Integrating ESG+ Metrics into Urban Green Infrastructure: A Comprehensive Sustainability Rating Framework

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Abstract. Urban Green Infrastructure (UGI) plays a crucial role in improving environmental performance, resilience, and quality of life in cities. However, existing sustainability assessment frameworks remain insufficient for urban-scale evaluation. Environmental, social, economic, and governance (ESG+) dimensions are not fully integrated at the urban scale. This gap motivated the development and application of the Green Infrastructure Sustainability Performance Assessment Model (GISPAM), a structured framework for evaluating the sustainability performance of UGI projects. The model has twelve criteria in four sustainability dimensions and applies a normalization, weighting, and aggregation process using the Rank Order Centroid (ROC) method and Multi Attribute Value Theory (MAVT). The framework contains three international case studies which are The High Line (USA), Cheonggyecheon Stream Restoration (South Korea), and Madrid Río (Spain). The results highlight the importance of multidimensional assessment and explain the practical applicability of GISPAM. GISPAM can be used as a transparent and comparable decision-support tool for UGI planning and management.

Keywords: Sustainability Assessment · Urban Green Infrastructure · Multi-Criteria Decision Aiding (MCDA)

1 Introduction

In recent decades, sustainability has become a major concern in urban planning and infrastructure development in cities. In this context, the Urban Green Infrastructures (UGIs) play a crucial and fundamental role in improving environmental performance and resilience. This is also reflected in the United Nations New Urban Agenda [1], which highlights the role of sustainable and resilient urban infrastructure in supporting inclusive and environmentally responsible urban development. However, less attention has been paid to decision-making processes for UGI, particularly regarding long-term management and performance evaluation. Since the 1990s, sustainability assessment in

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the built environment has developed and evolved from focused approaches to more integrated frameworks. Recent sustainability assessment models adopt a multidimensional perspective, integrating environmental, social and economic dimensions. In this context, several sustainability assessment frameworks, such as LEED, BREEAM and Envision, have been developed to provide structured assessment schemes [2]. Although these systems have expanded beyond the building scale to include urban communities [3], they still lack comprehensive and specialized integration of ESG (environmental, social, and governance) principles in general, but more specifically for green infrastructure. Furthermore, they often prioritize environmental metrics without fully incorporating governance efficiency as an integrated and equally important pillar. In addition, urban green infrastructure projects often involve multiple stakeholders, long-term management responsibilities, and trade-offs between ecological, social, economic, and governance objectives. For this reason, their assessment requires decision-support tools capable of integrating heterogeneous criteria and making sustainability priorities explicit. This is particularly relevant when comparing projects developed in different urban, institutional, and geographic contexts.

To bridge this gap, this study implements a framework based on multi-criteria decision analysis (MCDA), specifically with the application of multi-attribute value theory (MAVT) [4] to support decision-making in the context of UGIs [5]. In particular, the framework named Green Infrastructure Sustainability Performance Assessment Model (GISPAM) aims to integrate the concept of ESG+ rating to simultaneously assess environmental, social, economic and governance performance and to enable stakeholder involvement in the weighting and prioritization of criteria, ensuring that the assessment reflects the different priorities of decision makers (DMs).

This chapter is organized as follows: Sect. 2 reviews the existing literature on sustainability rating systems and ESG dimensions. Section 3 describes the methodology, focusing on the MAVT approach and stakeholder engagement. Section 4 presents the GISPAM model and its hierarchical structure, while Sect. 5 discusses the application of the model to case studies. Finally, Sect. 6 concludes and suggests future research directions.

2 Methodology

The research framework is based on MAVT to structure the sustainability assessment of urban green infrastructure. The process began with the conceptualization of an ESG+ framework, where twelve key criteria were identified across environmental, social, economic, and governance dimensions. To ensure that the model aligns with practical urban planning priorities, a panel of experts with academic and professional expertise in urban sustainability was consulted to define the value functions for each indicator and establish the relative importance of the criteria. To address the inherent subjectivity of the weighting process, the SMARTER method (Simple Multi-Attribute Rating Technique Exploiting Ranks) [11] was employed to translate expert rankings into surrogate weights through the Rank Order Centroid (ROC) method. All qualitative and quantitative indicators were then normalized to a dimensionless value scale ranging from 0 to 1 based on the identified value functions. Finally, sustainability performance was aggregated

using the MAVT additive model to calculate a synthetic index. This decision support framework enables a transparent assessment of trade-offs, supporting policy makers in evidence-based infrastructure management.

2.1 ESG-Based Criteria Selection

The selection of metrics started with the identification of the most recurring indicators in the environmental, social, economic, and governance dimensions of the built environment. This initial set was then refined to eliminate methodological redundancies and conceptual overlaps, ensuring that each criterion represented a distinct aspect of sustainability. This filtering process was essential to prevent double counting during the aggregation phase.

The criteria were selected based on two fundamental requirements: direct applicability to urban green infrastructure projects and the availability of real, accessible data. At the end of this process, twelve key criteria were identified, which form the backbone of the GISPAM.

For instance, in the renewable energy integration indicator, a value of 0 Wp/m^2 corresponds to a normalized score of 0.0, while a value of 10 Wp/m^2 corresponds to a score of 1.0. Values between these thresholds are calculated proportionally using a linear normalization function (Table 1).

Table 1. Criteria and Indicator Tables

Dimension Name	Criteria Name	Indicator
1. Environment	1.1 RES Integration	0.0–0 Wp/m^2; 0.5–2 Wp/m^2; 1.0–10 Wp/m^2
	1.2 Potable Water Reduction for Irrigation	0% - Fully potable water; 50% - Half potable half alternative water; 100% - Fully alternative water
	1.3 - Climate Adaptation and Resilience	0–5 °C temperature reduction (ΔT)
2. Social	2.1 - Universal Accessibility	0.0–30% accessible pathway network; 0.5–65% accessible pathway network; 1.0–100% accessible pathway network
	2.2 - Noise Reduction	0.0 - No major evidence for noise reduction; 0.5 - Indirect evidence for noise reduction; 1.0 - Strong Evidence for noise reduction
	2.3 - Visitor Intensity	0.0 – <1 million visitors/year; 0.5–10 million visitors/year; 1.0 – >10 million visitors/year
3. Economic	3.1 - Life Cycle Cost Efficiency	€/m^2 over the project life cycle

(*continued*)

Table 1. (*continued*)

Dimension Name	Criteria Name	Indicator
	3.2 - Operational Cost Reduction Evidence	1.0 - Quantified operational cost reduction or direct financial evidence; 0.5 - Design-based or qualitative operational efficiency evidence; 0.0 - No evidence reported
	3.3 - Property Value Increase	1.0 – Quantified property value increase reported; 0.5 – Qualitative economic regeneration evidence; 0.0 – No evidence reported
4. Governance	4.1 - Stakeholder Engagement and Public Involvement during design	0 – No stakeholder participation; 0.5 – Limited consultation or information sharing; 1 – Extensive participatory planning and co-design
	4.2 - Governance and Management Systems	0 (V = 0.0) – No maintenance plan. 1 (V = 0.3) – Ad-hoc or basic maintenance plan; 2 (V = 0.7) – Certified Environmental Management System (e.g., ISO 14001) or scheduled KPI monitoring; 3 (V = 1.0) – Fully integrated into municipal masterplans with guaranteed long-term funding
	4.3 - Transparency and Reporting	1.0 - Comprehensive official documentation publicly available; 0.5 - partial documentation available; 0.0 - no documentation

2.2 Data Normalization and Value Function Definition

Since the selected indicators use different units and scales, direct comparison was not possible. Therefore, a normalization process was applied. This step ensured comparability and measurability between the indicators, transforming raw data into dimensionless scales ranging from 0 to 1, where 0 represents the minimum or worst value while 1 represents maximum or best value. Intermediate values between 0 and 1 represent proportional performance between these thresholds. The reference thresholds were defined as a combination of international standards, academic literature, and best practice benchmarks in urban green infrastructure [6–10]. It includes guidelines related to energy performance, water management, and urban environmental quality.

This approach allows different indicators to be combined into a single performance score while maintaining consistency across multiple case studies.

2.3 Weighting Method

To determine the importance of each indicator, a structured weighting process was conducted through expert validation. A panel of six experts with academic and professional expertise who worked in urban sustainability, infrastructure planning, and decision-making processes were asked to rank the criteria and dimensions. The experts ranked the criteria and dimensions according to their own experiences. The panel included both researchers and practitioners with international academic and professional experience across Europe, the Middle East, and Asia. This ensured a balanced perspective between theoretical and practical considerations.

The final weights were calculated using the SMARTER approach, based on the ROC method [11]. This method provides a simple and transparent way to define weights based on preferences sorted by importance. At the same time, this method reduces subjectivity compared to direct weighting techniques. First, experts were asked to rate the relative importance of each sustainability dimension, i.e., ESG+, as well as the criteria within each dimension. Each expert ranked the criteria from most to least important using a Likert scale. For example, in a set of criteria, the first-ranked criterion receives a higher weight, say 0.61, the next criterion receives 0.28, and the third criterion has 0.11. The experts' ratings of the dimensions and criteria are presented in Table 2 and Table 3.

Table 2. ROC Weighted Dimension Table

Dimension Name	Rank	Average Score	ROC Weight
1 Environmental	1	4.67	0.520
2 Social	3	3.84	0.145
3 Economic	2	4.00	0.256
4 Governance	4	3.34	0.040

Table 3. ROC Weighted Criteria Table

Criteria Name	Rank	Average Score	ROC Weight
1.1 RES Integration	1	4.34	0.611
1.2 Potable Water Reduction for Irrigation	3	5.67	0.111
1.3 - Climate Adaptation and Resilience	2	5.33	0.277
2.1 - Universal Accessibility	2	5.33	0.277
2.2 - Noise Reduction	1	5.83	0.611
2.3 - Visitor Intensity	3	5.17	0.111
3.1- Life Cycle Cost Efficiency	2	5.50	0.277
3.2 - Operational Cost Reduction Evidence	1	5.67	0.611
3.3 - Property Value Increase	3	4.84	0.111

(*continued*)

Table 3. (*continued*)

Criteria Name	Rank	Average Score	ROC Weight
4.1 -Stakeholder Engagement and Public Involvement during design	1	5.50	0.611
4.2 - Governance and Management Systems	2	4.50	0.277
4.3 - Transparency and Reporting	3	3.84	0.111

2.4 Aggregation Method

The final sustainability performance score is calculated by aggregating the normalized criteria values and their respective weights using the MAVT additive model. In this phase, each normalized value is multiplied by its corresponding weight, determined through the SMARTER process. The overall sustainability score (V) is obtained by the sum of these weighted values, as shown in the following equation:

$$V = \sum_{i=1}^{n} w_i \cdot v_i \tag{1}$$

where n represents the number of criteria (12), w_i is the weight of the -th criterion, and v_i is its normalized performance value. The resulting GISPAM score is expressed on a scale from 0 to 1, where values approaching 1 indicate a higher sustainability performance. If the values closer to 1 means that project has higher sustainability performance score.

3 Empirical Application

3.1 Case Studies Selection

The GISPAM framework was tested on three international UGIs: The High Line (New York), Cheonggyecheon Stream Restoration (Seoul), and Madrid Río (Madrid). These cases were selected based on specific methodological criteria to ensure a comprehensive validation of the model.

First, the projects represent diverse UGI typologies, ranging from the adaptive reuse of an elevated industrial railway to the daylighting of a buried stream and the ecological conversion of a highway corridor. This variety is essential to test the flexibility of the GISPAM model across different physical and functional contexts.

Second, the scale diversity of these benchmarks allows for global validation. The cases vary from a local linear park to a large-scale regional riverfront, providing a broad testing ground for the model's scalability.

Third, the geographic dispersion and scale diversity of these benchmarks allow for global validation. By selecting cases from North America, East Asia, and Europe, the study tests the model against different regulatory frameworks, climatic conditions, and urban planning traditions.

Finally, the availability of high-quality data and official documentation for these international "best practices" ensures a rigorous quantitative application of the twelve indicators. By selecting these complexes, multi-billion-dollar interventions, the study demonstrates that the GISPAM model can capture the sustainability trade-offs of large-scale projects, making it applicable to a wide range of urban regeneration scenarios.

3.1.1 The High Line (USA)

The High Line is an elevated linear park and urban revitalization project located in New York City, United States. Developed on a former rail line built in the 1930s, the project repurposes the infrastructure into a multifunctional public space. Since its opening in 2009, The High Line has become a widely recognized tourist attraction point. The High Line combines different aspects of their design. These are ecological restoration, art, leisure, and pedestrian connectivity within an intense urban context. It has become an internationally recognized example of adaptive reuse, landscape urbanism, and public-private cooperation in city-making.

The project reduces environmental impacts through the reuse of existing steel infrastructure and the implementation of nature-based solutions, including extensive native planting and permeable surfaces. Furthermore, the park operates under a public-private partnership (PPP) governance model. The city of New York owns the infrastructure while the non-profit organization Friends of High Line manages daily operations and maintenance. The project also has attracted substantial private investment to surrounding neighborhoods. It contributes to local economic development while raising discussions to property value increase and potential green gentrification effects [12].

3.1.2 Cheonggyecheon Stream Restoration (South Korea)

Located in central Seoul, South Korea, the Cheonggyecheon Stream Redevelopment Project is a major urban regeneration project and linear ecological corridor. The project's primary goal was to rediscover and restore the historic Cheonggyecheon Stream by demolishing a highway. The project began in the early 2000s and was led by the Seoul Metropolitan Government in collaboration with various public and private stakeholders, including urban planners, environmentalists, and citizen groups.

The reconversion of the polluted industrial corridor into a public space generated a flow of tens of thousands of daily visitors, with direct benefits for public health and environmental quality. However, ecological success was mediated by complex governance: implementation required lengthy negotiations and the relocation of numerous street vendors, confirming how critical stakeholder coordination is in large urban regeneration projects [13].

3.1.3 Madrid Río (Spain)

Madrid Río project is a large-scale urban park and riverfront regeneration project developed along the Manzanares River in Madrid. By transforming former highway infrastructure into green public space, pedestrian routes, and recreational areas, the project became one of the most prominent examples of comprehensive urban regeneration integrating landscape design, mobility, and urban sustainability.

It also represents a major public infrastructure initiative that reconnected historically separated districts, enhancing accessibility, social cohesion, and urban livability [14].

3.2 Application of the GISPAM

To validate the GISPAM framework, three landmark UGIs projects were selected. These cases represent diverse geographic contexts, urban morphologies, and intervention scales, ranging from linear parks to large-scale riverfront restorations. The GISPAM framework was applied to the selected case studies to evaluate their sustainability performance. Data for the selected case studies were collected from official reports, academic publications and publicly available documentation. The selected criteria were measured using available evidence related to environmental, social, economic, and governance (ESG+) performance.

Criteria values were normalized using predefined threshold values and transformed to 0–1 scale. Then the normalized values were weighted using the Rank Order Centroid (ROC) method. The final sustainability performance score was then calculated using MAVT.

The value that comes from the calculation represents the overall GISPAM score for each project which enables direct comparison of sustainability performance between different urban green infrastructure projects.

4 Results

4.1 GISPAM Performances

The GISPAM model was systematically applied to the three selected case studies to assess their sustainability performance across the environmental, social, economic, and governance dimensions. The final sustainability scores were derived through the MAVT additive aggregation process, combining normalized criteria values with ROC-derived weights. The computed scores, presented in Table 4, reveal a differentiated performance pattern among the projects. Cheonggyecheon Stream Restoration achieved the highest overall score (0.473), followed by Madrid Río (0.421), while The High Line recorded the lowest score (0.347). On a scale from 0 to 1, these figures indicate moderate sustainability performance overall. The difference between the highest and lowest scores suggests variability in how the selected projects address ESG+ criteria. The aggregate scores provide a structured basis for comparing sustainability outcomes, but a disaggregated analysis by dimension is required to fully understand these differences. The following Section 4.2 breaks down the contributions of each ESG+ dimension to the final scores, offering further insight into the specific strengths and weaknesses of each project.

Table 4. Final GISPAM scores across case studies

Project Name	Cheonggyecheon Stream Restoration	The High Line	Madrid Ríos
GISPAM Score	0.473	0.347	0.421

4.2 Dimension-Based Results

Dimension calculations show differences in sustainability performance in the selected case studies based on ROC weighted dimensions scores. Among the four dimensions, governance scores are relatively stable across the three projects, with Cheonggyecheon Stream Restoration and The High Line both scoring 0.040, and Madrid Río scoring slightly lower at 0.030. This suggests that the three projects show comparable levels of structured management, stakeholder engagement, and publicly available documentation, although with some differences in implementation.

The social dimension shows particularly strong performance in the Madrid Río project which reached the highest score (0.137). This indicates strong public accessibility, recreational use, and community engagement. Similarly, Cheonggyecheon Stream Restoration showed more balanced social performance which is 0.080. And The High Line demonstrated moderate social performance which is 0.093. Mainly associated with visitor activity and accessibility features.

Economic performance also varies across the case studies, Cheonggyecheon Stream Restoration achieved the highest score which is 0.220. It reflects strong evidence of operational efficiency and economic impact. In contrast, The High Line and Madrid Río reached similar results, which is 0.142. It indicates moderate but consistent financial and economic performance.

Environmental performance also differs across the three projects. Cheonggyecheon Stream Restoration and Madrid Río showing relatively higher scores which are 0.133 and 0.112. Mainly associated with climate adaptation and ecosystem restoration measures. The High Line achieved a lower environmental score which is 0.072. It reflects more limited performance in renewable energy integration and water management indicators.

Overall, dimension calculations highlight the multidimensional nature of sustainability performance and show the ability of GISPAM model to find variations in environmental, social, economic, and governance dimensions in urban green infrastructure projects (Table 5).

Table 5. Dimension-based sustainability performance scores across case studies

Project Name/Dimension Name	Cheonggyecheon Stream Restoration	The High Line	Madrid Río
Environment	0.133	0.072	0.112
Social	0.080	0.093	0.137
Economic	0.220	0.142	0.142

(*continued*)

Table 5. (*continued*)

Project Name/Dimension Name	Cheonggyecheon Stream Restoration	The High Line	Madrid Río
Governance	0.040	0.040	0.030

4.3 Comparative Results Across Case Studies

A general comparison of the overall GISPAM scores shows that Cheonggyecheon Stream Restoration project achieved the highest sustainability performance, which is 0.473 in the selected case studies. This result reflects that Cheonggyecheon Stream Restoration has strong economic performance and balanced governance and environmental management strategies. Madrid Río project has the second highest performance, which is 0.421, and it shows a well-balanced sustainability profile. Especially in the social dimension which recorded the highest score in the all three projects.

On the other hand, The High Line Project reached the lowest overall score, which is 0.347. Even though the project performed consistently in governance and social dimensions other two dimensions, which are environmental and economic performance, are relatively lower than the other case studies. These differences highlight how project scale, management structure, and environmental interventions affect sustainability outcomes in urban green infrastructure projects.

Overall, the comparative results of GISPAM show that distinguishing sustainability performance across the projects with different urban contexts, design strategies, and operational characteristics. The dimension-based sustainability performance scores are visualized in Fig. 1.

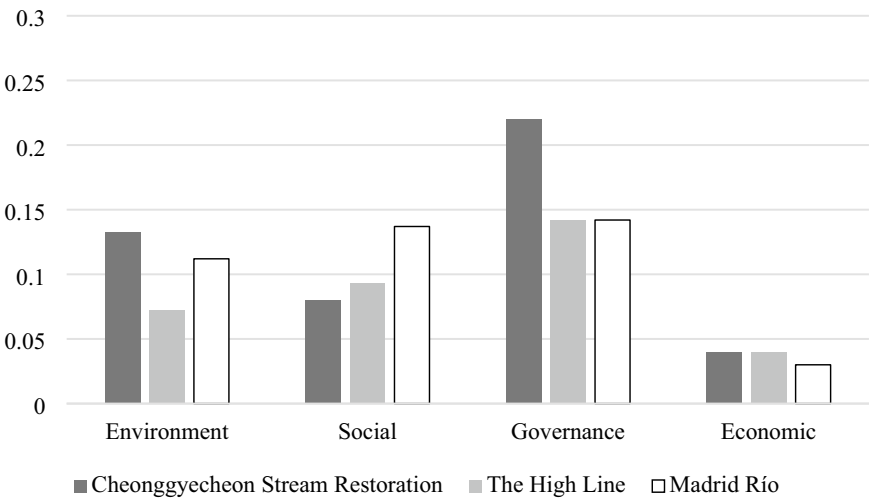

Fig. 1. Dimension-based sustainability performance scores across the three case studies.

5 Discussion

5.1 Interpretation of the Results

The results show that sustainability performance varies depending on the project scale, design strategy, and management structure. The Cheonggyecheon Stream Restoration project reached the highest overall GISPAM score. This reflects the strong economic performance and structured governance framework of Cheonggyecheon Stream Restoration. The project also benefits from large scale ecological restoration measures that contribute to environmental resilience.

Madrid Río shows a balanced performance across the sustainability dimensions, especially in the social dimension. This reflects the project's contribution to public accessibility, recreational use, and urban livability. The project represents a comprehensive urban regeneration initiative integrating landscape design, mobility, and public space development.

On the other hand, The High Line project has the lowest overall score in all three case studies. Although it performs well in the social and governance dimensions, its environmental and economic performance is relatively lower due to limited renewable energy integration and moderate long term cost efficiency. Notably, although Cheonggyecheon achieves the highest overall score, no single project dominates across all four ESG+ dimensions. This suggests that sustainability performance in UGI projects is not determined by excellence in any one dimension, but rather by the balance achieved among environmental, social, economic, and governance outcomes. These findings highlight how different project priorities and operational contexts affect sustainability outcomes, confirming that a multidimensional assessment is essential to capture the complexity of UGIs performance.

5.2 Implications of the GISPAM

The application of the GISPAM shows the value of using an integrated ESG based framework for evaluating urban green infrastructure projects. Combining environmental, social, governance, and economic dimensions into a single assessment structure, the model provides a comprehensive understanding of sustainability performance at urban scale.

The results show that sustainability cannot be evaluated using a single criterion or dimension. It needs a multidimensional approach to capture complex interactions between environmental performance, social benefits, economic efficiency and governance capacity. In this context, The GISPAM provides a practical tool for policymakers, planners and DMs to support evidence-based planning and long-term sustainability management.

Furthermore, property value increase can be interpreted as an indicator of consumer preferences and project-area attractiveness. However, although this criterion captures relevant economic benefits, it may also signal green gentrification and potential social displacement [15]. For this reason, economic outcomes should be interpreted alongside social criteria such as accessibility, inclusiveness, and community engagement. The GISPAM framework therefore supports a balanced, multidimensional assessment where such trade-offs can be identified.

5.3 Limitations of the Study

This study has several limitations that should be considered when interpreting the results. First, the availability of data availability varies across case studies. In some cases, this required the use of indirect indicators or proxy data.

Since the GISPAM framework is based on MAVT, variations in criteria weights are expected to influence the final sustainability score. This sensitivity should not be considered a weakness of the model, but rather a feature of multi-criteria decision support, as it allows different stakeholders' priorities to be reflected in the assessment. In this study, the ROC method was adopted to provide a transparent and reproducible baseline weighting structure based on expert rankings. Future applications of GISPAM may test alternative weighting scenarios, such as equal weighting or stakeholder-specific weighting, to examine how different decision-making priorities affect the final scores.

Second, the reference thresholds used for normalization were based on literature and best-practice benchmarks, as well as local conditions and project-specific contexts. Future research could refine these thresholds using larger datasets and more standardized performance indicators.

Even though there are limitations, the results show that using GISPAM is a structured and transparent framework. With evaluating sustainability performance in urban green infrastructure projects.

6 Conclusion

GISPAM is an integrated framework designed to evaluate the sustainability performance of urban green infrastructure projects using environmental, social, governance and economic (ESG+) dimensions.

The model was applied to three international case studies. These three international case studies show that sustainability performance varies depending on project scale, management structure, and long-term operational strategies. The results showed that a multidimensional approach is crucial to capture the complexity of sustainability in urban environments.

These findings also show the importance of transparent evaluation methods. It supports evidence-based planning and decision-making in urban development. This structured and comparable assessment framework shows that GISPAM can assist planners and policy makers. To identify strengths and weaknesses in sustainability performance.

There are different options for future research. It may focus on refining thresholds, expanding the dataset to additional case studies and improving availability of standardized performance data for urban green infrastructure projects.

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