cross-scale, multi-scale, framework, model, policy, and governance. Terms like scale, multi-scale, and cross-scale targeted studies involving different spatial or administrative levels; framework and model helped identify method-oriented literature; and policy and governance aided in locating implementation-focused studies related to the SDGs. The detailed search strategy is illustrated in Table 2:

Table 2. Literature Search Strategy Table

Database	Search Scope / Fields	Publication range	Search Terms / Strings
Web of Science	Core Collection: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH	2015.01.01 – 2025.01.01	TS = (“urban sustainability” OR “sustainability assessment” OR “sustainable development evaluation”) AND TS = (“scale” OR “multi-scale” OR “cross-scale” OR “scale integration”) AND TS = (“framework” OR “index” OR “model” OR “tool” OR “methodology”) AND TS = (“policy” OR “localization” OR “governance” OR “SDG implementation”)
Scopus	Article Title, Abstract, Keywords	2015 – 2025	Search within: “urban sustainable development”, “community”, “neighborhood”, “district”, “scale”, “cross-scale”, “multi-scale”

3.2 Preliminary Screening and Duplication

The initial search was performed in May 2025. Titles, keywords, and abstracts were manually screened for relevance. Retrieved records were imported into EndNote for automatic deduplication. Studies were excluded based on the following criteria:

- (a) Assessments focusing solely on a single scale;
- (b) Cross-scale analyses conducted on non-urban systems;
- (c) Studies lacking an explicit cross-scale analytical perspective or multi-scale integration methods.

3.3 Full-Text Review

Following the preliminary screening, full-text reviews were conducted to examine definitions of “scale,” evaluation frameworks, and cross-level analytical methods. The initial search retrieved 5,463 records (Web of Science: 2,234; Scopus: 3,229). After deduplication, 4,651 studies remained. On this basis, we further excluded studies focusing on global, subnational (e.g., regional, delta-level), or non- “city–community” scales. After strict screening, 52 studies were identified as cross-scale analyses involving urban sustainability. To reduce regional and institutional bias, cases were selected from different countries, with multiple cases from the same country avoided. Ultimately, 14 core studies were included in this systematic review. These studies explicitly addressed urban-community cross-scale sustainability assessment, aligning with the study’s thematic focus.

3.4 Flowchart

To enhance the transparency and reproducibility of the review, the entire review process—including identification, screening, eligibility, and inclusion stages—was documented in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. A PRISMA flowchart was then constructed to visually summarize each stage of the literature selection process, as illustrated in Figure 1:

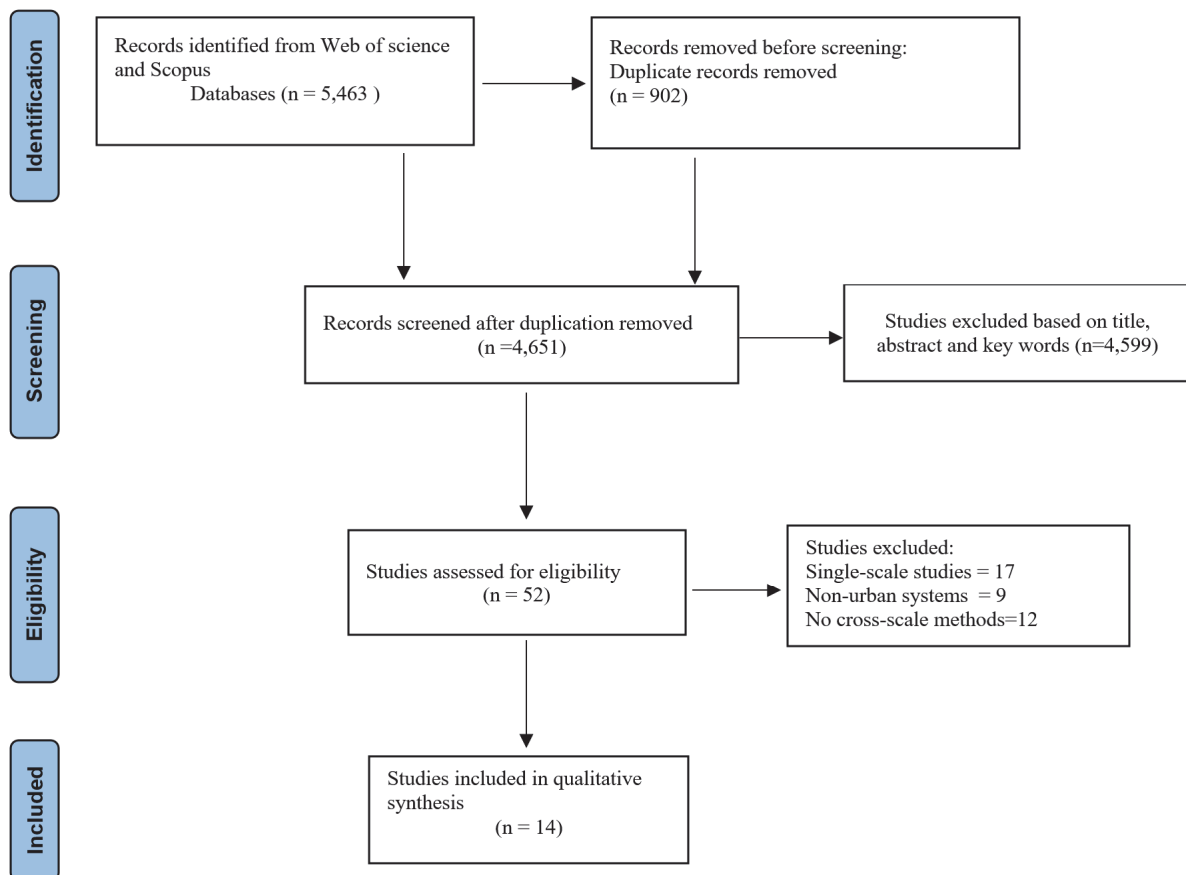


Figure 1. Literature Screening Flowchart for Cross-Scale Sustainability Assessment of Cities and Communities

4. Results

Although the initial search yielded a large volume of literature, the overall findings indicate that current research on urban sustainability assessment remains predominantly concentrated on single-scale analysis. Cross-scale evaluations still present methodological and conceptual challenges, and systematic literature exploring inter-scale relationships remains relatively limited.

4.1 Basic Characteristics and Geographic Distribution of Included Literature

Ultimately, fourteen representative core articles were selected for in-depth analysis. This decision aligns with the study's focus on examining the interactive relationships between the city and community scales, while ensuring conceptual clarity and representativeness across diverse case contexts. Consequently, numerous articles were excluded because they either focus only on a single scale or cover broader research topics unrelated to the cross-scale perspective. Although this rigorous selection criterion inevitably reduced the sample size, it effectively filtered out irrelevant materials, allowing for a more focused exploration of research progress and innovations in cross-scale sustainability assessment. The fourteen included papers can therefore be considered the most methodologically relevant and typologically representative results within the field of urban sustainability assessment.

Table 3. Basic Characteristics of Included Literature on Urban-Community Cross-Scale Sustainability Assessment

No.	Citation	Assessment Scale	Spatial Field	Tool/Framework	Area
1	Hayek et al. (2015)	Regional-Local	Environment + Social proxy indicators	UrbanSim	Zurich, Switzerland
2	Yigitcanlar et al. (2015)	Urban-community	Comprehensive sustainability assessment	MUSIX + ILTIM	Gold Coast, Australia
3	Fernández and Wu (2018)	Municipal-Pixel- Block	Environmental- social equity	EIPI index	Santiago, Chile
4	Sarrica et al. (2018)	National-Regional- Local	Energy sector	Discourse analysis framework	Italy
5	Roszkowska et al. (2024)	National-City- Community	Comprehensive sustainability	MIDIA method	EU member states
6	Ali et al. (2020)	City-Community- Building Metropolitan-	Building energy assessment	Deep learning + MCDA	Dublin, Ireland
7	Gohaud et al. (2025)	Central urban-Fine- grained neighborhoods	Urban morphology	QGIS + Momepy	Daegu, South Korea
8	Kissinger and Stossel (2021)	Global-Regional- Local	Urban ecology	Material flow analysis	Tel Aviv, Israel
9	Jiang and Ma (2025)	Macro-Meso-Micro	Urban planning + Data science	UVPN model	New York City, USA
10	Yu et al. (2023)	City-Community	Spatial morphology	K-means + GIS	Greater London, UK
11	Wang et al. (2024)	City-District-Street- Apartment complex	Public space sustainability	Indicator framework	Xi'an, China
12	Brelsford et al. (2017)	Nation-City- Neighborhood	Sustainability heterogeneity	Sustainability index	Brazil/South Africa
13	Hamilton et al. (2015)	Multi-spatial (City- Community) + Multi-temporal	Environmental modeling	IAM framework	Global framework
14	Pastor-Escuredo et al. (2022)	Global-Regional- National-Local	Sustainable governance	Federated learning + AI	Methodological framework

The basic characteristics of the included literature are presented in Table 3. Geographically, the selected literature

spans Europe, North America, Asia, Oceania, and Latin America, encompassing both developed economies (e.g., Switzerland, the United States) and emerging ones (e.g., China, Brazil). Cases cover diverse urbanization stages and institutional contexts, including both empirical research on specific cities and framework-based methodological analyses. Additionally, more than half of the studies ($n = 8$) developed frameworks incorporating three or more spatial scales, employing mainstream approaches such as computational simulation and spatial analysis. These studies provide a high-quality analytical foundation for meaningful comparative analysis in this review, with quality prioritized over quantity.

4.2 Classification and Integration Trends in Multi-Scale Assessment Methods

After clarifying the basic characteristics and geographic distribution of the included literature, further analysis of these research methods reveals the evolution of methodologies in this field.

As shown in Table 4, research methodologies in this field reveal a diversified landscape, dominated by quantitative models and spatial analysis. Computational simulation and spatial analysis constitute the mainstream methodologies and approaches, adopting data-driven techniques such as proxy models, machine learning, and geographic information systems (GIS). This reflects that cross-scale assessments rely heavily on complex data processing and dynamic system simulation techniques. Moreover, a distinct trend toward method integration has emerged. Over one-third of the reviewed studies combine multiple analytical approaches. Two common combinations stand out: (1) computational simulation paired with spatial analysis, and (2) multi-criteria analysis paired with dynamic methods. The former enhances simulation accuracy through spatial data, while the latter optimizes decision-making logic from a dynamic perspective. Both combinations effectively address the limitations of using a single methodology.

Table 4. Classification of Multi-Scale Assessment Methods and Number of Studies Method Category Specific Methods Number of Studies

Method Category	Specific Methods	Number of Studies
Computational Simulation	Agent-based modeling, System dynamics, Machine/Deep learning	6
Spatial Analysis	GIS, Remote sensing, Morphometric analysis, Spatial clustering	7
Multi-criteria Analysis	MCDA, Index construction, Dynamic comparative analysis	4
Qualitative & Frameworks	Content analysis, IAM, Governance frameworks	3

4.3 Imbalance in Application Domain Distribution and Dimension Coverage

In line with methodological characteristics described above, the application domains covered in the literature also exhibit distinct emphases, reflecting current research priorities and thematic imbalances within the field.

As presented in Table 5, the included literature covers multiple core dimensions of urban sustainability, though the distribution across these dimensions remains uneven. Environmental and ecological themes make up the largest proportion, followed by spatial form and vitality. In contrast, dimensions like sociocultural aspects and governance mechanisms receive relatively limited attention.

Table 5. Distribution of Cross-Scale Sustainability Assessment Application Domains

Application Fields	Representative Themes	Number of Involved Literatures
Environment and Ecology	Energy Modeling, Environmental Equity, Urban Metabolism, Heat Island Effect	9
Spatial Form and Vitality	Urban Form, Neighborhood Classification, Urban Vitality, Public Space	5
Governance and Policy	Multi-scale Governance, Policy Discourse Analysis, Sustainable Development Goals Assessment	3
Socio-economics	Comprehensive Sustainability Assessment, Land Use Efficiency	2

This distribution reveals a persistent imbalance in current cross-scale assessments: environmental and spatial dimensions are far more emphasized than social and governance aspects. This imbalance may be attributed to two factors: the relative availability of quantifiable environmental data and the more developed state of spatial analysis techniques compared to social-scientific measurement frameworks.

5. Discussion

5.1 Research Progress

5.1.1 Synergistic Evolution of Assessment Pathways and Methods

Cross-scale sustainability assessment has evolved along three primary pathways, each requiring tailored technical methods for implementation, which helps effectively connect theoretical frameworks with practical analytical tools. The top-down approach focuses on macro-level urban policies and combines them with comprehensive economic and environmental data analysis. However, this pathway frequently overlooks internal disparities. For example, cities like Tokyo and Mexico City exhibit pronounced imbalances between central and peripheral areas, which obscure disparities in land use and population distribution, resulting in less effective policy outcomes. To solve this problem, Wang et al. (2024) incorporated community indicators and integrated apartment-level and county-level data to optimize assessment results. In contrast, the bottom-up approach centers on community-based feedback mechanisms and micro-scale data to identify urban needs. For instance, Sun et al. (2021) used street-level images to provide spatial solutions for mitigating urban heat islands, while Jiang and Ma (2025) used neighborhood POI data to predict urban vitality patterns. Although these methods offer precise local representations, their generalizability is often constrained by sample representativeness. The hybrid approach combines the advantages of both pathways, employing hierarchical frameworks that merge universal indicators with region-specific ones to achieve bidirectional adaptation. Little et al. (2019) developed a hierarchical model for decision-making under uncertainty, and Feleki et al. (2018) introduced the “middle-ground method,” integrating core indicators with expert opinions to build a flexible evaluation system applicable across European cities.

To further quantify the comparative effectiveness of the three pathways, a complementary meta-analysis was conducted on the 14 core studies, using computed standardized effect sizes (Cohen’s d) as the statistical indicator. The synthesis outcomes of the three pathways demonstrate that the hybrid approach consistently performed better at resolving scale mismatches. It had higher effect size values in most case studies. The bottom-up approach ranks second, while the top-down pathway was relatively less effective at addressing community-level heterogeneity. This finding aligns with the United Nations Human Settlements (2023), which highlights method integration as a major trend enhancing the precision the accuracy of cross-scale sustainability assessments.

Overall, the evolution of cross-scale assessment methodologies has evolved from unidirectional transmission to bidirectional coupling between scales. Top-down pathways often integrate macro-environmental data analysis, as seen in Fernández and Wu (2018), who used city-scale datasets to prioritize intervention measures in Santiago. Conversely, bottom-up pathways rely on micro-attribute data, such as Gohaud et al. (2025) who examined community revitalization indicators or Ali et al. (2020) who modeled building energy consumption to support macro-level decisions. The hybrid pathway, combining both directions, is exemplified by Kissinger and Stossel (2021), who developed a hierarchical model linking cities, neighborhoods, and buildings to simulate metabolic processes, and Lotze-Campen et al. (2018) combining “universal metrics with localized adaptations” for EU city evaluations. This evolution not only addresses the limitations of single pathways but also enhances the analytical rigor of assessments by integrating methods with pathways. Ultimately, it uncovers causal linkages between micro-level community features and macro-level urban performance, identifies conflicts between short-term local needs and long-term urban strategies, and supports the construction of comprehensive evaluation frameworks.

Notably, cross-scale assessment methods show clear regional commonalities and differences in application. Developed countries widely adopt hybrid methods due to their robust multi-source data infrastructure and mature technical support. In contrast, developing countries often face constraints like data barriers and high technical costs, which make simplified versions of “lightweight models and localized indicators” more practical. These disparities are primarily driven by economic development, data openness, and institutional maturity.

5.1.2 Innovation and Technical Limitations in Research Methods and Indicator Systems

Current urban and community cross-scale sustainability assessments have achieved synergistic development by integrating diverse methodologies and innovating indicators across multiple dimensions, collectively enhancing the explanatory capacity of evaluations for complex urban systems. Methodologically, computationally simulated pathways leverage proxy models and machine learning to translate micro-level indicators into macro-level system

behaviors by simulating agent-level interactions. For example, in the Limmattal region in Switzerland, the UrbanSim model was employed to couple community-scale variables—such as building density, functional mix, and urban transportation accessibility—revealing trade-offs between retail growth and open space reduction caused by light rail construction. Similarly, Dublin’s building energy consumption study leveraged deep learning to model energy linkages across the “building-community-city” mechanism. Spatial analysis methods integrate multi-source spatial data through GIS, linking spatial scales via geographic units. For instance, in Santiago, Chile, researchers developed an Environmental Improvement Priority Index that combines remote sensing data with community statistics, effectively identifying spatial disparities in environmental inequity. The research in the New York study revealed that increased street vegetation coverage correlates with higher pedestrian traffic. Multi-dimensional indicator integration pathways construct composite metric systems that align with SDGs or local needs; the Gold Coast, Australia study, for instance, combined community-scale impervious surface ratios and vegetation coverage within city-level measures of land-use mix and public transit service levels. The resulting regional community sustainability index confirmed a negative correlation between community green spaces and urban heat island intensity. Qualitative analytical approaches dissect the cross-scale effects of institutional dimensions like policy and culture. The Italian energy discourse research, for example, reveals disparities between national and local discussions as well as deviations in policy implementation.

At the indicator level, the synthesis of studies (see Table 6) shows that while social dimension indicators cover areas like population, income, and health, current research remains predominantly focused on environmental and economic dimensions. This evident lack of sociocultural factors constrains these assessments from fully understanding resident well-being. For example, Valderrey et al. (2023) included sociocultural indicators—like community cohesion—when assessing the cross-scale vulnerabilities of Mexican communities, while Wang et al. (2024) pointed out the role of community participation and social equity in aligning city- and community-level goals for SDG 11.7.

Table 6. Heatmap of Cross-Scale Sustainability Assessment Indicators by Reference Frequency and Spatial Scale

Dimension	Indicator Category	Reference	Frequency
Economic	Per capita GDP; Unemployment rate	3 (4,5,7)	3
Economic	Industrial structure; Value-added share of energy industry; Investment in renewable energy	3 (4,7,8)	3
Economic	Land price; Real estate market activity; Urban land use efficiency	3 (1,7,11)	3
Social	Population size and growth rate; Population density; Aging rate	5 (5,7,8,9,11)	5
Social	Income level and disparity; Housing conditions; Accessibility of public space resources for low-income groups	4 (3,5,7,11)	4
Social	Health status; Crime rate; Traffic accident rate; Noise pollution perception	3 (5,8,11)	3
Social	Education level; Accessibility of public service facilities (e.g., schools, hospitals); Public transport share rate	4 (2,3,5,7)	4
Social	Civic engagement; Energy citizenship awareness; Community cohesion	2 (4,7)	2
Environmental	Energy/water consumption intensity; Waste generation and recycling rate; Urban metabolic flows	5 (2,5,6,8,11)	5

Environmental	Greenhouse gas and air pollutant emissions concentration; Urban heat island intensity; Traffic noise pollution	5 (1,2,5,8,11)	5
Environmental	Land use efficiency; Green space ecosystem service value; Public space quality and accessibility; Morphological indicators (building, street)	6 (1,2,7,8,10,11)	6
Environmental	Emergency response capacity for natural disasters; Stormwater runoff coefficient; Environmental exposure and resource allocation disparities	5 (2,3,8,11,12)	5

Low High

Despite this limitation, the findings simultaneously highlight cross-dimensional coupling characteristics. For instance, urban land-use efficiency encompasses economic attributes along with environmental and social impacts. Similarly, community green space planning and waste recycling systems not only improve local environments but also provide insights for urban resource utilization. The nested nature of scales is also evident—energy consumption intensity, for example, has different meanings and drivers at the building, community, and city scales—and this propels indicator systems from single-dimensional and single-scale frameworks toward multidimensional, multi-scale ones.

However, both methodological approaches and the design of indicators have major limitations. First, computational simulation methods are constrained by overly simplified model assumptions and limited data coverage. The “rational assumption” about how residents choose where to live does not align with real-world behavior, as seen in Dublin’s study on energy certificate coverage limitations. To address these gaps, common calibration approaches include adopting spatial interpolation to fill missing data points and integrating multi-source data fusion methods to mitigate prediction bias. Second, spatial analysis methods have a problem with variable grid cells. For example, London-based research indicates that altering grid resolution yields significant differences in the accessibility of green spaces. Third, multi-dimensional indicator integration depends on “path-dependent” subjective weighting. While communities help adjust these weights, the process is easily influenced by subjective factors. Similarly, qualitative analysis methods can effectively explain governance logic, but struggle with directly measuring performance evaluations.

When it comes to indicator design, the issue is entrenched dimensional imbalance. Economic and environmental dimensions—being easier to quantify and supported by stronger research foundations—continue to dominate, while sociocultural dimensions remain underrepresented due to difficulties in data collection and limited scholarly attention. Micro-level indicators, such as community cohesion and energy citizenship, are key to driving sustainable change. However, due to their highly localized nature, they are difficult to capture the full spectrum of macro-level statistical systems. This imbalance cannot be resolved solely through method optimization. It requires a fundamental rebalancing of dimension weights within the overall evaluation framework design.

5.2 Challenges in Cross-Scale Assessment

Drawing on practical evidence summarized in Table 7, this section identifies four core bottlenecks in cross-scale assessment: data integration barriers, high technical costs, imbalanced indicator systems, and methodological constraints. Collectively, these issues hinder the effective implementation and wider adoption of cross-scale assessment frameworks.

Table 7. Challenges in Cross-Scale Sustainability Assessment and Case Evidence

Challenge Category	Sub-category	Representative Cases and Evidence
I. Structural Barriers in Data Integration	1. Scale heterogeneity and data aggregation bias	Chile: The environmental data is resampled from 30m to 100m resolution, and some spatial details are not detailed; London: adjusting the analysis grid from 1km to 2km caused the CBD identification to disappear entirely. Dublin: EPC data covers only 39% of the building stock, and buildings outside this range, there is uncertainty in the model's predictions; Brazil: Census data is collected only once every 10 years; EU: Sustainable assessment based only on 2015 and 2020 data, failing to capture short-term fluctuations.
	2. Data incompleteness and update latency	Building data from housing departments and real-time carbon emission data from environmental agencies offer in statistical granularity and spatial resolution, resulting in a 25% error rate in cross-scale metabolic analysis.
	3. Interdepartmental data silos	Gold Coast, Australia: The MUSIX model uses high-resolution "visual and digital interpretation aerial images", which are expensive to obtain and complex to process. UrbanSim model requires complex multi model coupling (such as with traffic model MATSim) and spatial explicit data analysis.
II. Technical Costs and Barriers	High technical thresholds and computational costs	73% of studies fail to incorporate subjective wellbeing and social equity indicators. South Korea's urban form metrics show limited applicability in African cities. Santiago's environmental justice study excluded employment and income data.
III. Indicator System Inadequacy and Dimension Imbalance	1. Incomplete multidimensional representation	South Korea: "Complete neighborhoods" with 5-minute walkable access conflicts with urban-scale transportation efficiency goals, resulting in a 35% discrepancy between planned and actual service accessibility across multiple levels.
	2. Disconnection between local needs and higher-level goals	Models like UVPN and UrbanSim lack interoperability regarding variable interactions. Linear aggregation masks extremes, such as Sydney's green space evaluation missed urban heat islands. London's study proposed a 62.5m measurement threshold with no consensus exists.
IV. Methodological Constraints and Adaptation Barriers	1. Limitations of static, single-scale modeling	Some studies rely solely on discourse analysis or static GIS layers, which cannot capture feedback loops of multi-system interactions
	2. Weak integration of qualitative and quantitative methods	

5.2.1 Structural Barriers to Data Integration

Data integration faces fundamental challenges due to severe data fragmentation across different scales and sectors. Three key problems contribute to this: aggregation bias arising from scale heterogeneity, incomplete and outdated data, and prominent cross-departmental data silos. When combined with inconsistent data standards among agencies, these issues generate "spatiotemporal resolution mismatches", ultimately weakening the accuracy and effectiveness of cross-scale linkage analyses.

5.2.2 High Technical Barriers and Computational Costs

The application threshold for cross-scale sustainability assessment remains relatively high. One reason is the substantial cost of acquiring high-resolution spatial and temporal data, as well as the computational burden of

running complex models. In addition, lengthy data access cycles further limit efficiency. Another reason is the lack of lightweight tools and the academic-oriented background of most technical personnel. Consequently, these factors hinder research outcomes from moving beyond academia to practical use, particularly for small and medium-sized cities that face limited data resources.

5.2.3 Imbalanced Indicator Systems and Misaligned Objectives

Existing indicator systems have two major weaknesses: incomplete dimensional coverage and limited regional adaptability. Current frameworks often prioritize environmental and spatial indicators, while neglecting subjective well-being and social equity. Additionally, conflicts exist between community-level local needs and city-level macro goals, leading to mismatches between multi-scale planning and real-world situations, making assessments disconnected from practical demands.

5.2.4 Insufficient Methodological Depth and Dynamism

Current methodologies rely heavily on static analysis tools, which inadequately capture dynamic feedback across multiple systems amid rapid urbanization. Moreover, between quantitative modeling and qualitative institutional analysis remains weak. And there are also no universal standards for scale conversion. These limitations collectively reduce the scientific rigor of cross-scale assessments.

5.3 Limitations

The study's limitations mainly lie in the research design, data sources, and sample representativeness. First, the literature retrieval relied exclusively on two major databases: Web of Science and Scopus. While this approach ensures academic authority, it may have excluded relevant cross-scale studies on specific regions—such as small-to-medium cities in East Asia—stored in databases like Elsevier ScienceDirect and CNKI. This results in a limitation of single data sources. Second, while the 14 core documents selected through strict screening provide representative cases, the limited sample size restricts the generalizability of findings across cities and communities with different socioeconomic and institutional contexts. Third, the research period of 2015–2025 aligns with the implementation phase of the 2030 Agenda for Sustainable Development, ensuring policy relevance but overlooking earlier theoretical contributions. Consequently, the retrospective examination of the cross-scale assessment remains incomplete and fails to fully establish early research with contemporary practices.

6. Conclusions and Outlook

Theoretically, existing studies such as Elmqvist et al. (2019) mainly identified fragmentation of cross-scale urban sustainability research but did not link assessment pathways with specific methodologies. Building on this, this study clarifies how different assessment approaches can be aligned with computational simulation and spatial analysis techniques, thereby strengthening the linkage between theory and method. Policy-wise, this study goes beyond previous general calls for multi-scale coordination by proposing actionable strategies that bridge the gap between theoretical advocacy and practical policy implementation.

Methodologically, this study conducted a systematic review of literature from 2015 to 2025 following the PRISMA protocol and proposes three main contributions. First, it identifies a cross-scale assessment classification framework that integrates pathways and methodologies, clarifying the technical logic of top-down, bottom-up, and hybrid approaches. Second, it identifies two fundamental features of sustainability indicators—cross-dimensional coupling and cross-scale nesting. Third, an empirical analysis reveals an imbalance among domain dimensions, with environmental and spatial aspects dominating, whereas sociocultural dimensions remain chronically underrepresented due to challenges in data accessibility. Current challenges—such as data incompatibility and methodological barriers—call for practical solutions. Future efforts should focus on three priorities: enhancing the cross-scale transferability of sociocultural indicators, developing shared cross-scale model repositories to lower technical thresholds, and promoting community-participatory evaluation mechanisms that incorporate residents' subjective well-being. Testing hybrid assessment models in medium-sized cities is also recommended to evaluate their applicability in data-limited contexts.

In short, adopting a cross-scale perspective is essential for understanding and promoting the collaborative sustainable development of cities and communities. With these improvements, cross-scale assessments can more effectively uncover causal links between micro- and macro-level processes and support multi-level coordinated governance, thereby contributing to the achievement of SDG 11 and the broader 2030 Sustainable Development Goals.

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