

Review

Green Campus Assessment Supported by Remote Sensing Big Data: A Review of Concepts, Tools, Evidence Pathways, and Future Directions

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Abstract

Campus sustainability assessments increasingly rely on broad indicator systems, yet their empirical foundation remains heavily dependent on institutional self-reports, administrative records, and checklist-based scoring. These data types capture governance and educational activities effectively. However, they are less suitable for evaluating spatially heterogeneous or temporally dynamic environmental conditions, such as greenspace distribution, land use composition, and thermal environments. Such conditions are difficult to verify through self-reporting alone. Remote sensing and GIS offer potential solutions by providing externally verifiable and cross-campus comparable measurements, but their integration into formal assessment standards remains underdeveloped. The literature reveals three persistent gaps: an evidence gap (over-reliance on self-reports), a spatial gap (limited inclusion of spatially explicit indicators), and a standardization gap (case studies without transferable protocols). These gaps are relevant in China, where diverse campus forms intensify comparability challenges. To address these issues within the Chinese context, this review proposes a conceptual two-level framework. The framework comprises a comprehensive assessment structure covering governance, education, operations, environment, and participation. It is paired with a separate spatial evidence module based on remote sensing and GIS. This framework is a conceptual reference and an operational pathway, rather than an empirically validated or calibrated tool. The framework intends to guide the systematic integration of spatial evidence into future Chinese green campus standards. However, threshold values, weighting schemes, and contextual adjustment factors would require further empirical testing and policy deliberation.



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Keywords: green campus assessment; campus sustainability assessment; remote sensing big data; GIS; spatial evidence; evaluation standards; sustainable campus; China

1. Introduction

To coordinate global progress across economic, social, and environmental dimensions, the United Nations 2030 Agenda established the 17 Sustainable Development Goals (SDGs) as a universal framework [1]. Reaching these targets depends heavily on academic institutions, which positions education systems as a foundational element in sustainable transformation. UNESCO reinforced this mandate through its Education for Sustainable

Development: A Roadmap (ESD for 2030), which outlines five priority action areas and identifies the greening of learning environments and the adoption of a Whole-Institution Approach as key levers for change [2]. This progression is reflected in UNESCO's 2024 Green School Quality Standard, which structures green schools around four core domains: governance, facilities and operations, teaching and learning, and community engagement [3]. This progression signals a broader shift within the green campus agenda, moving from isolated environmental upgrades toward a systemic, quality-driven approach to institutional governance.

China's green campus agenda stands on a foundation of long-term policy continuity, tracing back to early environmental education initiatives. In 2003, the Ministry of Education issued the Implementation Guidelines for Environmental Education in Primary and Secondary Schools (Trial) [4]. These guidelines integrated ecological themes into basic curriculum reforms and practical coursework. The national strategy changed in 2019, when the Overall Plan for the Action to Create Green Living designated green schools as one of seven priority initiatives [5]. This change shifted campus greening from localized, voluntary advocacy to a state-level institutional mandate within China's broader ecological civilization framework. Following this, local governments launched initiatives around 2020 under the Action Plan for Green School Creation [6,7]. These initiatives targeted a 60% compliance rate by 2022 and introduced distinct evaluation metrics for higher education versus primary and secondary systems. Consequently, green campus governance transitioned away from campaign-style promotion toward structured, standardized evaluation. This trajectory is reinforced by the Outline for Building a Leading Country in Education (2024–2035), which emphasizes high-quality monitoring and assessment mechanisms [8]. This directive provides institutional backing for transitioning green campuses from demonstration projects toward systemic, quality-oriented governance.

Academically, campus sustainability assessment (CSA) has developed into a diverse field that includes indicator systems, ranking tools, self-assessment frameworks, certification schemes, and management-oriented approaches [9–11]. Previous reviews have classified assessment tools and compared their indicator domains, methodological structures, and institutional functions [10,12,13]. These studies show that existing tools differ substantially in their objectives, data sources, scoring procedures, and implementation contexts [10,14,15]. However, the proliferation of tools has not produced a unified or easily transferable standard, because ranking, certification, self-assessment, and reporting systems follow different assessment logics [10,13,16].

A further limitation is that much of the existing review literature remains concentrated on higher education institutions. Although the green campus agenda increasingly covers both universities and primary and secondary schools, the transferability of assessment frameworks across educational levels remains insufficiently examined [3,6,7]. This gap matters because campus size, governance structure, and management capacity differ substantially between higher education institutions and schools. Student age groups and curriculum functions also vary considerably. Therefore, a green campus assessment standard needs to balance common sustainability principles with education-level-specific interpretation.

Another unresolved issue concerns the evidence base of green campus assessment. Existing tools still rely heavily on institutional self-reports, internal statistics, administrative documents, and checklist-based scoring [9,10,17]. These data sources are useful for evaluating governance arrangements, curriculum integration, management processes, and participation activities [12,13,18]. Nevertheless, they are less effective for assessing spatially heterogeneous, temporally dynamic environmental attributes that are difficult to verify through self-reporting alone. Examples include greenspace distribution, land use compo-

sition, impervious surfaces, land surface temperature, and surrounding environmental exposure [19–21].

Recent studies have shown that GIS, satellite imagery, UAV data, and other geospatial methods can assess campus-scale environmental conditions [19,21,22]. For example, remote sensing has been used to estimate greenspace, land cover, thermal environments, and selected GreenMetric-related infrastructure indicators [17,21,22]. However, these applications are still largely case-based and remain weakly connected to formal assessment clauses, scoring rules, verification procedures, and standard-setting processes [17,21,23]. Thus, a methodological gap persists between the growing availability of remote sensing data and its limited integration into mainstream CSA tools.

Taken together, three research gaps can be identified. First, there is an evidence gap: existing systems have expanded indicator coverage, but their empirical foundation depends largely on self-reported administrative data [9,10,17]. Second, there is a spatial gap: many campus environmental conditions are inherently geographic, but spatially explicit indicators remain marginal in formal green campus assessment tools [17,19,21]. Third, there is a standardization gap: remote sensing and GIS studies have shown technical potential, but there is limited guidance on how spatial evidence can be translated into comparable, context-sensitive, and operational green campus standards [10,17,23].

This review shifts the focus from tool classification to the evidence architecture of green campus assessment. Rather than focusing solely on what dimensions existing tools include, it examines how campus environmental performance can be measured, verified, and compared using traceable spatial evidence. Specifically, this review integrates three bodies of literature: campus sustainability assessment tools, green campus policy and standard systems, and remote sensing-based environmental monitoring [10,17,24]. This integration allows the review to clarify where remote sensing can strengthen assessment validity and where conventional institutional data remain indispensable.

Remote sensing data is therefore not treated as a replacement for existing CSA approaches. Instead, it is conceptualized as a complementary spatial evidence layer that can support selected environmental indicators while remaining linked to broader dimensions such as governance, education, operations, and participation. This distinction is relevant because satellite imagery, UAV data, and GIS can improve the objectivity of spatial indicators, but they cannot directly capture institutional culture, curriculum quality, or stakeholder engagement [17,21,22].

To address these gaps, this review adopts a two-step strategy. First, it reviews international assessment tools and remote sensing applications to diagnose the nature of the evidence and comparability problems. Second, based on this diagnosis, it proposes a two-level framework for China's diverse educational and geographic contexts. This framework is intended to bridge the gap between technical potential and operational standards, and to inform China's ongoing green campus policy development.

Accordingly, this review addresses the following objectives:

1. To synthesize the development of green campus assessment concepts, tools, and standard systems, and to identify the main evidence, spatial, and standardization gaps in existing studies.
2. To examine how remote sensing data and GIS can support selected spatially observable environmental indicators, while clarifying their technical limitations and applicability.
3. To propose a conceptual two-level framework that integrates remote sensing-derived indicators into green campus assessment standards. The framework comprises a comprehensive assessment structure and a separate spatial evidence module. It is designed for China's diverse educational and geographic contexts, with an emphasis on context-sensitivity and verifiability.

The details of the proposed framework and its implications for green campus assessment are presented and discussed in Section 7.

Figure 1 presents the overall logic of this review. The first part summarizes the evolution of green campus assessment concepts, tools, and policy demands. The second part examines the potential and limitations of remote sensing big data for generating spatial evidence. The final part discusses how spatial indicators may be connected with assessment dimensions, indicator systems, validation procedures, uncertainty control, and China-oriented standard development.

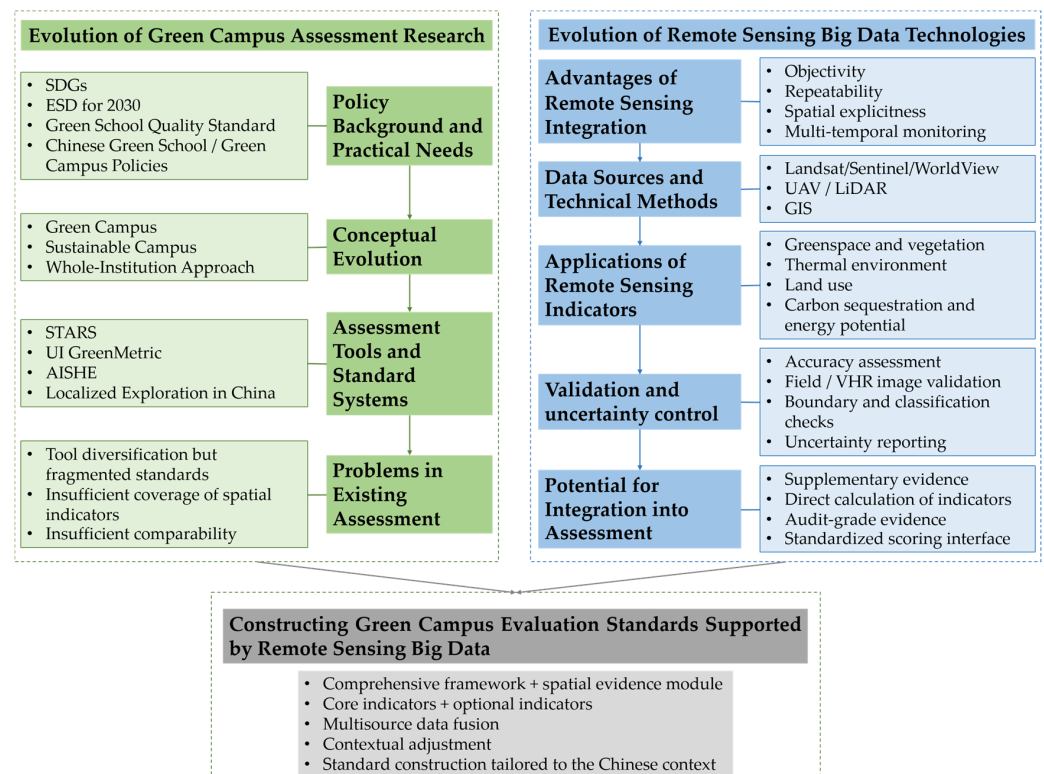


Figure 1. Overall logical framework of research on green campus evaluation standards supported by remote sensing big data.

2. Theoretical Foundations and Conceptual Evolution of Green Campus Assessment Research

2.1. The Evolving Connotation of Campus Sustainability

Early iterations of the green campus focused on physical and technical modifications, such as landscape greening, resource conservation, and waste mitigation [25,26]. This initial lens restricted the evaluation scope primarily to the immediate ecological performance of the campus as a physical space. However, as scholarly discourse shifted toward long-term sustainability transitions, the broader concept of the sustainable campus superseded this narrow definition. This broader paradigm requires systemic synchronization across a university's core pillars, including teaching, research, governance, daily operations, and civic responsibility [12,18,24–26]. Velazquez et al. defined the sustainable university as a dynamic organizational ecosystem that uses education, research, and outreach to reduce negative socio-environmental impacts and promote sustainable habits in wider society [25]. Expanding this institutional view, Alshuwaikhat and Abubakar analogized the university to a micro-city driven by metabolic flows of energy, materials, and transit [26]. They argued that campus assessment must simultaneously evaluate administrative policy, engineering solutions, and grassroots participatory mechanisms. The contemporary campus is therefore

no longer viewed merely as an eco-friendly physical site, but as a nested socio-ecological-technical system.

During this evolution, the core orientation of campus sustainability shifted from an early focus on environmental performance toward an integrated emphasis on governance, teaching, operations, and participation. Alghamdi et al. identified management, academia, environment, engagement, and innovation as five representative benchmarks in their review of higher education assessment tools [12]. Dawodu et al. argued that environment, education, and governance have become the three most prominent dimensions in sustainable campuses design [18]. Caeiro et al. and Gutiérrez-Mijares et al. similarly argued that campus sustainability should be understood not merely as greening facilities, but as a holistic transformation encompassing operations, teaching, research, and stakeholder participation [10,24]. Thus, the green campus represents the starting point of campus sustainability transitions, while the sustainable campus denotes a broader concept accommodating multidimensional governance goals and long-term institutional change. As shown in Figure 2, the evolution is not merely a terminological shift. Its connotation has gradually expanded from environmental performance toward a comprehensive framework encompassing governance, education, research, operations, and participation.

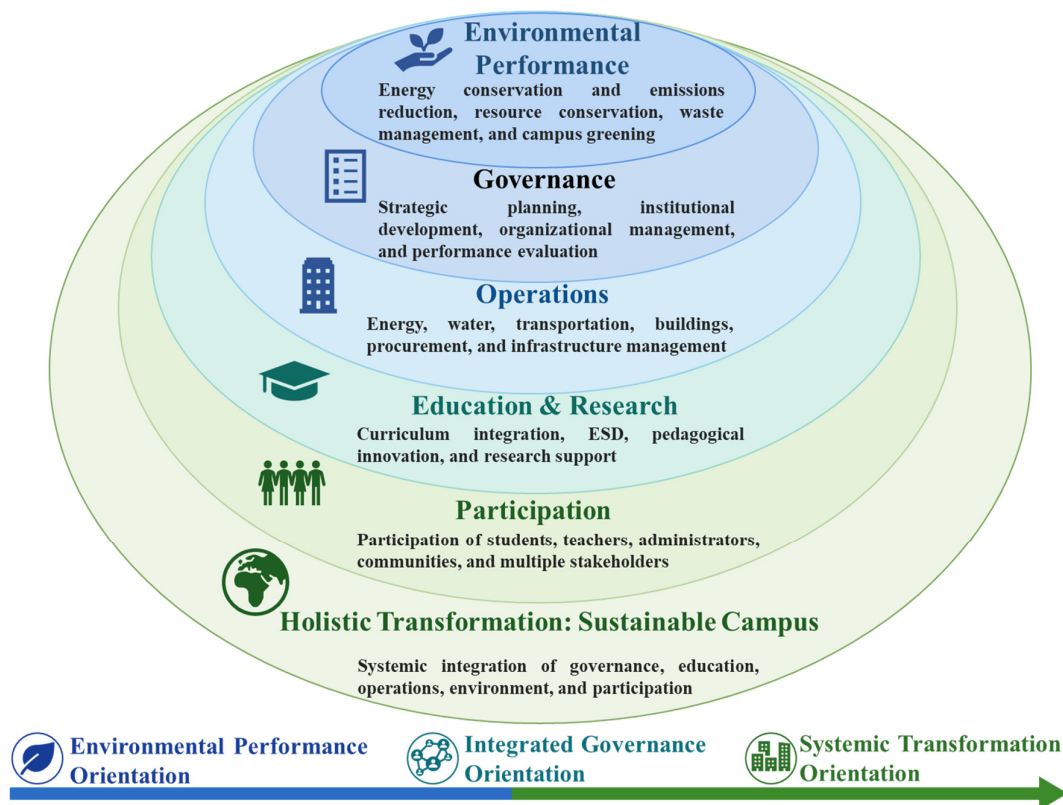


Figure 2. Conceptual evolution framework from the green campus to the sustainable campus.

2.2. Knowledge Structure and Research Hotspots in Green Campus Assessment Research

To examine the knowledge structure, research hotspots, and evolutionary characteristics of the field, this study conducted a visual analysis of the sampled literature using CiteSpace 7.0.R0 (64-bit) Advanced. The literature was retrieved from the Web of Science Core Collection, with the search performed on 15 May 2026. The advanced search query was:

TS = (("green campus" OR "sustainable campus" OR "campus sustainability" OR "campus sustainability assessment" OR "green school" OR "school sustainability") AND

(assess OR evaluat OR standard* OR indicator* OR framework* OR ranking OR benchmark* OR certification OR audit OR monitoring))

An initial query yielded 717 records. Non-journal formats, including book chapters, early access materials, proceeding papers, and retracted articles, were excluded. Restricting the language to English resulted in a final dataset of 569 publications for bibliometric mapping. Figure 3 presents the PRISMA-style flow diagram summarizing the identification, screening, and inclusion process.

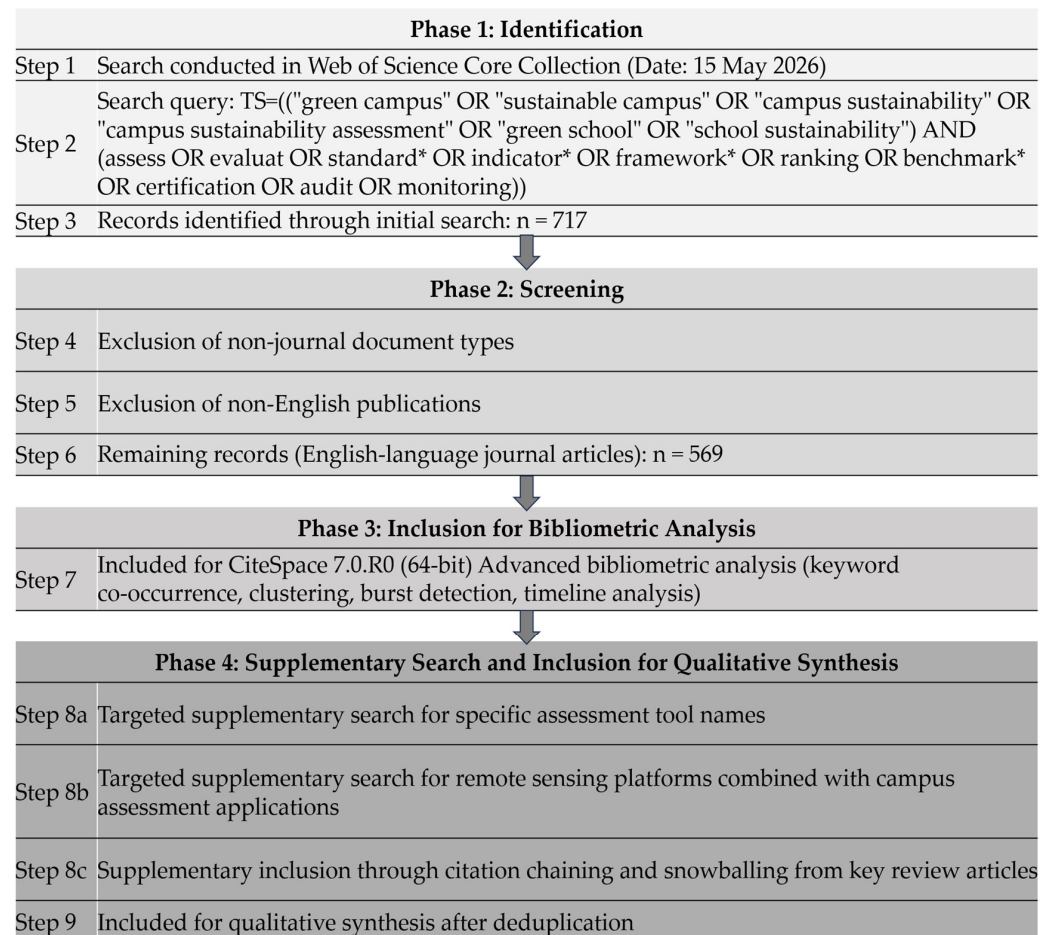


Figure 3. PRISMA-style flow diagram of the literature search, screening, and inclusion process. * is a wildcard character used to represent any number of characters.

Figure 4 charts the annual publication trend of green campus assessment research from 1 January 1996 to 15 May 2026. To ensure interpretability of temporal dynamics, the analysis distinguishes between complete indexing years (1996–2025) and a partial indexing year (2026). The apparent fluctuation observed in the most recent period is primarily attributable to incomplete coverage in the Web of Science Core Collection at the time of data retrieval (15 May 2026), rather than substantive changes in research activity.

All CiteSpace visualizations presented in this study (Figures 5–8) were generated based on a unified dataset and consistent parameter configuration. The data were retrieved from the Web of Science Core Collection, covering the time span from 1996 to 2026 with a slice length of one year. The node type was set to Keyword, and the node selection criterion was adopted as g-index ($k = 20$). The Link Retaining Factor (LRF) was set to 2.5, L/N to 10, Look Back Years (LBY) to -1 , and the edge weight (e) to 1.0. Network pruning was performed using the Pathfinder algorithm, applied to both sliced networks and the merged network. The resulting keyword co-occurrence network comprises 373 nodes and

1690 links (network density = 0.0244), with the largest connected component accounting for 89% of the entire network (334 nodes). Clustering quality assessment yielded a Modularity Q of 0.3895, a Weighted Mean Silhouette S of 0.6513, and a Harmonic Mean (Q, S) of 0.4875, indicating that the clustering structure exhibits good internal consistency and interpretability. Keyword burst detection for Figure 7 was performed using CiteSpace default settings ($\gamma = 1.0$, minimum duration = 2 years).

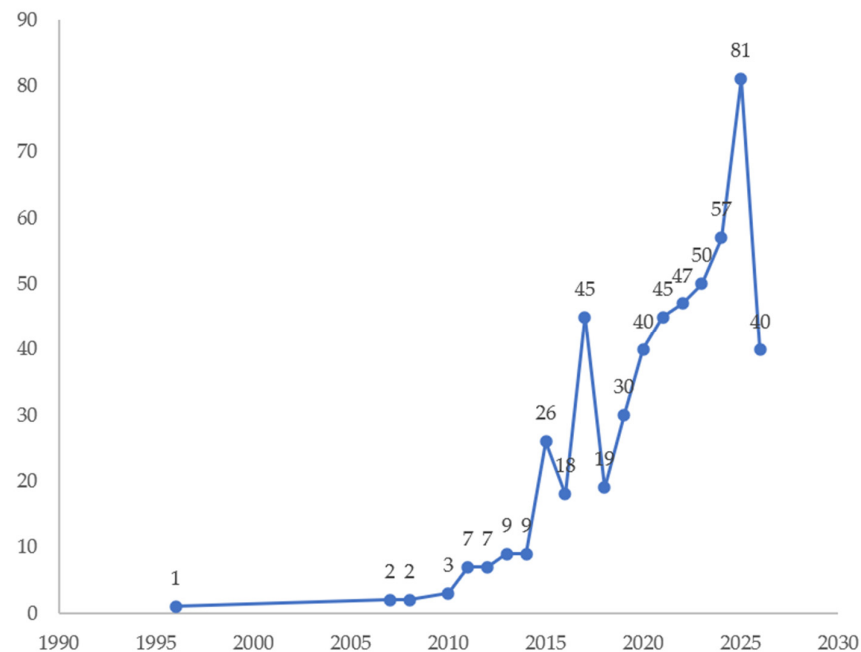


Figure 4. Annual publication trend of green campus assessment research (1996–2026). Note: Data for 2026 is partial due to indexing lag in the Web of Science Core Collection as of 15 May 2026.

Mapping the bibliometric dataset into a keyword co-occurrence network (Figure 5) shows the main themes and keyword relationships in the sampled literature. The network is organized around frequently occurring terms such as campus sustainability, sustainable campus, green campus, climate change, life cycle assessment, carbon footprint, framework, energy, management, and design. These terms have relatively high frequency and connectivity in the keyword network, indicating that they are prominent topics in the reviewed corpus. Their links with climate change, life cycle assessment, carbon footprint, and energy suggest that campus sustainability assessment is often discussed in relation to low-carbon transitions, resource auditing, and operational management. In addition, the appearance of terms such as air pollution, comfort, heat, perceptions, and quality indicates that some studies have begun to address spatially explicit and user-related environmental conditions, including thermal comfort, ambient air quality, and satisfaction.

Building on the keyword co-occurrence analysis, the study further conducted keyword clustering to describe the major thematic groupings in the sampled literature, as shown in Figure 6. The dominant clusters include sustainability reporting, university campus operation, moderating role, modeling approach, education institution, green-gray space, green school building, green space, and thermal environment. These clusters indicate that the reviewed literature is concentrated on institutional reporting, campus operations, educational settings, spatial quality, built environments, and microclimate-related topics. Sustainability reporting and university campus operations occupy central positions in the keyword network, suggesting that institutional tracking and operational management are frequently discussed themes. Meanwhile, clusters such as green space, thermal environment, green-gray space, and green school building show that spatial quality and campus

environmental conditions have gained visibility in recent studies. However, these results should not be interpreted as proving the scientific importance of these topics. They indicate patterns of attention within the sampled literature and need to be interpreted together with qualitative review evidence.

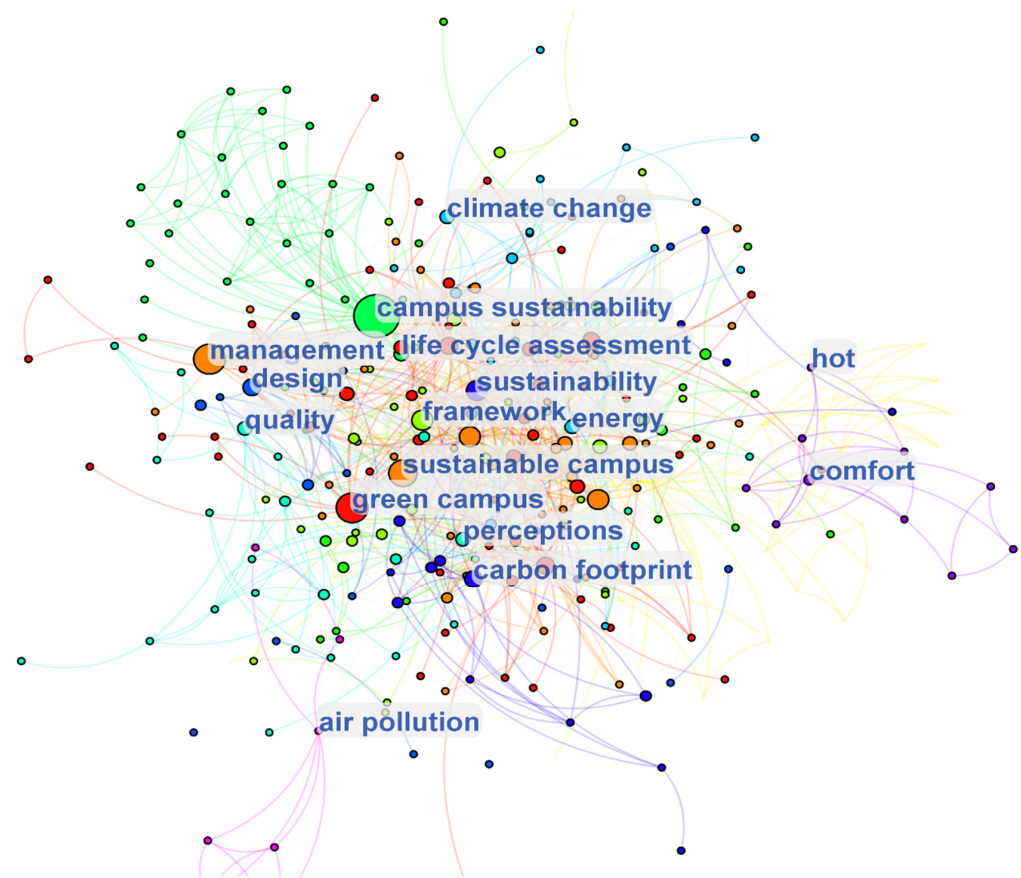


Figure 5. Keyword co-occurrence network of green campus assessment research. Nodes represent keywords, with larger nodes indicating higher frequencies of occurrence. Links represent co-occurrence relationships among keywords, and different colors indicate thematic associations across different time slices or network structures. The network was generated using CiteSpace 7.0.R0 (64-bit) Advanced with the following parameters: time span 1996–2026, slice length = 1 year; node type = Keyword; node selection criterion = g-index ($k = 20$), LRF = 2.5, L/N = 10, LBY = −1, $e = 1.0$; pruning = Pathfinder (applied to both sliced and merged networks); network size: $N = 373$, $E = 1690$ (density = 0.0244); largest connected component = 334 (89%); clustering quality: Modularity $Q = 0.3895$, Weighted Mean Silhouette $S = 0.6513$, Harmonic Mean (Q, S) = 0.4875.

Taken together, Figures 5 and 6 suggest that the sampled literature is concentrated on broad sustainability frameworks, campus operations, environmental performance metrics, and selected spatial environmental topics. At the same time, the bibliometric results alone cannot determine whether a topic is scientifically important or insufficiently studied. Therefore, the interpretation here is combined with the qualitative synthesis of assessment tools and remote sensing applications. This combined reading suggests that the mechanisms for embedding remote sensing evidence into formal standards, ensuring cross-institutional comparability, and adapting spatial indicators to diverse educational and geographic contexts remain insufficiently specified in the existing literature.

The keyword burst dynamics mapped in Figure 7 track changes in research attention within green campus assessment scholarship. The strongest bursts are associated with sustainability assessment, campus sustainability, and climate change. The 2015–2020 burst

for sustainability assessment reflects a period in which framework design and assessment methodology received concentrated attention. This was followed by the 2017–2018 burst for campus sustainability, suggesting a more direct focus on the campus as the unit of sustainability evaluation. More recently, the 2024–2026 burst for climate change indicates that green campus assessment has become increasingly connected with carbon neutrality, climate mitigation, and broader environmental governance agendas.

However, the burst results should be interpreted cautiously. The absence of strong burst terms such as remote sensing, GIS, or assessment standard construction does not by itself prove that these topics are absent or unimportant. Keyword burst analysis captures sudden increases in attention, rather than the full scale, maturity, or methodological depth of a research area. Therefore, the burst results are used here only as supplementary evidence. When read together with the keyword co-occurrence and clustering results in Figures 5 and 6, they suggest that remote sensing and GIS have not yet become dominant organizing themes in the formal green campus assessment literature.

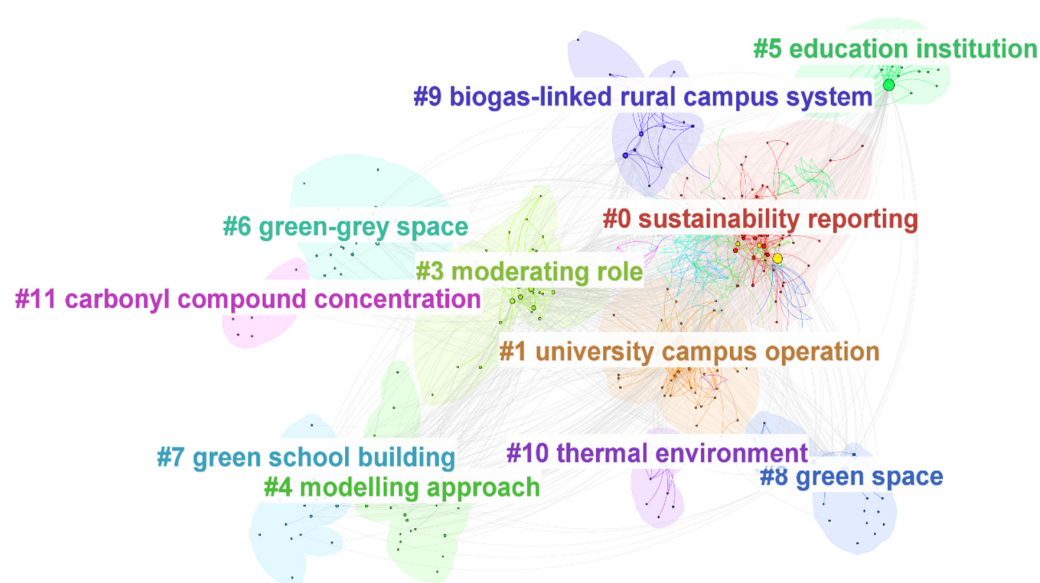


Figure 6. Keyword clustering map of green campus assessment research. Nodes represent keywords, links represent co-occurrence relationships among keywords, and different colors indicate different clusters. Cluster numbers are ranked by size, with #0 representing the largest cluster. The network was generated using the same CiteSpace parameters as in Figure 5 (see Figure 5 caption for full parameter details).

Top 3 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	1996–2026
sustainability assessment	2015	3.52	2015	2020	
campus sustainability	2008	3.74	2017	2018	
climate change	2016	3.6	2024	2026	

Figure 7. Keyword burst map of green campus assessment research. The figure shows the keywords with the strongest burst intensity in the sample literature and their duration. Red intervals indicate burst periods, reflecting phases in which a keyword received significantly heightened attention, while blue intervals indicate all other periods. The burst detection was performed on the same keyword co-occurrence network as in Figures 5 and 6 (see Figure 5 caption for full CiteSpace parameters). Burst detection used CiteSpace default settings ($\gamma = 1.0$, minimum duration = 2 years).

This interpretation is also consistent with the qualitative synthesis of existing tools and applications. Current research has demonstrated the feasibility of using remote sensing

and GIS to measure campus greenspace, land use structure, thermal conditions, and other spatial indicators [17,21,22]. Nevertheless, these applications remain only weakly integrated with formal assessment clauses, scoring thresholds, weighting systems, and verification procedures [10,17,23]. Thus, the issue is not whether remote sensing and GIS can generate useful campus-scale environmental data, but how such spatial evidence can be systematically embedded into comparable, context-sensitive, and operational green campus assessment standards.

The temporal evolution of keyword clusters mapped in Figure 8 demonstrates that the field's thematic trajectory resists simple linear substitution; instead, it unfolds through distinct thematic clusters with sharply differentiated lifespans. The most enduring backbone of the literature consists of a foundational group: #0 sustainability reporting, #3 moderating role, and #5 education institution. Activating after 2005 and pressing forward through roughly 2026, these themes represent the longest-lasting, most persistent core axis of campus sustainability research, anchoring it firmly to institutional context, reporting frameworks, and mechanism-oriented interpretations. A second distinct cluster group, comprising #1 university campus operation and #8 green space, dominated the middle phase of the discipline's development, with activity clustered primarily between 2005 and 2025. This phase served as a critical evolutionary bridge, steering scholarship away from basic environmental remediation and toward administrative operations and spatial landscape analysis. More recently, a third wave spearheaded by #4 modeling approach and #6 green-gray space surged after 2015 and continues to expand through 2026. This trajectory captures a modern, ongoing pivot toward greater spatialization, methodological sophistication, and micro-scale refinement. In contrast, a fourth cohort, #7 green school building, #9 biogas-linked rural campus system, and #10 thermal environment surfaced after 2010 but remained only locally active. While these specialized topics never achieved the dominant, institutional scale of the core framework themes, they mark vital, time-specific expansions into physical built environments, microclimates, and niche campus ecosystems. Finally, #11 carbonyl compound concentration represents a lone, historical category. Activating around 1996 and completely fizzling out before 2015, this line reflects the field's early, exploratory chemical–environmental phase, which ultimately failed to secure a mainstream foothold in the modern literature.

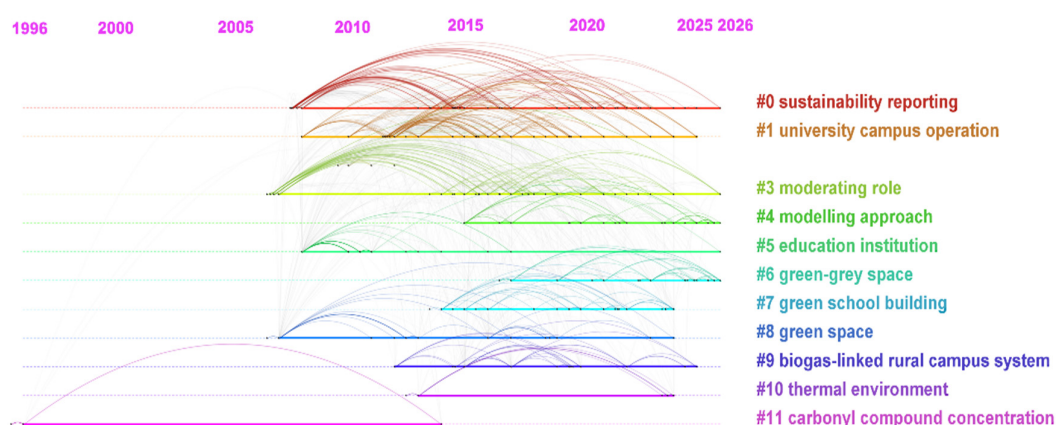


Figure 8. Keyword timeline map of green campus assessment research. The figure shows the temporal distribution of the major keyword clusters in green campus assessment research. The horizontal axis represents time, while differently colored timelines represent different cluster themes. Cluster numbers are ranked by size. Links indicate knowledge relationships among keywords within the same cluster. The timeline visualization was generated using the same CiteSpace parameters as in Figure 5 (see Figure 5 caption for full parameter details).

As mapped in the temporal distribution of Figure 8, green campus assessment research did not evolve along a simple, linear path. Instead, a distinct structural backbone materialized after 2005, providing a foundation from which the scholarship branched outward into specialized domains like operational management, greenspace planning, spatial modeling, and microclimate analysis. Tracing these specific nodes reveals a layered historical progression. Clusters #0, #3, and #5 have consistently anchored the literature, proving that assessment frameworks, institutional contexts, and explanatory mechanisms form the permanent intellectual core of the field. Building upon this base, campus operations (#1) and greenspace (#8) acted as critical transitional bridges during the discipline's intermediate years. More recently, the continued momentum of clusters #4 and #6 captures a modern shift toward sophisticated spatial configurations and methodological rigor, while the remaining nodes (#7, #9, #10, and #11) represent either niche, localized subtopics or largely abandoned early explorations. Ultimately, this timeline illustrates a dynamic compounding effect. Rather than abandoning its early priorities, the field has grown by grafting advanced spatial environments and technical methodologies onto a highly stable theoretical core, culminating in the integrated and geographically refined research landscape we see today.

2.3. The Basic Logic of Campus Sustainability Assessment

Rather than reducing performance to a simplistic score, CSA operates on the premise of translating abstract sustainability mandates into identifiable, measurable, comparable, and manageable information [10,13]. Gutiérrez-Mijares et al. pointed out that existing assessment approaches differ in sustainability in data characteristics, collection methods, assessment scope, and implementation level [10]. They also noted differences in sustainability pillars, university functions, and national perspectives. This indicates that CSA is essentially a family of methods rather than a single tool. A recent review by Pragya and Padmanabhan showed that numerous sustainability assessment tools with different purposes have emerged globally, and that their differences are reflected in their evaluation objectives and application contexts [13]. Ferrer-Balas et al. argued that campus sustainability assessment performs multiple roles, including reflection, monitoring and planning, comparison, and legitimation, extending beyond the presentation of results [27].

In terms of methodological structure, CSA can generally be divided into four levels: indicator systems, rating and ranking systems, audit and certification systems, and reporting and monitoring systems [10,13,27]. Indicator systems constitute the foundational level, with the primary task of decomposing sustainability into dimensions, criteria, and indicators. Examples include the structured criteria tree proposed by Shi and Lai, as well as the five-dimensional assessment system developed by Chen et al. for Chinese universities [24,28]. Rating and ranking systems emphasize inter-institutional comparison and incentive diffusion. Among them, UI GreenMetric and STARS are the two most representative tools. The former is oriented toward global ranking dissemination, while the latter emphasizes transparency, self-reporting, and continuous improvement [14,29,30]. Audit and certification systems, by contrast, place greater emphasis on institutional embedding, process maturity, and continuous improvement. This logic is reflected in AISHE, EcoCampus, and campus practices associated with EMAS and ISO 14001 [31,32]. Reporting and monitoring systems serve information disclosure, continuous tracking, and decision support. In recent years, research on university sustainability reporting has increased significantly [33], suggesting that the closed loop of assessment–disclosure–improvement is becoming an important direction in CSA. In this sense, CSA may be understood as a multilayered methodological structure. Indicator systems address what is to be assessed. Rating and ranking systems address how comparison is conducted. Audit and certifica-

tion systems address how improvement is organized. Reporting and monitoring systems address how sustainability performance is tracked.

2.4. *Constituent Elements of Green Campus Evaluation Standards*

A green campus evaluation standard must first clarify its evaluation objectives. Existing studies indicate that such standards generally serve four types of purposes: internal improvement, external ranking, certification compliance, and policy monitoring. These different purposes lead to substantial differences in evaluation emphasis [13,16,27]. Second, the evaluation dimensions constitute the structural backbone of the standard. Current research has already moved from single-dimensional environmental assessment to multidimensional and integrated assessment covering governance, teaching and research, operations, culture, and social participation [9,12,16,18,24]. For example, Horan and O'Regan extracted a concise set of indicators from STARS and GreenMetric, covering energy, greenhouse gases, water, waste, transport, education, research, and governance [16]. In the Chinese higher education context, Chen et al. proposed five major dimensions: organizational management, energy and resource conservation, friendly environment, campus culture, and social outreach [24]. Third, indicator design determines whether a standard can balance theoretical completeness with practical operability. Existing studies emphasize that indicators should be relevant, measurable, obtainable, and interpretable. Otherwise, they may impose excessive data burdens or fail to support cross-campus comparison [10,16,28]. Fourth, weighting and scoring constitute the core of fairness and outcome orientation in evaluation, as different weighting methods can directly affect institutional rankings and policy implications [13,14,16,29]. Fifth, data sources determine the credibility and verifiability of an evaluation standard. Traditional standards have relied largely on school self-reporting, statistical reports, and administrative records, whereas in recent years, GIS, remote sensing, and spatialized data have begun to provide more objective evidence for campus environmental and operational assessment [10,16,33]. Sixth, comparability and contextual adaptability are two challenging principles to balance in green campus evaluation standards [15,34,35]. Sonetti et al. and Boiocchi et al. have both pointed out that campus morphology, climatic zones, infrastructure conditions, and intensity of use can significantly affect assessment results [15,34,35]. Therefore, an effective evaluation standard requires not only a set of core common indicators, but also contextual adjustment mechanisms. Thus, a green campus evaluation standard is not simply an assemblage of indicators. It is a comprehensive institutional instrument composed of evaluation objectives, dimensions, indicator design, weighting, scoring, and data sources. It also requires mechanisms for comparability and contextual adaptability. Seventh, comparability and contextual adaptability represent a fundamental tension in green campus evaluation standards [15,34,35]. An effective standard must balance cross-institutional benchmarking against contextual heterogeneity in campus morphology, climate, infrastructure, and educational level. To address this, this review proposes a methodological principle of “core indicators plus typological or contextual adjustment factors.” Under this framework, a shared set of core indicators ensures a common foundation for comparison, while adjustment factors—such as campus type (compact vs. dispersed, urban vs. suburban), educational stage, and regional climate—are applied to differentiate benchmarks, interpret scores, or adjust weightings. This dual structure aims to reduce systematic bias that may arise from direct, unadjusted comparisons, supporting both standardization and fairness. Thus, a green campus evaluation standard is not merely an assemblage of indicators, but a comprehensive institutional instrument integrating objectives, dimensions, indicators, scoring, data sources, and mechanisms for comparability and contextual adaptability.

3. International Evolution of Green Campus Assessment Tools and Standard Systems

3.1. *Origins and Evolution of Core Assessment Tools*

International green campus assessment tools did not evolve along a single technical trajectory. Rather, with the expansion of sustainability practices in higher education, multiple parallel tool genealogies gradually emerged. These include scoring and ranking tools, self-assessment and improvement tools, audit and certification tools, network/charter-based frameworks, and environmental management system (EMS)-based tools [31,32,36–43]. Among these, STARS represented a shift from scattered case-based practices toward a transparent, self-reporting, and comparable framework. Its purpose was to support continuous improvement, peer comparison, and information sharing through a common measurement framework, rather than simply to produce external rankings [30,36–38]. The development of STARS began in 2006 and entered a pilot stage in 2008. Since then, it has undergone multiple revisions, focusing primarily on improving applicability, reportability, and data quality [36,37]. By contrast, UI GreenMetric was launched by Universitas Indonesia in 2010. It is oriented toward global university sustainability ranking, and aims to provide a relatively accessible framework for comparing green campus performance worldwide [14,29,44]. AISHE originated from Dutch higher education sustainability certification practice. Its primary orientation is to measure both the extent and the maturity of sustainability integration within organizations [31,45]. It therefore functions more as a tool for educational process enhancement and organizational improvement than as a competitive global ranking instrument. The developmental logic of the ISCEN Charter is different. It emphasizes principled commitments, institutional leadership, governance integration, learning and research, and networked collaboration among universities [39]. It is therefore closer to a charter-based framework than to a detailed scoring system. EcoCampus, EMAS, and ISO 14001 are rooted in the tradition of Environmental Management Systems (EMS), with a primary focus on improving environmental performance, ensuring compliance, and conducting audits [32,40–43]. Consequently, their influence on campus assessment is expressed mainly through process governance rather than global ranking. Overall, the international system of green campus tools has expanded from an early emphasis on environmental performance to multidimensional frameworks that simultaneously address governance, teaching, research, operations, and participation. However, boundaries remain among different tools in terms of their objectives, evidence requirements, and application contexts. Figure 9 summarizes the main genealogy of these tools. They comprise multiple types, including ranking/benchmarking tools, self-assessment/improvement tools, network/charter-based frameworks, audit/certification tools, and EMS-based tools. These tools differ in evaluation purposes, data requirements, and methodological logics. They reflect a shift in green campus assessment from a narrow environmental orientation toward integrated governance and organizational transformation.

3.2. *UI GreenMetric: Global Benchmarking, Ongoing Refinement, and Persistent Comparability Challenges*

Among existing international tools, UI GreenMetric is the most widely adopted and has contributed to making campus sustainability a visible global benchmarking issue [14,29]. Its six categories include setting and infrastructure, energy and climate change, waste, water, transportation, and education and research. This structure enables comparison of campus sustainability performance [29,44]. Beyond ranking, the framework assists universities in organizing sustainability information, identifying performance gaps, and communicating efforts internationally.

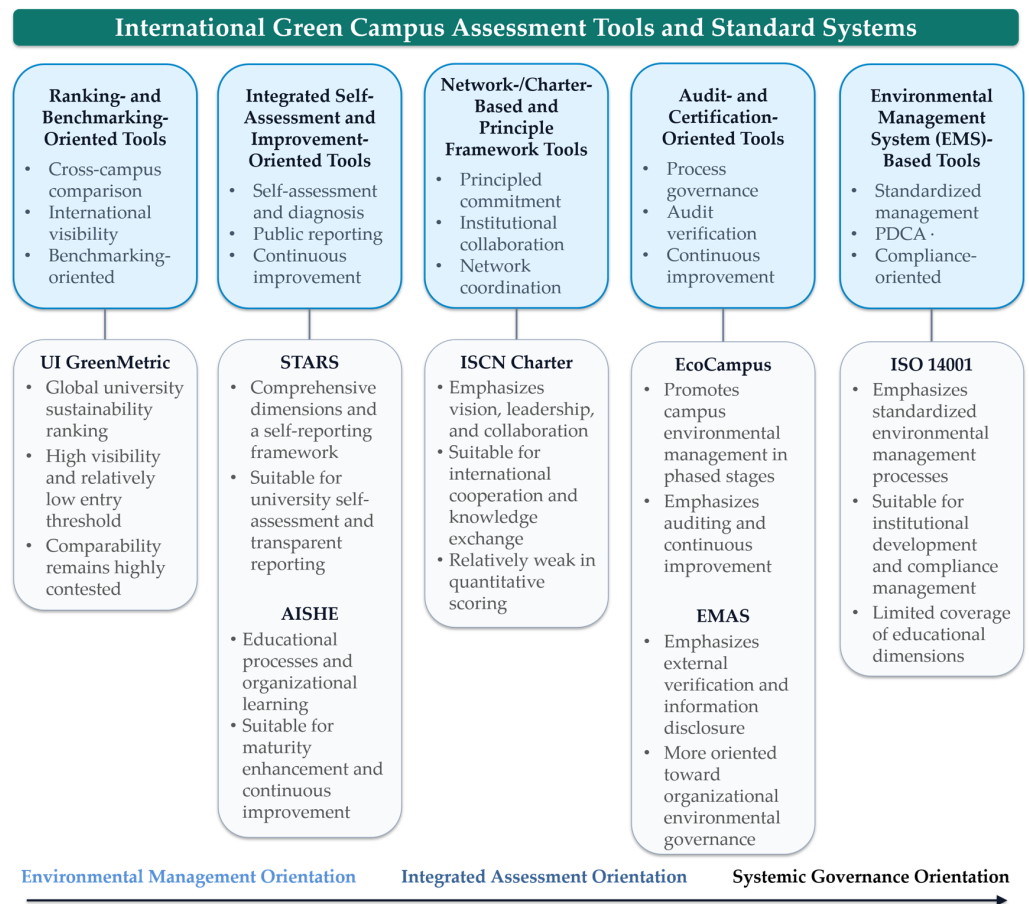


Figure 9. Genealogy of international green campus assessment tools.

Recent developments show that UI GreenMetric has undergone continued refinement. The 2025 guideline indicates continued indicator refinement, including revised and newly added items. These reflect emerging sustainability priorities [44]. This suggests a gradual effort to improve the framework's relevance and to capture not only physical infrastructure and operational inputs, but also broader sustainability actions and outcomes.

UI GreenMetric supports regional adaptation and knowledge exchange through its World University Rankings Network. International, regional, and national workshops, together with regional coordinators, provide channels for sharing practices and interpreting indicators across diverse institutional and geographic contexts [44]. Although these mechanisms cannot fully resolve contextual comparability problems, they can mitigate the risk of treating universities in different climates, regions, and campus forms as directly equivalent.

Data verification has also received increased attention. The guideline requires structured responses and supporting evidence for several criteria, and campus maps or other documents are recommended for spatially related indicators [44]. These requirements enhance transparency and facilitate the integration of geospatial data. This applies especially to indicators related to campus area, green open space, land cover, transportation infrastructure, and environmental facilities.

Nevertheless, methodological concerns remain. Previous studies have noted that UI GreenMetric must balance scientific rigor with practical feasibility, and that scores may still be influenced by climate, location, campus morphology, infrastructure conditions, and self-selection reporting bias [14,15,46]. Therefore, UI GreenMetric is a benchmarking tool with both strengths and limitations. For green campus standard development in China, its indicator organization, dissemination capacity, regional networking, and evidence-submission mechanisms offer valuable references. However, its scoring logic should not

be directly transplanted. One possible approach is to adapt its benchmarking structure while strengthening contextual adjustment, education-level differentiation, and spatial verification through remote sensing and GIS.

3.3. Characteristics and Boundaries of Applicability of STARS, AISHE, and Related Tools

Compared with GreenMetric, STARS places greater emphasis on integrated governance, institutional self-assessment, and public reporting, rather than on the dissemination effects associated with global ranking [30,36–38]. STARS is therefore more suitable for universities with established internal data governance capacity and an interest in continuous improvement through public reporting [30,36]. AISHE, by contrast, integrates sustainability with educational processes, organizational learning, and institutional maturity. Its emphasis is on determining the degree of sustainability integration within the organization, rather than on competitive ranking [31,45]. AISHE is useful for improving teaching processes and strengthening organizational capacity. However, it has lower global visibility and offers less rapid cross-institutional comparison than GreenMetric [31,45]. The ISCN Charter emphasizes principled commitments to institutional leadership, governance integration, learning and research, and network collaboration, rather than detailed scoring logic [34,39]. It is therefore better characterized as a directional framework for university sustainability than as a quantitative scoring tool. EcoCampus, EMAS, and ISO 14001 share a common EMS logic, and their main strengths lie in incorporating campus environmental governance into standardized processes through phased implementation, audit verification, and continuous improvement mechanisms [32,40–43]. Accordingly, these tools cannot replace one another. They correspond to different logics: integrated self-assessment, educational improvement, network-based commitment, and environmental management. For green campus standards in China, this implies that the strengths of these tools may be selectively adapted, while no single tool should be transplanted in its entirety. To more clearly compare the differences among major international green campus assessment tools in terms of evaluation logic, data sources, and applicability boundaries, Table 1 provides a systematic summary of the main tools. As the table shows, these tools are not simple substitutes for one another; instead, they serve distinct purposes, including ranking dissemination, organizational improvement, principled advocacy, and environmental management.

Existing international green campus assessment tools exhibit clear differences in objectives, evaluation logics, and data requirements. Ranking-oriented tools emphasize cross-institutional comparability, while self-assessment systems focus on organizational learning and continuous improvement. In contrast, audit- and EMS-based frameworks prioritize standardized environmental management processes, and charter-based approaches mainly provide normative guidance rather than quantitative assessment.

These differences indicate that no single framework is sufficient for comprehensive green campus evaluation. A composite approach integrating benchmarking capability, governance-oriented assessment, and process-based management is therefore required, with appropriate contextual adjustments for institutional and environmental heterogeneity.

Table 1. Comparative overview of major international green campus assessment tools.

Tool Name	Tool Type	Applicable Object	Core Dimensions	Main Data Sources	Main Strengths	Main Limitations
UI GreenMetric	Ranking/benchmarking	Universities worldwide	Setting and infrastructure, energy and climate change, waste, water, transportation, education and research	School self-reported data, statistical materials, with some spatial data used for supplementary verification	Strong international dissemination, facilitates cross-institutional benchmarking, relatively low entry threshold, rapidly increases the visibility of green campus issues	Comparability remains highly contested; results are easily affected by climate, location, campus morphology, and institutional background; self-selection reporting bias may exist
STARS	Integrated self-assessment/improvement	Higher education institutions	Academics, engagement, operations, planning and administration, innovation and leadership	Self-reported data, reports, administrative data, publicly disclosed materials	Comprehensive framework emphasizing transparency, self-assessment, continuous improvement, and public reporting; suitable for internal governance enhancement	High data requirements, relatively high implementation costs, and weaker direct international comparability than single ranking tools
AISHE	Self-assessment/improvement; audit-supporting	Higher education institutions	Educational processes, organizational learning, institutional embedding, maturity enhancement	Interviews, self-assessment, organizational documents, management process materials	Strong emphasis on educational process improvement and organizational capacity enhancement; suitable for internal diagnosis and sustainability transitions	Limited international visibility and weak capacity for rapid cross-institutional comparison
ISCN Charter	Network/charter-based framework	Higher education institutions; members of international university networks	Institutional leadership, governance commitment, learning and research, campus and community collaboration	Commitment documents, institutional reports, case-based experience	Emphasizes principled guidance, international cooperation, and knowledge exchange; strengthens strategic commitment to sustainability	Limited quantitative scoring capacity; difficult to use directly for fine-grained comparison or ranking

Table 1. Cont.

Tool Name	Tool Type	Applicable Object	Core Dimensions	Main Data Sources	Main Strengths	Main Limitations
EcoCampus	Audit/certification	Universities and educational institutions	Environmental management, continuous improvement, phased implementation, institutional process development	Audit materials, environmental management records, process documents	Clear phased progression, well suited to building organizational environmental management capacity, closely linked to certification pathways	More focused on environmental management processes; insufficient coverage of teaching, research, and participation
EMAS	Audit/certification; EMS-based	Universities and other organizations	Environmental performance, compliance, audit verification, environmental information disclosure	Audit data, environmental management records, externally disclosed materials	Strong requirements for external verification and information disclosure; highly institutionalized and credible	Heavily focused on environmental management and compliance; insufficient for a full-scope sustainability assessment of campuses
ISO 14001	EMS-based	All types of organizations, including universities	Environmental management processes, PDCA cycle, compliance management, continuous improvement	Management documents, process records, audit materials	High degree of standardization, clear pathway for institutional development, well suited to the formalization of environmental management	Primarily focused on environmental management; limited coverage of education, research, participation, and campus culture

3.4. Localized Exploration of Green Campus Assessment Tools in the Chinese Context

Research on green campus assessment in China has not simply replicated international tools. Instead, it has developed in response to the limitations of global frameworks, particularly their weak integration of spatial evidence and insufficient comparability across campus types. Studies by Chen et al. and Du et al. have reconstructed indicator systems to accommodate China's diverse university and school settings. This adaptation is important because direct transplantation of tools like GreenMetric or STARS may lead to systematic biases when applied to China's compact urban campuses, large suburban universities, and diverse primary and secondary schools without contextual adjustments. Accordingly, localized research in China has progressed from tool introduction to structural redesign. Examples include the two-level tool structure proposed by Du et al. and the five-dimensional assessment system developed by Chen et al. for Chinese universities.

4. Technological Pathways Through Which Remote Sensing Big Data Enters Green Campus Assessment

4.1. Theoretical Advantages of Remote Sensing Big Data for Campus Assessment

Remote sensing provides spatially explicit observations of campus vegetation, buildings, water bodies, impervious surfaces, and thermal environments. It has been widely used as a data source for campus environmental assessment [17,19,20].

In this review, "remote sensing big data" is defined operationally, not by data volume. Its big-data character rests on four features: (1) global spatial coverage from open-access archives (e.g., Landsat, Sentinel); (2) long-term time-series continuity; (3) scalable processing workflows; and (4) integration with administrative and field data. Thus, the term refers to open-access, temporally continuous, spatially explicit, and operationally scalable Earth observation data and GIS workflows. This definition emphasizes reproducibility, comparability, and scalability—which are relevant for national-level standard development. Small-scale case studies remain relevant because their methods are designed for broader application.

Compared with questionnaires, administrative records, and self-reported information, remotely sensed observations provide more consistent measurements for selected environmental indicators [17,19,20]. Landsat supports long-term monitoring through its continuous archive of surface reflectance and land surface temperature products [47], while Sentinel provides higher spatial resolution and revisit frequency for monitoring vegetation and land-cover dynamics [48].

GIS-based spatial analysis supports boundary delineation, spatial aggregation, hotspot identification, and indicator calculation [17,19]. Previous reviews have reported that spatial indicators remain underrepresented in existing campus sustainability assessment frameworks, indicating opportunities for broader integration of remote sensing and GIS techniques [17]. Cross-campus comparability remains dependent on campus boundary delineation, classification accuracy, and contextual normalization [17,19]. As established in Section 2.4, this review adopts a "core indicators plus typological or contextual adjustment factors" principle to address such comparability challenges.

Sensor characteristics vary in spatial, spectral, radiometric, and temporal resolution, which affects their suitability for campus-scale indicators [47,48]. Medium-resolution satellite data such as Landsat and Sentinel are suitable for long-term and cross-campus monitoring, but may produce mixed-pixel effects in small or fragmented campuses. By contrast, high-resolution satellite imagery, UAV data, and LiDAR are more suitable for fine-scale analysis, though they are often constrained by cost, temporal continuity, and cross-site standardization [21–23].

Temporal resolution, cloud contamination, and data availability further influence the reliability of remotely sensed indicators. Optical imagery is particularly affected by atmospheric conditions, leading to variability in vegetation, water, and land surface temperature measurements across regions and seasons.

Seasonal and phenological variability also introduces uncertainty, as surface conditions may fluctuate due to rainfall, irrigation, and short-term meteorological changes [20,49].

Different spatial technologies serve complementary roles rather than interchangeable functions. Satellite imagery is mainly used for long-term and regional monitoring, whereas UAV and LiDAR are more appropriate for high-resolution structural analysis. GIS provides spatial processing and indicator aggregation functions across multi-source datasets [19,21,23].

Remotely sensed indicators are also subject to uncertainties arising from atmospheric correction, image registration, classification algorithms, and boundary delineation [17,19]. To address these, remote sensing should be combined with field validation, administrative records, and other institutional data. Transparent reporting of data sources, acquisition dates, resolution, preprocessing methods, and accuracy information is also essential.

As shown in Figure 10, the integration of remote sensing into green campus assessment is not a single-step process. It involves a technical chain: data acquisition, preprocessing, uncertainty control, spatial analysis, indicator extraction, validation, and linkage with evaluation clauses.

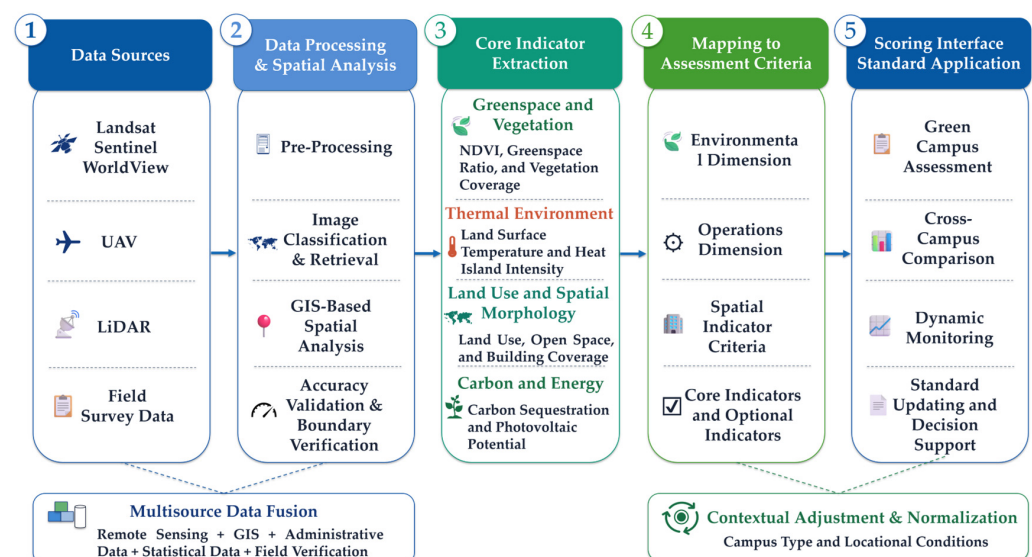


Figure 10. Technological pathway through which remote sensing big data enters green campus assessment.

4.2. Major Data Sources and Technical Methods

Satellite remote sensing is the most frequently reported data source in green campus environmental assessment studies [22,47–51]. Landsat is widely used in campus-scale studies of land surface temperature and long-term vegetation dynamics due to its continuous observation record and thermal infrared capability [47,49,52,53]. Addas et al. applied Landsat-8 imagery to estimate land surface temperature and examined its relationship with vegetation and built-up areas on university campuses [49]. Wibowo and Salleh used Landsat data to analyze urban heat patterns, surface temperature distribution, and heat hazards on university campuses [52,53]. Sentinel-2 imagery is commonly used for mapping campus vegetation, water bodies, and land cover because of its high spatial resolution and short revisit cycle [22,48]. Incekara et al. applied Sentinel-2B data to estimate the GreenMetric Setting and Infrastructure indicators. Their study demonstrated that remotely sensed imagery can support standardized estimation of greenspace and non-greenspace proportions [22]. High-resolution imagery such as WorldView is commonly used for detailed mapping of

campus boundaries, buildings, and vegetation due to its fine spatial resolution [50,51,54]. Studies using WorldView data have applied it to land use and land cover classification and to analyze spatial patterns of campus greenness and built-up intensity [51,54].

UAV, LiDAR, and GIS techniques are increasingly used together with satellite imagery to improve spatial resolution and indicator extraction in campus-scale studies [21,23,55–59]. UAV-based photogrammetry has been applied to estimate vegetation structure, greenspace area, and carbon-related indicators, while UAV thermal infrared imagery supports microscale analysis of campus heat islands [21,56]. LiDAR is commonly used for three-dimensional campus structure analysis and rooftop photovoltaic potential assessment [23]. GIS provides spatial integration functions such as interpolation, buffering, area statistics, and indicator aggregation across multi-source datasets [19,57–59]. At the same time, existing studies generally show that the integration of field surveys with remote sensing validation remains indispensable [51,55]. Tonietto et al. used field vegetation surveys to validate classification accuracy when comparing different land use and land cover methods [55]. Dharmawan et al. combined field investigation with image interpretation to enhance the reliability of their campus classification results [51]. This suggests that remote sensing-based green campus assessment is better suited to a composite technical pathway combining remote sensing extraction, GIS-based computation, and field validation.

4.3. Typical Applications of Remote Sensing Indicators in Green Campus Assessment

Vegetation-related indicators are the most frequently reported application of remote sensing in green campus assessment. Common indicators include NDVI, vegetation coverage, tree canopy cover, greenspace area, vegetation health, carbon storage, and carbon sink estimation [51,55,60,61]. NDVI has been widely used to monitor vegetation dynamics and spatial changes in campus greenness [60,61]. Several studies have combined land use classification with carbon storage coefficients to estimate campus carbon storage and biosequestration capacity, while UAV point clouds and tree mapping have been used to support carbon-related assessments [21,55]. These applications indicate that vegetation indicators can provide information not only on greenspace extent but also on selected ecosystem service functions within campus environments.

Thermal environment indicators are another major application of remote sensing in green campus assessment, including land surface temperature, surface heat island intensity, heat risk exposure, and thermal comfort [49,52,53,56]. Landsat-based studies have identified temperature differences among campus land cover types and reported relationships between built-up areas and land surface temperature [49,52,53]. UAV thermal infrared imagery has further been used to analyze microscale heat island patterns and the combined influence of impervious surfaces and vegetation structure [56]. Integrated assessments of greenspace exposure and heat stress have also revealed environmental inequalities among different campus types [54].

Land use and spatial morphology indicators represent another category of remote sensing application. They relate to GreenMetric Setting and Infrastructure, campus planning and management, and spatial environmental quality [21,22,51,54,59]. Typical indicators include land use land cover, the proportion of open space, building coverage, permeable surfaces, water body proportion, and green-gray spatial patterns [21,22,51,59]. Incekara et al. used Sentinel-2 imagery to estimate GreenMetric scores for the Setting and Infrastructure category. Their results indicate that remote sensing classification can correspond to formal evaluation indicators [22]. Dharmawan et al. and Sulaiman et al., respectively, demonstrated the computability of indicators such as buildings, vegetation, water bodies, and permeable surfaces from campus land cover classification and GIS-based extraction [51,59]. Csomós et al. combined greenspace and thermal variables to explain spatial differences

in school environmental quality. Their findings suggest that land cover and spatial morphology can describe campuses and contribute to explaining assessment outcomes [54]. Methodologically, the significance of such indicators lies in the fact that they are not only among the easiest objects to extract using remote sensing, but also serve as key intermediate variables linking environmental performance to scoring systems.

Energy and carbon indicators represent another emerging direction for remote sensing in campus sustainability assessment. This direction mainly includes rooftop photovoltaic potential, spatial visualization of building carbon emissions, and the estimation of carbon storage and biosequestration [21,23,55,57]. The study by Stack and Narine showed that LiDAR and GIS can be used to identify rooftops suitable for photovoltaic installation on campus buildings and to estimate their potential electricity generation and contribution to campus energy demand [23]. Adenle and Alshuwaikhat combined building area and vectorized spatial results to establish a model for spatial estimation and visualization of carbon emissions on a university campus [57]. Tonietto et al. further expanded the scope of low-carbon campus assessment from the perspectives of carbon storage and biosequestration [55]. Together, these studies show that remote sensing can support not only spatial environmental assessment of green campuses, but also quantitative analysis of energy transition and carbon-neutral campuses [21,23,55,57]. However, this direction is still dominated by case studies. No unified standard has been established for accounting boundaries, emission scopes, or valuation methods. Standardized application is therefore not yet widespread.

Finally, schoolyard and learning environment quality indicators represent an emerging area in which remote sensing-based assessment extends from higher education to basic education settings [54,62]. Serrano-Jiménez et al. proposed a GIS- and remote-sensing-based multicriteria assessment model for environmental ergonomics in schoolyards to support decision-making on schoolyard renewal [62]. Csomós et al., from an urban planning perspective, analyzed the green and thermal environmental quality of educational institutions, demonstrating that remote sensing methods can already be used to evaluate greenspace exposure and heat risk in the learning environments of children and adolescents [54]. This direction is notable because it extends green campus assessment to K–12 school settings and connects sustainability assessment with health, equity, and learning experience.

To systematically summarize the technical basis for the integration of remote sensing big data into green campus assessment, Table 2 synthesizes the major data sources, technical methods, and the indicators that can be extracted from them. As the table shows, different data sources differ substantially in spatial scale, indicator suitability, and application boundaries. Landsat and Sentinel are more suitable for cross-campus and temporal monitoring, while high-resolution imagery, UAVs, and LiDAR are more suitable for detailed mapping and thematic diagnosis; GIS and field surveys, meanwhile, provide essential support for indicator computation and result validation.

Table 2. Relationships among remote sensing data sources, technical methods, and green campus assessment indicators.

Data Source	Spatial/Temporal Resolution	Main Technical Methods	Indicators Suitable for Extraction	Typical Campus Applications	Main Limitations
Landsat series	30 m (multispectral and thermal infrared), revisit cycle of approximately 16 days; suitable for long-term time-series analysis	Land surface temperature retrieval, NDVI calculation, land use classification, temporal change detection	Land surface temperature (LST), surface heat island intensity, greenspace coverage, long-term vegetation change, land use change	Diagnosis of campus thermal environments, interannual greenspace change analysis, long-term environmental monitoring	Spatial resolution is relatively coarse, limiting the identification of fine-scale intra-campus patterns; thermal analyses are more suitable for macro-scale assessment than for microscale thermal diagnosis
Sentinel-2	10–20 m, multispectral, revisit cycle of approximately 5 days	Multispectral classification, vegetation index extraction, water body identification, spatial pattern analysis	NDVI, greenspace ratio, vegetation coverage, water bodies, open space, building and non-greenspace ratios, land use	Estimation of GreenMetric Setting and Infrastructure indicators, extraction of campus greenspace and non-greenspace, medium-to high-frequency environmental change monitoring	No thermal infrared bands and therefore unable to directly retrieve land surface temperature; may still lack sufficient detail in densely built campus interiors
High-resolution commercial remote sensing (e.g., WorldView)	Sub-meter to meter-level, high spatial resolution; temporal resolution depends on task acquisition	Detailed land use classification, object identification, campus boundary mapping, tree canopy identification	Campus boundaries, building coverage, canopy cover, open space, schoolyard vegetation, detailed land use	Detailed campus mapping, identification of environmental quality in educational institutions, analysis of schoolyards and surrounding spaces	High data cost and limited area coverage; not conducive to long-term continuous monitoring over large samples
UAV remote sensing	Centimeter-level, highly flexible; temporal resolution depends on mission schedule	Orthophoto generation, 3D point cloud reconstruction, fine-scale classification, microscale structural measurement	Greenspace area, building footprints, open space, tree structure, detailed campus infrastructure, carbon stock estimation	Calculation of UI GreenMetric Setting and Infrastructure indicators, estimation of campus greenspace carbon stocks, microscale environmental mapping	Limited coverage; relatively high flight and processing costs; standardization and cross-site consistency are comparatively weak

Table 2. Cont.

Data Source	Spatial/Temporal Resolution	Main Technical Methods	Indicators Suitable for Extraction	Typical Campus Applications	Main Limitations
UAV thermal infrared remote sensing	Centimeter- to decimeter-level, highly flexible	Thermal infrared imaging, microscale thermal environment monitoring, thermal anomaly identification	High-resolution land surface temperature, localized thermal hotspots, surface heat island intensity, heat risk exposure	Diagnosis of campus surface heat islands, analysis of thermal effects under different landscape configurations, optimization of microscale thermal comfort	Strongly affected by weather conditions and sampling windows; rigorous standardization of sampling conditions is required for cross-campus comparison
LiDAR	High-precision 3D point cloud, high spatial resolution; temporal resolution depends on task acquisition	Construction of digital surface models and digital elevation models, rooftop slope and aspect analysis, canopy structure extraction, 3D morphological measurement	Rooftop photovoltaic potential, canopy height, building volume, three-dimensional spatial morphology, shading structure	Assessment of campus photovoltaic potential, 3D morphology analysis, research on relationships between greenspace structure and buildings	High acquisition cost and substantial technical requirements; more suitable for fine-grained thematic analysis than for routine large-scale updates
GIS spatial analysis	Not an independent remote sensing data source; serves as a platform for multisource data integration and spatial computation	Buffer analysis, heat maps, area statistics, spatial interpolation, landscape metric calculation, visual representation	Open space ratio, building coverage ratio, transportation accessibility, thermal hotspots, spatial zoning, environmental exposure patterns	Integrated campus environmental assessment, calculation of spatial indicators, construction of visual monitoring platforms	Dependent on the quality of upstream data; does not produce original observational data itself; results are highly dependent on boundary rules and data preprocessing
Field surveys and on-site verification data	Point or plot scale; temporal resolution depends on survey schedule	In situ measurement, questionnaires, vegetation inventories, plot surveys, boundary verification, accuracy validation	Tree inventories, ground vegetation characteristics, local environmental information, classification accuracy testing, on-site attribute data	Validation of remote sensing classification, parameter assignment for carbon stock estimation, verification of schoolyard environmental quality	Limited coverage, high labor costs, and difficulty in supporting large-scale continuous monitoring
Multisource integrated data (remote sensing + GIS + administrative data + statistical data + field verification)	Depends on the integrated scales of the component datasets	Data fusion, indicator mapping, cross-validation, normalization, and contextual adjustment	Integrated spatial indicators, operation-related indicators, indicators for standard scoring interfaces	Integrated green campus assessment, cross-campus comparison, dynamic monitoring, standard updating, and decision support	Data integration is complex and places high demands on boundary consistency, temporal matching, accuracy control, and workflow standardization

4.4. How Remote Sensing Evidence Can Be Embedded into Assessment Tools and Scoring Systems

According to current research, the integration of remote sensing evidence into green campus assessment can be categorized into four levels: supplementary evidence, direct source indicator calculation, audit-grade evidence, and standardized scoring interface [10,11,17,19,21,22,58,59]. The first level is supplementary evidence, in which remote sensing images, classification maps, and spatial distribution maps serve as supporting materials for traditional self-assessment results [22,59]. The second level is the direct calculation of indicators, where remote sensing and GIS are used to contribute directly to formal assessment indicator computation [21,22,59]. Incekara et al. used Sentinel-2 to estimate GreenMetric Setting and Infrastructure scores [22]. Fuentes et al. employed UAV point clouds to estimate seven GreenMetric indicators [21]. These cases illustrate that remote sensing can serve as a direct source of scoring, rather than merely supplementary documentation. The third level is audit-grade evidence, whereby remote sensing imagery, classification results, point cloud models, and GIS statistics begin to acquire characteristics similar to audit-grade evidence when they form traceable, verifiable, and reproducible chains of evidence [17,21,58]. The fourth level is the transition from individual measurements to a standardized scoring interface. The current challenge lies not in whether indicators such as NDVI, land surface temperature, building coverage, or open space ratios can be extracted, but in how these results can be mapped onto evaluation clauses, threshold intervals, weighting structures, and scoring rules [10,11,17,59]. Adenle et al. noted that existing formal tools insufficiently cover spatial indicators [17]. Gutiérrez-Mijares et al. and Basheer et al. suggested that future sustainability assessment requires stronger data standardization and methodological transparency [10,11]. Embedding remote sensing into green campus assessment implies more than adding a new data source. It suggests a shift from self-reporting to multisource evidence. In this context, satellites, UAVs, and LiDAR provide spatial evidence; GIS supports indicator computation and spatial representation; and field surveys provide validation and interpretation. These elements can contribute to scalable, verifiable, and updatable interfaces for green campus evaluation standards.

To make the four-level integration logic more explicit, Table 3 summarizes how remote sensing evidence can enter green campus assessment, from supplementary documentation to a standardized scoring interface.

Table 3. Four-level integration pathway of remote sensing evidence into green campus assessment.

Integration Level	Main Function	Typical Evidence or Indicators	Link to Assessment Standards	Key Caution
Level 1: Supplementary evidence	Provides visual and descriptive support for existing self-reported assessment results	Satellite images, UAV images, classification maps, spatial distribution maps	Used as supporting materials for campus environmental claims or planning descriptions	Improves transparency but does not directly generate scores
Level 2: Direct indicator calculation	Converts spatial data into measurable assessment indicators	NDVI, greenspace ratio, land use composition, impervious surface ratio, LST	Can be mapped to environmental quality, setting and infrastructure, thermal comfort, or climate adaptation indicators	Requires consistent boundaries, preprocessing, and normalization
Level 3: Audit-grade evidence	Supports verification of reported data and improves traceability	Boundary checks, land-cover classification results, point clouds, GIS statistics, field-validated maps	Used to verify self-reported green space, land coverage, environmental facilities, or spatial performance claims	Requires accuracy assessment, validation, and uncertainty reporting
Level 4: Standardized scoring interface	Connects spatial indicators with formal scoring rules	Normalized spatial scores, threshold intervals, benchmark values, weighted indicator scores	Used to translate spatial variables into clauses, thresholds, weights, and scoring systems	Requires contextual adjustment and empirical calibration before formal standardization

The higher the integration level, the greater the need for validation, contextual adjustment, and transparent scoring rules. To make the integration of remote sensing evidence more operational, spatial indicators can be embedded into green campus assessment standards through a quantitative interface linking variables, clauses, scoring rules, and verification procedures. First, each remote sensing-derived variable should be mapped to a specific assessment dimension. For example, NDVI, greenspace ratio, and land use composition can support the environmental quality or setting and infrastructure dimension, while land surface temperature can inform thermal comfort, climate adaptation, or health-related environmental quality [17,21,22].

Second, spatial variables should be converted into standardized indicator scores. Positive indicators, such as vegetation vitality or greenspace ratio, may be scored using threshold classification or normalization methods. Negative indicators, such as impervious surface ratio or heat exposure, should be scored inversely. For context-sensitive indicators, such as campus density or open-space configuration, interval-based thresholds are more appropriate than simple linear ranking.

Third, contextual adjustment is needed before cross-campus comparison. Because campus morphology, climatic zone, educational level, and urban density can influence spatial indicators, a single threshold may not be suitable for all campuses [15,17]. Therefore, core indicators can be kept consistent across institutions, while differentiated benchmarks can be applied to universities, primary and secondary schools, compact urban campuses, and large suburban campuses.

It should be noted that this review does not seek to establish universal threshold values, weighting schemes, or benchmark systems. Instead, it proposes an interface through which remote sensing-derived indicators can be incorporated into future assessment standards. The specification of these parameters requires empirical calibration, cross-campus validation, and policy consensus across different educational and geographic contexts.

Finally, remote sensing evidence can enter assessment systems through two modes. In the direct scoring mode, spatial indicators receive explicit weights within the environmental or infrastructure dimension. In the evidence-verification mode, remote sensing is used to check or adjust self-reported information, such as reported green open space, land coverage, or environmental facilities.

Following this integration logic, Table 4 summarizes how major remote sensing indicators can be linked to green campus assessment dimensions, indicator types, educational settings, and potential scoring functions.

Table 4. Mapping relationships between remote sensing indicators and green campus assessment dimensions.

Remote Sensing Indicator	Corresponding Assessment Dimension	What It Represents	Indicator Type	Applicable Educational Setting
Normalized Difference Vegetation Index (NDVI)	Environmental dimension; spatial-indicator dimension	Campus vegetation vitality, level of greenspace coverage, distribution of greening space	Core indicator	Higher education; primary and secondary schools; schoolyards
Greenspace area	Environmental dimension; spatial-indicator dimension	Total amount of campus greenspace; level of greenspace resource provision	Core indicator	Higher education; primary and secondary schools; schoolyards

Table 4. Cont.

Remote Sensing Indicator	Corresponding Assessment Dimension	What It Represents	Indicator Type	Applicable Educational Setting
Greenspace ratio/vegetation coverage	Environmental dimension; spatial-indicator dimension	Level of green infrastructure; configuration of campus greenspaces	Core indicator	Higher education; primary and secondary schools; schoolyards
Land surface temperature (LST)	Environmental dimension; health and comfort dimension	Thermal environmental status, localized heat risk, surface thermal exposure	Core indicator	Higher education; primary and secondary schools; schoolyards
Surface heat island intensity	Environmental dimension; operations and environment dimension	Magnitude of campus heat island effects; thermal burden of the built environment	Core indicator	Higher education; primary and secondary schools
Land use/land cover types	Spatial-indicator dimension; environmental dimension	Campus spatial composition, functional zoning structure, green-gray spatial pattern	Core indicator	Higher education; primary and secondary schools
Building coverage ratio	Operations dimension; spatial-indicator dimension	Density of the built environment; intensity of land development	Core indicator	Higher education; primary and secondary schools
Open space ratio	Spatial-indicator dimension; environmental dimension	Supply of open space; sufficiency of activity space	Core indicator	Higher education; primary and secondary schools; schoolyards
Campus boundaries and spatial morphology	Spatial-indicator dimension	Overall campus form, compactness and diffuseness, morphological type	Core indicator (for contextual adjustment)	Higher education; primary and secondary schools
Soil-Adjusted Vegetation Index (SAVI)	Environmental dimension	Vegetation cover conditions, especially suitable for areas with a strong bare-soil background	Optional indicator	Higher education; primary and secondary schools
Tree canopy coverage	Environmental dimension; learning-environment quality dimension	Shading capacity, ecological regulation capacity, environmental comfort	Optional indicator	Primary and secondary schools; schoolyards; higher education
Heat risk exposure	Health and learning-environment dimension	Level of exposure of students, teachers, and staff to high-temperature environments	Optional indicator	Primary and secondary schools; schoolyards; higher education
Thermal comfort-related indicators	Health and learning-environment dimension	Comfort of outdoor activities; pleasantness of learning environments	Optional indicator	Primary and secondary schools; schoolyards; higher education
Permeable surface ratio	Environmental dimension; operations dimension	Stormwater regulation capacity; ecological permeability	Optional indicator	Higher education; primary and secondary schools
Water body area/water body ratio	Environmental dimension	Level of blue infrastructure; microclimate regulation capacity	Optional indicator	Higher education; primary and secondary schools
Green-gray pattern index	Environmental dimension; spatial-indicator dimension	Spatial mosaic relationship between greenspace and impervious surfaces	Optional indicator	Higher education; primary and secondary schools

Table 4. Cont.

Remote Sensing Indicator	Corresponding Assessment Dimension	What It Represents	Indicator Type	Applicable Educational Setting
Rooftop photovoltaic potential	Operations dimension; energy dimension	Potential for renewable energy supply and low-carbon transition capacity	Optional indicator	Higher education; some primary and secondary schools
Spatial estimation of building carbon emissions	Operations dimension; carbon management dimension	Distribution of building carbon emissions; locations of emission hotspots	Optional indicator	Higher education
Carbon storage	Environmental dimension; carbon sequestration dimension	Carbon storage capacity of greenspaces and trees	Optional indicator	Higher education; primary and secondary schools
Biosequestration capacity	Environmental dimension; carbon sequestration dimension	Capacity of campus ecosystems to continuously absorb carbon	Optional indicator	Higher education; primary and secondary schools
Schoolyard vegetation quality	Learning-environment quality dimension; environmental dimension	Greening quality of schoolyards; conditions for children's contact with nature	Optional indicator	Primary and secondary schools; schoolyards
Environmental ergonomics indicators for schoolyards	Learning-environment quality dimension	Usability, comfort, and adaptability of outdoor learning and activity spaces	Optional indicator	Primary and secondary schools; schoolyards
Composite green-thermal environmental quality indicators for educational institutions	Learning-environment quality dimension; environmental equity dimension	Integrated environmental quality of educational institutions in terms of greenspace exposure and heat stress	Optional indicator	Primary and secondary schools; higher education; schoolyards

5. Differences in the Application of Remote Sensing Big Data Across Educational Settings

5.1. Higher Education Campuses: The Most Studied and the Most Maturely Framed Setting

Existing studies show that higher education campuses represent the most studied and most developed setting for integrating remote sensing into green campus assessment. This is largely because higher education institutions have developed established assessment tool systems, such as GreenMetric, STARS, AISHE, and various localized frameworks. They also tend to have clearer campus boundaries, more developed facilities management, and greater data governance capacity [10,11,13,19]. As a result, remote sensing indicators can be aligned with existing higher education assessment systems, supporting cross-campus comparison and dynamic monitoring [10,11,13]. In practical applications, studies of higher education campuses have already covered multiple dimensions, including operations, energy, carbon emissions, thermal environments, greenspace, and spatial structure [19,23,49,55,61]. For example, GIS has been used for the spatialized assessment of campus operational activities, Landsat and UAV thermal infrared imagery have been employed to diagnose campus thermal environments, LiDAR combined with GIS has been used to identify rooftop photovoltaic potential, and remote sensing together with land cover classification results has been applied to the estimation of carbon storage, biosequestration, and greenspace patterns [19,23,49,55,61]. Overall, higher education represents a more developed research context, with established assessment tools, a broader set of remote sensing indicators, and clearer cross-campus comparative logic [10,11,13,19,23,49,55,61]. However, the most developed applications remain in

environmental and operational dimensions. Governance, curriculum, research, and participation still depend largely on non-remote-sensing data.

5.2. Primary and Secondary Schools: Growing but Still Fragmented

Compared with higher education, remote sensing research on primary and secondary schools has increased in recent years. However, the number of studies remains limited, topics are fragmented, and frameworks are underdeveloped. Existing research has mainly focused on schoolyards, greenspace exposure, thermal environments, and environmental quality, while relatively few studies have developed integrated assessment tools for overall school sustainability performance [54,62,63]. Serrano-Jiménez et al. constructed a remote sensing- and GIS-based assessment model for schoolyards environmental ergonomics to support renewal and thermal optimization [62]. Csomós et al. combined schoolyard vegetation, surrounding greenspaces, and land surface temperature to identify inequalities in green and thermal quality [54]. Assessment goals in primary and secondary school differ from those in higher education. They tend to focus on student health, learning environments, outdoor activity experience, and environmental equity, rather than on governance performance, energy management, or cross-campus benchmarking [54,62]. This means that the central question is not simply whether a school is “green,” but rather what kinds of green–thermal environmental combinations students are exposed to [54,62]. Accordingly, current research on primary and secondary schools is more aligned with environmental exposure assessment and learning-environment quality evaluation than with a fully developed green campus standard system.

5.3. Comparability Across Different Campus Types

Comparability across different educational settings and campus types is a methodological challenge when introducing remote sensing into green campus assessment. Although remote sensing improves the objectivity of environmental indicators, it does not automatically eliminate biases arising from differences in campus morphology, location, and function [15,34,35,64,65]. First, compact and dispersed campuses differ in building density, greenspace structure, and transportation organization. Direct comparison on the same scale may therefore be inappropriate [34,64,65]. The Clusters Approach proposed by Sonetti et al. and the Campus Urban Morphology parameter proposed by Marrone et al. were both intended to improve the rationality of such comparisons [34,64]. Second, urban-embedded and stand-alone campuses face different land constraints and environmental conditions [54,64,65]. Schools in dense urban cores may have less scope for greenspace expansion and thermal mitigation. Direct comparison of greenspace ratios or open space without differentiation may introduce systematic bias [54,64,65]. Third, higher education and primary and secondary schools differ in functional objectives. Higher education assessment typically includes research, governance, energy, and transportation. Primary and secondary school assessment tends to emphasize student health, activity space, and environmental equity. Consequently, even when the two share certain remote sensing indicators, identical weighting or interpretive frameworks may not be appropriate [54,62,63]. Finally, differences in climatic zones and national institutional contexts amplify the complexity of comparison [15,35]. Boiocchi et al. have pointed out that contextual factors such as climate, infrastructure conditions, and patterns of use can significantly influence assessment results. A more reasonable future approach is therefore to construct a comparative framework based on shared core indicators plus typological or contextual adjustment factors [15,34,35,64,65].

Overall, the differences in the application of remote sensing big data across educational settings essentially reflect differences in assessment goals, spatial conditions, data

foundations, and institutional logics. Higher education represents the most studied and maturely framed setting, whereas primary and secondary schools remain comparatively fragmented because their assessment logic is more oriented toward health, environmental quality, and equity. These cross-setting disparities directly inform the implementation of the “core indicators plus typological or contextual adjustment factors” principle established in Section 2.4. Applying this principle requires that core spatial indicators provide a common benchmarking foundation, while typological factors—campus morphology, location, and educational stage—differentiate benchmarks or weighting schemes to prevent distortion from direct one-scale-fits-all comparisons. Future research should therefore operationalize this layered approach, moving beyond uniform scoring toward a framework that is both standardized and context-sensitive.

6. Main Progress and Limitations of Existing Research

6.1. Progress Achieved

One notable development is that campus sustainability assessment has evolved from scattered case studies into a diversified toolkit. This toolkit now includes indicator systems, ranking frameworks, audit and certification schemes, and reporting and monitoring instruments. The scope of research objects, methodological approaches, and application contexts has also expanded substantially. This evolution indicates that campus sustainability assessment has moved beyond experience-based judgments about whether a campus is “green” and has gradually become a framework that is measurable, comparable, and manageable.

Second, assessment dimensions have broadened significantly. Consequently, the concept of a “green campus” has expanded beyond energy savings, landscaping, and waste reduction to encompass whole-institutional transformation. Existing reviews have repeatedly pointed out that environment, education, and governance have become the most representative core dimensions of campus sustainability assessment, while management, academia, engagement, and innovation have also gradually become common analytical frameworks [12,18].

Third, remote sensing and GIS have progressed from auxiliary visualization tools to sources of quantitative indicators. Standardized workflows now allow direct extraction and comparison of metrics such as greenspace, land surface temperature, land use/land cover, carbon storage, rooftop photovoltaic potential, and open space [17,21–23,55]. In particular, studies linked to GreenMetric have used Sentinel imagery and UAV point clouds to estimate Setting and Infrastructure indicators [21,22]. This marks a shift in which remotely sensed evidence begins to inform scoring directly, rather than serving only as supplementary material. Overall, existing research has moved from developing assessment tools toward incorporating spatial evidence into evaluation frameworks.

6.2. Main Limitations

Despite the growing variety of assessment tools, this proliferation does not indicate maturity of standards. Different tools serve different purposes, and the underlying logics of ranking, certification, self-assessment, and reporting are fundamentally distinct. As a result, the field has experienced methodological expansion rather than standard unification.

First, spatial indicators are underrepresented in formal assessment tools. Although existing tools generally recognize the spatial properties of campus environments, relatively few systems take campus-wide spatial indicators as a core component of formal assessment.

Second, remote sensing applications are still largely confined to case studies. Studies vary considerably in data sources, boundary delineation, classification algorithms, validation approaches, and statistical conventions. Technical feasibility has been demonstrated repeatedly, but transferable and unified standards have not yet emerged.

Third, most research remains at the measurement stage, without embedding evaluation standards. Variables such as NDVI, land surface temperature, greenspace ratio, and photovoltaic potential can be extracted, but stable mappings between these variables and evaluation clauses, threshold ranges, weighting structures, and scoring rules are lacking.

Fourth, comparability across campus types, regions, and climatic conditions is insufficient. Compact versus dispersed campuses, urban-embedded versus stand-alone campuses, and different educational levels differ structurally in greenspace, thermal environment, and transportation patterns. Direct comparisons without typological classification or contextual adjustment may produce misleading results.

Fifth, existing research shows a clear bias toward higher education. Although studies on primary and secondary schools and schoolyards have increased, they remain focused on localized topics such as greenspace, heat exposure, and student environmental quality. An integrated assessment framework comparable to that for universities has not been developed for these settings.

Sixth, the integration of remote sensing data with governance, education, and participation dimensions remains limited. Spatial technologies are effective in measuring environmental and operational variables, but they are less capable of directly measuring institutional arrangements, curricula, and culture; as a result, remote sensing remains, to a considerable extent, confined to the environmental dimension.

Seventh, green campus evaluation standards tailored to the Chinese context are underdeveloped. Localized studies in China have gradually moved from borrowing international tools toward contextual reconstruction, but they still occupy a transitional phase between adaptation of external frameworks and reorganization of local indicators.

6.3. Comparison with Existing Reviews and Contributions of This Review

Compared with earlier reviews, a discernible shift in perspective is evident. Previous studies have largely concentrated on classifying CSA tools [10,12,13], which provides a strong foundation for understanding tool diversity. However, they have paid less attention to the underlying evidence systems. A move from a purely typological focus toward an examination of evidence architecture therefore appears necessary.

Furthermore, while the multidimensional nature of campus sustainability is widely accepted [10,18,24], a critical operational distinction can be inferred from the literature. Not all dimensions depend on the same type of evidence. Governance and education, for instance, rely on institutional and curricular data, whereas selected environmental indicators are amenable to spatial measurements. Clarifying this distinction allows remote sensing to serve as a complementary evidence layer.

Finally, previous tool-based discussions have rarely connected to the mechanisms of standard-setting. This suggests that a more operational pathway—for example, a two-level framework—is needed to guide the integration of spatial indicators into formal standards, particularly for the Chinese context. This review builds on previous work on assessment dimensions and tool comparison, while adding a spatial-data perspective that clarifies where remote sensing can contribute, where it remains limited, and how it can be embedded into evidence-informed standard development.

6.4. Controversies and Methodological Challenges

The prominent controversy concerns the tension between standardization and contextual adaptation. Without standardization, cross-campus comparison is difficult to achieve. Yet excessive standardization overlooks differences in climate, location, campus morphology, and institutional background.

A second challenge concerns the relationship between objective spatial data and subjective management data. These are not substitutes, but complementary and mutually constraining forms of evidence. Spatial data enhance verifiability, while management data carry information on governance, teaching, participation, and organizational culture— aspects that are difficult to capture through remote sensing alone.

A third challenge concerns the tension between indicator universality and campus-type differences. The same greenspace ratio, land surface temperature, or open space proportion may have entirely different meanings and improvement costs in higher education versus primary and secondary schools, or in inner-city versus suburban campuses. Thus, while indicators may be shared, interpretive frameworks and weighting structures cannot simply be treated as universal.

A fourth challenge lies in the reliability and operability of multisource data integration. Although satellites, UAVs, LiDAR, GIS, field surveys, and administrative records can theoretically complement one another, boundary consistency, temporal alignment, accuracy control, and data governance workflows all affect the stability of assessment results. In short, existing research has already provided a strong answer to the question of whether remote sensing can be used for campus assessment, but it has not yet adequately answered how remote sensing evidence can be embedded into green campus evaluation standards in a low-cost, replicable, and institutionalized manner.

To further clarify the relationship between existing research gaps and the direction of this study, Table 5 systematically summarizes the main limitations in green campus assessment research, the methodological problems they generate, and the response pathways proposed in this study. As the table suggests, the most critical shortcoming of current research does not lie in the absence of tools or remote sensing methods, but in the lack of a standardized pathway that integrates comprehensive assessment frameworks, spatial evidence, contextual adjustment, and localized Chinese needs.

Table 5. Existing research gaps and the response pathways of this study.

Existing Research Gap	Specific Manifestations	Problems Caused	Response Pathway of This Study	Expected Innovation
Assessment tools are abundant, but standards remain fragmented	Diverse tools such as GreenMetric, STARS, AISHE, EcoCampus, EMAS, and ISO 14001 differ substantially in objectives, dimensions, and scoring logics	Difficulty in forming a unified, stable, and transferable green campus evaluation standard	Construct an assessment standard structure based on a comprehensive framework + spatial evidence module on the basis of reviewing existing tools	Move from parallel tools to integrated standards, forming a unified analytical framework tailored to the Chinese context
Insufficient coverage of spatial indicators in formal tools	Formal assessment tools include only limited campus-wide, spatially based indicators; spatial evidence remains largely auxiliary	Campus environmental assessment still relies excessively on school self-reporting, reducing objectivity and verifiability	Incorporate greenspace, thermal environment, land use, carbon sequestration, and energy potential as core spatial indicators in the standard system	Upgrade spatial indicators from supplementary information to formal assessment clauses
Remote sensing research remains focused on case-based measurement	Existing studies are concentrated on single-campus cases, local indicators, or thematic diagnoses; data sources, boundary rules, and algorithmic workflows differ greatly	Technical feasibility is evident but difficult to replicate; a unified standardized pathway is lacking	Establish a standardized technical workflow from data source → indicator extraction → clause mapping → scoring interface	Advance from case-based remote sensing studies to a transferable standard construction method

Table 5. Cont.

Existing Research Gap	Specific Manifestations	Problems Caused	Response Pathway of This Study	Expected Innovation
Most studies remain at measurement rather than standard embedding	Variables such as NDVI, land surface temperature, land cover, and photovoltaic potential can be extracted, but are seldom incorporated into formal scoring rules	Remote sensing outputs are difficult to directly serve green campus standards and policy applications	Explore mappings between remote sensing indicators and assessment dimensions, scoring thresholds, and weighting structures	Construct an interface mechanism for embedding remote sensing indicators into green campus evaluation standards
Insufficient comparability across campus types	Significant differences exist among compact/dispersed campuses, urban-embedded/stand-alone campuses, and higher education/primary-secondary school settings	Direct horizontal comparison is likely to be distorted, undermining the fairness of rankings or scores	Introduce contextual adjustment and typological interpretation mechanisms to form a framework of core indicators + contextual adjustment factors	Improve interpretability and fairness across different campus types
Higher education is overrepresented, while primary and secondary schools are underrepresented	Higher education settings have mature tools and rich research, whereas studies on primary and secondary schools focus mainly on greenspace, thermal environments, and children's exposure quality	Structural imbalance in green campus assessment frameworks across educational stages	Incorporate both higher education and basic education into standard design, constructing shared core indicators and stage-specific interpretive frameworks	Extend green campus evaluation standards from higher education to broader educational settings
Weak integration of remote sensing with governance, education, and participation dimensions	Remote sensing is well suited to environmental and operational variables, but less able to directly reflect curricula, institutions, culture, and participation	Risk of reducing the green campus concept to environmental performance alone	Adopt a dual-layer structure of comprehensive framework + spatial evidence module, using remote sensing for spatially expressible dimensions while retaining governance and education indicators	Avoid an overly environmentalized approach and preserve the comprehensiveness of the standard
Insufficient integrated standards for the Chinese context	Existing Chinese research remains largely at the stage of borrowing international tools, restructuring local indicators, and exploratory case studies	Lack of an evaluation standard that simultaneously accommodates Chinese campus types, policy contexts, and digital updating capacity	Construct a green campus evaluation standard with scalability, operability, and digital updating capacity within the policy context of green schools and green campuses in China	Build a bridge between the localization of international tools and the internationalization of Chinese standards
Multisource data integration still lacks a low-cost, replicable workflow	Satellites, UAVs, LiDAR, GIS, administrative data, and field verification can complement one another, but workflows remain complex	High implementation costs and difficulty in large-scale diffusion	Construct a multisource integration framework of remote sensing + GIS + administrative data + statistical data + field verification	Improve the implementability, updateability, and digital application potential of the standard

7. Research Implications for Green Campus Evaluation Standards Supported by Remote Sensing Big Data

7.1. Implications at the Assessment Framework Level

The comprehensive framework retains governance, education, operations, environment, and participation as its main dimensions, ensuring that campus sustainability is not reduced to a narrow set of environmental indices. The spatial evidence module incorporates remote sensing-derived indicators for spatially observable environmental conditions, providing externally verifiable and cross-campus comparable measurements.

This dual structure enables a “core indicators plus contextual adjustment” mechanism. Core indicators—such as greenspace ratio and land surface temperature—ensure a common foundation for comparison across all campuses. Contextual adjustment factors—including campus morphology (compact vs. dispersed), educational level (higher education vs. primary and secondary), and climatic zone—are then applied to differentiate benchmarks and interpret scores. This design directly responds to the comparability and heterogeneity issues identified in Section 6.

7.2. Implications at the Indicator System Level

Existing literature has shown that indicators such as greenspace, thermal environment, land use, carbon sequestration, energy potential, and open space possess clear ecological and operational significance, as well as relatively high extractability and cross-campus comparative potential. These indicators should therefore be prioritized as part of the core spatial indicator set of green campus evaluation standards. At the same time, given differences in campus types, data conditions, and assessment objectives, the indicator system should adopt a layered model of core indicators and optional indicators, in which core indicators emphasize cross-campus generalizability, while optional indicators serve particular campus types, regional contexts, or thematic assessment goals. In terms of design principles, indicators should be computable, verifiable, and comparable. In other words, they should not only have clear data sources and algorithmic rules, but also be capable of establishing stable mappings with assessment clauses and scoring logics.

7.3. Implications at the Data and Methods Level

The preceding literature review shows that a single data source is insufficient to support a complete green campus evaluation. Future research should therefore construct a multisource integration framework of remote sensing + GIS + administrative data + statistical data + field verification. Methodological design requires advanced standardization of campus boundaries, indicator statistical units, data temporal windows, and update cycles. Without such standardization, even extractable indicators cannot form comparable or replicable evaluation interfaces. In addition, because factors such as climate, campus morphology, intensity of use, and locational conditions influence environmental performance, future standards should strengthen the normalization of indicators and contextual adjustment in order to improve both the fairness and the interpretability of cross-campus comparison. To accommodate varying technical capacities, a three-tiered implementation pathway for the spatial evidence module is proposed. At the basic level, institutions with limited GIS expertise may rely on publicly available satellite imagery processed through pre-calibrated, open-source tools to extract core indicators such as greenspace ratio and NDVI. At the intermediate level, institutions with dedicated GIS support can incorporate higher-resolution imagery and more sophisticated analyses, including land use classification and land surface temperature mapping. At the advanced level, institutions with specialized technical teams may further integrate UAV data, LiDAR, and field-validated surveys for fine-scale thematic diagnosis and audit-grade evidence. This phased structure

enables progressive adoption: campuses can enter at the basic tier and scale up as technical capacity and data infrastructure develop, avoiding a rigid all-or-nothing requirement.

7.4. Research Directions for Constructing Green Campus Evaluation Standards in China

Green campus evaluation standards tailored to the Chinese context must account for the complexity of campus types, differences in development stages, and the ongoing advancement of green campus policies. They cannot simply copy international tools, but should instead reconstruct the evaluation framework within local institutional and policy contexts. Structurally, future evaluation standards should broaden their scope to encompass both higher education and basic education systems, while avoiding a rigid, one-size-fits-all scoring logic. Instead, the architecture should anchor itself to a shared bedrock of core spatial indicators while deploying tailored interpretive lenses that respect the unique realities of different educational stages. Operationally, a localized Chinese standard must prioritize scalability, practical ease of use, and automated digital updating loops. This ensures the framework functions not merely as an academic exercise, but as an active toolkit for institutional management, regional green school initiatives, and live monitoring dashboards.

While current scholarship has advanced campus tracking tools, diversified evaluation dimensions, and demonstrated the viability of geospatial indicator extraction, a critical void remains: the field has yet to deliver a cohesive evaluation standard that unifies comprehensive governance frameworks, objective spatial evidence, multi-source data streams, and localized adjustment mechanisms. The complete structural blueprint of this integrated research architecture is detailed in Figure 11.

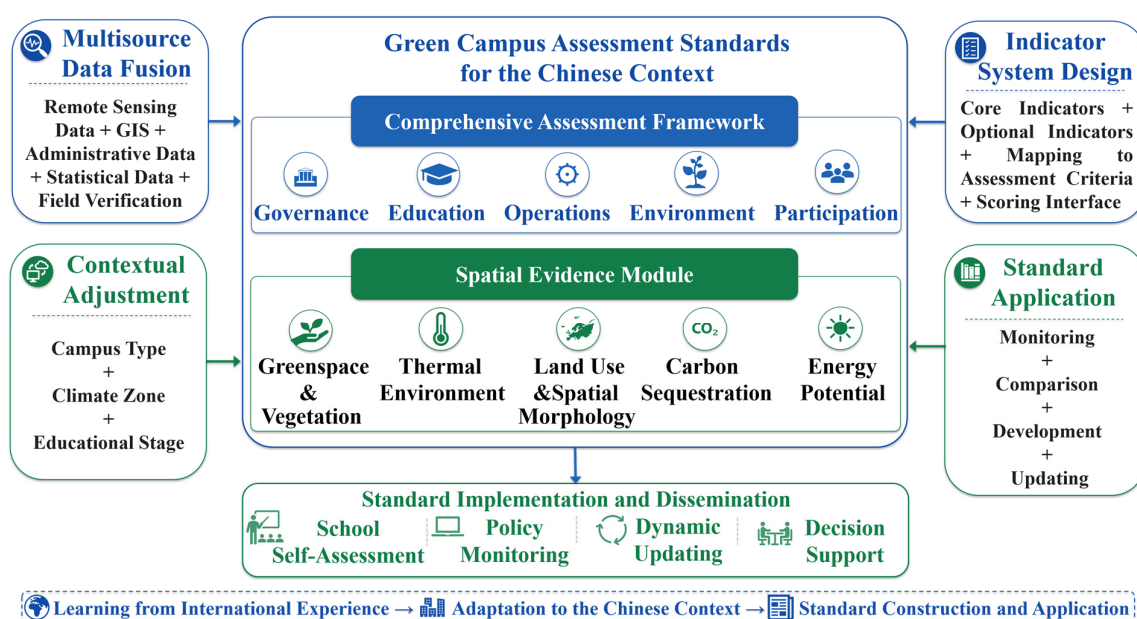


Figure 11. Framework for constructing green campus assessment standards in the Chinese context based on a comprehensive framework + spatial evidence module.

8. Conclusions

Research on campus sustainability has evolved beyond its historical focus on basic environmental performance. The conceptual transition from a green campus to a sustainable campus represents a fundamental shift: it moves beyond physical facility upgrades and resource conservation toward a whole-institution approach encompassing governance, pedagogy, operations, environmental quality, and stakeholder participation. While interna-

tional frameworks such as STARS, UI GreenMetric, AISHE, ISCN, EcoCampus, EMAS, and ISO 14001 have provided diverse methodological approaches, a unified evaluation standard that reconciles scientific rigor, cross-institutional comparability, and local contextual adaptability remains absent.

For the academic literature, this review shifts the analytical focus from tool classification to evidence architecture. It shows that while assessment tools have proliferated, their empirical foundation remains anchored in self-reported and administrative data—a limitation that becomes particularly problematic for spatially heterogeneous environmental conditions. By synthesizing remote sensing applications and GIS-based studies, the review provides a systematic framework for understanding how spatial evidence can complement conventional indicators. It thereby offers a pathway for integrating externally verifiable, cross-campus comparable measurements into green campus assessment, addressing the evidence, spatial, and standardization gaps identified in existing research.

For policy and practice—particularly in the Chinese context—this review proposes a conceptual two-level framework as a reference for future standard development. The framework comprises a comprehensive assessment structure (governance, education, operations, environment, participation) and a separate spatial evidence module based on remote sensing and GIS. Its “core indicators plus contextual adjustment” mechanism addresses the comparability challenges arising from China’s diverse campus forms—ranging from compact urban universities to sprawling suburban campuses and primary and secondary schools.

This framework is a conceptual reference and operational pathway, not an empirically validated tool. Its threshold values, weighting schemes, and contextual adjustment factors require further empirical testing and policy deliberation before formal standardization. Nonetheless, it offers a structured approach for embedding spatial evidence into China’s evolving green campus policy landscape.

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Abbreviations

The following abbreviations are used in this manuscript:

GIS	Geographic Information System
SDGs	Sustainable Development Goals
ESD	Education for Sustainable Development
CSA	Campus Sustainability Assessment
UI GreenMetric	UI-GreenMetric World University Rankings
STARS	Sustainability Tracking, Assessment and Rating System

AISHE	Assessment Instrument for Sustainability in Higher Education
EMS	Environmental Management Systems
ISO	International Organization for Standardization
ISCN	International Sustainable Campus Network
EMAS	Eco-Management and Audit Scheme
UAV	Unmanned Aerial Vehicle
LiDAR	Light Detection and Ranging
NDVI	Normalized Difference Vegetation Index
LST	Land Surface Temperature
SAVI	Soil-Adjusted Vegetation Index

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