A Quantitative Evaluation Framework for Scenic Area Development Planning from the Perspective of Sustainable Tourism

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Abstract. Based on the United Nations 2030 Sustainable Development Goals (SDGs), this study constructs a quantitative evaluation framework for the sustainable development of scenic areas, encompassing economic, environmental, and social dimensions. In the economic dimension, indicators such as tourism revenue growth rate, capital investment, and labor input are used to measure the economic contribution of scenic areas. The environmental dimension assesses the ecological impact through indicators including carbon emissions, water resource consumption, and waste discharge. The social dimension evaluates the effects of tourism activities on society using indicators such as community participation, resident well-being, and social negative effects. Data sources include questionnaire surveys, government statistics, and field investigations, with expert interviews employed to determine weight coefficients. The weight allocation follows an expert scoring method, assigning weights based on the importance of each indicator. A mathematical model is then developed to calculate the Sustainable Tourism Index (STI), defining different STI value intervals for scenic areas. The findings provide a quantitative basis for policymakers to formulate scientifically sound tourism planning strategies, ensuring that scenic areas balance economic growth with environmental protection and social well-being, thereby promoting the practical application and implementation of SDGs in scenic area development planning.

Keywords: Sustainable Development, Tourism Scenic Area Planning, Comprehensive Evaluation.

1. Introduction

In the era of accelerated global economic integration, the tourism industry, with its unique appeal and immense potential, has become a key driver of local economic

The rapid development of the global economy and population growth have led to significant challenges in the tourism industry, including excessive resource consumption, ecological degradation, and imbalanced community interests, despite its role in driving economic growth[1]. These issues not only threaten the long-term sustainability of tourism but also contradict the core principles of the United Nations 2030 Sustainable Development Goals (SDGs)[2]. Against this backdrop, sustainable tourism has emerged as a comprehensive development model that balances economic, environmental, and social benefits, drawing widespread attention from both academia and industry worldwide[3].

The concept of sustainable tourism originated in the 1980s, with early studies focusing on mitigating the negative impact of tourism on natural resources[4]. As the theory of sustainable development has evolved, its connotation has gradually expanded to encompass the coordinated development of economic, environmental, and social dimensions. Western academia emphasizes "multi-stakeholder governance" as the core logic. For instance, Farmaki et al. (2020) proposed a "multi-actor network governance" framework, highlighting the dynamic collaboration among governments, enterprises, and communities[5]. In contrast, Chinese scholars have developed a "core stakeholder prioritization" model based on local practices, promoting the synergy between ecological protection and rural revitalization through rural and heritage tourism, while enhancing resident participation through a "community empowerment" mechanism[6]. These theoretical differences reflect the variations between China and the West in institutional environments and cultural values.

The shift toward quantitative evaluation has become a key trend in sustainable tourism research in recent years. Early studies primarily relied on qualitative analyses, such as the "environment-economy-society" three-dimensional model proposed by Bramwell and Lane (2015)[7]. With the advancement of the SDGs, scholars have begun developing operational indicator systems. For example, Dodds and Butler (2022) created an evaluation tool based on the SDGs, incorporating resource efficiency and economic inclusiveness[8]. Meanwhile, domestic studies have introduced the entropy-weight method to optimize weight allocation, proposing an "ecological-economic-social" three-dimensional evaluation model[9].

However, existing literature still exhibits significant shortcomings. First, indicator design tends to focus on a single dimension without dynamic integration. For instance, Gössling et al. (2021) developed a carbon emission model but overlooked social equity indicators[10], while Li Hua et al. (2022) proposed an ecologically prioritized framework that fails to balance economic and social dimensions[11]. Second, there is a lack of methodological innovation and cross-disciplinary integration. While Zhang Qiang et al. (2021) optimized spatial planning using GIS technology, they did not incorporate policy tools (such as carbon taxes) to analyze sustainability impacts[12]. Third, empirical research has been concentrated in developed regions or ecologically sensitive areas, with insufficient validation for cultural heritage sites and emerging tourist destinations[13].

To address these limitations, this study proposes the following improvements:

Construction of a Multi-Dimensional Dynamic Evaluation Framework

Enhancement of Cross-Disciplinary Method Integration

Expansion of Empirical Scenarios for Differentiated Applications

Through these innovations, this study aims to provide scientific tools for the green transformation of the global tourism industry, promoting the coordinated optimization of economic, environmental, and social benefits while contributing to the realization of the SDGs.

2. Construction of the Sustainable Development Index Model

Firstly, regarding the economic model, its objective is to optimize revenue and tourist distribution. This model aims to maximize tourism revenue while mitigating overcrowding at popular attractions. A logarithmic linear regression form is employed to describe the relationship between tourism economic growth and multiple input factors. The mathematical expression is as follows:

$$\ln G_{it} = \alpha_0 + \psi \ln T_{it} + \phi_1 \ln K_{it} + \phi_2 \ln L_{it} + \phi_3 \ln M_{it} + \mu_{it} + \epsilon_{it} \quad (1)$$

In this model, G_{it} represents the economic growth rate (which can be substituted by GDP growth rate), T_{it} indicates the level of tourism development (which can be represented by tourism revenue or the number of tourists), K_{it} denotes capital investment (which can be represented by fixed asset investment in tourism), L_{it} reflects labor input (which can be represented by the number of employees in the tourism industry), and M_{it} stands for the number of scenic spots (the number of tourist attractions in a given region). M_{it} represents individual fixed effects (used to control for regional differences), and ϵ_{it} represents the random disturbance term.

Furthermore, for the environmental model, resource consumption and ecological impacts must be considered. This model evaluates the consumption of natural resources caused by tourism activities, including carbon emissions, water consumption, and waste discharge. The model separately considers the resource consumption of natural and cultural attractions, aiming to optimize tourist flows in order to reduce negative environmental impacts. The mathematical expression for this is:

$$P = \sum_{k=1}^{M} N_k \cdot (A_k \cdot G_k + W_{unit} + F_{unit}) \quad (2)$$

In this model, N_k represents the number of tourists at the k-th attraction. $A_k \cdot G_k$ represents the product of tourism revenue and the comprehensive carbon emissions for attraction k (used to calculate carbon emissions). W_{unit} indicates the water consumption per tourist, and F_{unit} represents the waste discharge per tourist.

For the social impact model, it takes into account the spillover effects and residents' well-being. This model measures the impact of tourism activities on residents' happiness, encompassing both positive effects brought by tourism (such as economic growth and employment opportunities) and negative effects (such as congestion and rising living costs). The goal of the model is to optimize the distribution of tourist flow to improve the quality of life for residents and ensure the fair distribution of tourism benefits. The mathematical expression for this is:

$$S=S_o+H_r-S_t \tag{3}$$

In this model, S_o represents the initial social happiness index (based on historical data), H_r denotes the residents' happiness index (impacted by the positive effects of tourism activities), and S_t represents the negative social impacts (such as congestion and rising housing costs).

Finally, for the Sustainable Tourism Index (STI) model, it requires the integration of factors from the economic, environmental, and social dimensions. By combining the entropy weight method and the analytic hierarchy process (AHP), the weighted parameters are calculated, and the sustainable tourism index of a particular attraction is computed. This index aims to ensure economic growth while minimizing environmental burdens and enhancing social well-being. The mathematical expression is as follows:

$$W_j=\frac{1-H_j}{\sum_{j=1}^{n}(1-H_j)} \tag{4}$$

$$H_j=-k\sum_{i=1}^{m}P_{ij}\ln P_{ij} \tag{5}$$

$$STI=\alpha\cdot E-\beta\cdot P+\gamma\cdot S \tag{6}$$

In this model, STI represents the Sustainable Tourism Index (target value), E stands for economic benefits (calculated by the economic model), P denotes environmental burden (calculated by the environmental model), and SSS represents social impacts (calculated by the social model). A，β，γ are the weight coefficients for economic, environmental, and social factors, respectively (derived from surveys completed by experts in relevant fields). The specific STI value range and corresponding government measures are shown in Table 1:

Table 1: STI Value Range and Government Response Measures

STI	Government Response Measures
0.8 - 1.0	Maintain Existing Policies: Continue to implement current sustainable tourism policies, optimize resource allocation, and improve efficiency. For example, strengthen infrastructure construction and enhance the capacity of popular scenic spots to better cope with tourist flows. Further Investment in Environmental Protection: Increase investment in environmental protection and ecological restoration projects to promote the further achievement of sustainable tourism goals. Strengthen ecological monitoring and assessment to ensure long-term ecological balance. Optimize Resource Allocation: Use technological tools, such as big data and geographic information systems, to accurately analyze tourist flow, reasonably plan scenic spot resources, and avoid redundant investments and resource waste.
0.6 - 0.8	Limit Tourist Numbers: In cases where the STI value is high but showing a downward trend, the government should limit the number of tourists per day, especially during peak periods, and implement tourist flow management. For example, introduce reservation systems or ticketing restrictions. Increase Environmental Taxes: By increasing tourist taxes and environmental taxes, the government can enhance investment in ecological protection, cultural heritage preservation, and infrastructure development. Some of the revenue can be used for environmental protection and community development projects to ensure that local residents benefit from tourism.

0.4 - 0.6	Strengthen Community Participation: Enhance the participation of local communities in tourism planning and management to ensure that communities can benefit from the prosperity of tourism and mitigate the impact of overtourism on residents' quality of life. Implement Stricter Visitor Restrictions: In cases of high environmental and social pressure, the government should impose stricter visitor restrictions, especially in environmentally sensitive areas, potentially setting up more crowd control measures in scenic spots to limit tourist numbers and prevent further resource depletion and ecological degradation. Increase Investment in Environmental Protection: In situations where STI values are declining, the government needs to increase investment in environmental protection for tourist attractions, particularly in areas suffering from resource consumption and ecological system degradation. Funds should be directed towards ecological restoration, pollution control, and environmental monitoring projects. Strengthen Waste and Water Resource Management: In response to waste and water resource consumption issues, the government should implement stricter waste management policies and promote water conservation measures to reduce the environmental burden of tourism activities.
0.2 - 0.4	Strict Control of Tourist Numbers: When STI values are low, the government should strictly control tourist numbers, possibly by setting tourist limits or enforcing stricter reservation systems to ensure that the tourism burden does not exceed the carrying capacity of the destination. Initiate Ecological Restoration Projects: When STI values are at low levels, ecological restoration becomes the top priority. The government should launch large-scale ecological restoration projects, especially for damaged natural attractions, to restore ecological functions. Promote Community Adjustment and Relocation: To reduce the negative impacts of tourism activities on local residents, the government may need to promote community adjustments or relocations in certain areas, alleviating the pressure of tourism on the community's quality of life.
0 - 0.2	Suspend New Tourism Projects: When STI values are at the lowest levels, the government should halt all new tourism project developments, especially those with high environmental impact, and concentrate resources on restoring the environmental and infrastructure conditions of scenic spots. Establish Special Funds for Ecological Restoration: The government should establish special funds for ecological restoration, focused on the environmental recovery, pollution control, and ecological restoration of damaged scenic areas, aiming to protect natural resources and ecosystems. Promote Community Development: Given the severe impact of overtourism on residents' lives, the government should increase investment in community development projects to ensure that residents benefit from the revival of the tourism industry, particularly in terms of infrastructure, social welfare, and public services.

3. Empirical Analysis

Singapore is a major international tourist destination in Southeast Asia, attracting a large number of visitors due to its developed economic system, favorable business environment, and efficient governance. However, as a city-state with limited land resources, Singapore is relatively constrained in terms of natural and cultural resources, and the development of tourism may also have environmental and social impacts. Therefore, assessing its level of sustainable tourism development is crucial for formulating future policies. This paper calculates and analyzes Singapore's Sustainable Tourism Index (STI) based on the economic, environmental, and social dimensions to provide a more comprehensive understanding of its sustainable development status.

In this study, we used the Sustainable Tourism Index (STI) model to evaluate the status of Singapore's sustainable tourism development. Through the quantitative analysis of relevant indicators from the economic, environmental, and social dimensions, we ultimately calculated Singapore's STI value, revealing the current status of Singapore's tourism sustainability and the necessary response measures.

In the tourism economic impact, labor market, and tourism priority dimensions, Singapore scored 0.414, 0.641, and 0.570, respectively, showing certain advantages in tourism policy support, labor supply, and tourism prioritization. However, the score for tourism service infrastructure was 0.157, indicating room for improvement in scenic area construction and service facilities, which may affect the visitor experience and long-term growth of the tourism industry. Using these scores in formula (1), the E value was calculated. In the environmental dimension, Singapore's environmental sustainability score was 0.438, the natural resources score was 0.175, and the cultural resources score was 0.380. Using these in formula (2), the P value was calculated. In the social dimension, Singapore's safety and security and health and hygiene scores were relatively high, at 0.514 and 0.536, respectively. These were used in formula (3) to calculate the S value.

Regarding weight allocation, the entropy method was used to calculate scores for Singapore's business environment, human resources and labor market, natural resources, environmental sustainability, cultural resources, health, and hygiene. Based on formulas (4) and (5), the weight values for the economic, environmental, and social factors were calculated to be Economic Dimension (α) = 0.50, Environmental Dimension (β) = 0.17, and Social Dimension (γ) = 0.33. These were then used in formula (6) for calculation. The specific results are shown in Table 2.

Table 2: STI Value Calculation Results for Singapore

Dimension	Score	Weight Coefficient
Economic Dimension	0.414	0.50
Environmental Dimension	0.438	0.17
Social Dimension	0.514	0.33
Total STI	0.413	

Based on the above analysis, the STI value for Singapore is 0.413, which falls within the range of 0.4 to 0.6. This indicates that Singapore's tourism industry faces certain challenges in terms of sustainability, particularly in environmental and resource management. According to the government response measures corresponding to the STI value range, we recommend the following actions for Singapore:

Implement stricter visitor restrictions: Particularly in environmentally sensitive areas, measures such as limiting visitor numbers and controlling tourist flow should be adopted to prevent further resource depletion and ecological degradation.

Increase investment in environmental protection: The government should enhance investment in ecological restoration, pollution control, and environmental monitoring, especially in areas where resource consumption and ecological degradation are more severe.

Strengthen waste and water resource management: Stricter waste management policies should be implemented, and water-saving measures should be promoted to reduce the environmental burden caused by tourism activities.

Following this approach, we applied the model to Japan and Sri Lanka, adjusting the weight parameters based on local conditions. The specific results are shown in Table 3. The STI values for these two regions were calculated as 5.33 and 3.49, respectively. By comparing with Singapore's STI value, it is evident that different economic, environmental, and social conditions in each region lead to varying STI values, which, in turn, provide local governments with more tailored responses for the sustainable development of their tourism industries.

Table 3: STI Value Calculation Results for Singapore, Japan, and Sri Lanka

Region	Economic Dimension	Environmental Dimension	Social Dimension	STI
Singapore	0.414	0.438	0.514	0.413
Japan	0.481	0.516	0.621	0.533
Sri Lanka	0.344	0.320	0.373	0.481

By implementing these measures, the local regions are expected to gradually improve the sustainability of their tourism industries, enhance ecological protection, and increase resource utilization efficiency, thereby promoting the healthy development of tourism. This also demonstrates the feasibility of the STI model.

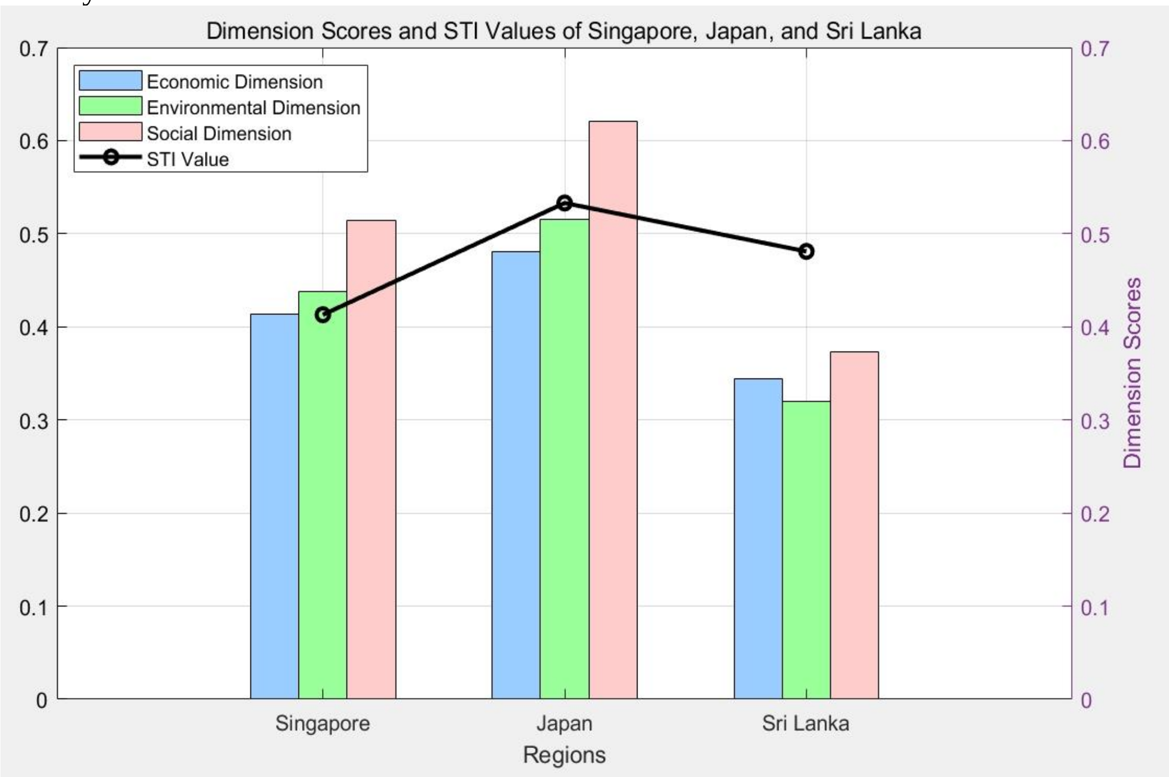

Figure 1: STI of Singapore, Japan, and Sri Lanka

Based on the results from the economic, environmental, and social dimensions, Singapore's tourism sustainability index is at a relatively good level, but there is still room for improvement. Firstly, Singapore should strengthen the development of tourism service infrastructure to enhance the overall visitor experience. This could include the addition of comprehensive resort facilities, theme parks, and cultural experience centers to compensate for the lack of natural and cultural resources. Secondly, in light of environmental resource constraints, Singapore can further develop smart tourism and sustainable tourism projects, utilizing technology to optimize the management of tourism resources and promote green tourism models. Additionally, moderately adjusting tourism opening policies to attract more international visitors will help enhance Singapore's competitiveness in the global tourism market.

4. Conclusion and Outlook

This study, based on the United Nations 2030 Sustainable Development Goals (SDGs), constructs a quantitative evaluation framework for sustainable development in scenic areas, encompassing economic, environmental, and social dimensions. By integrating key indicators such as tourism revenue growth rate, carbon emissions, and community engagement, and determining weights through the expert scoring method and the analytic hierarchy process (AHP), the Sustainable Tourism Index (STI) model is proposed. An empirical analysis using Singapore as a case study calculates its STI value at 0.413, indicating room for improvement in resource management and environmental sustainability. The study demonstrates that this framework can accurately identify development weaknesses in scenic areas and, by matching STI value ranges with differentiated policies (e.g., visitor flow control, environmental protection investments), provides a scientific basis for governments to balance economic growth, ecological conservation, and social well-being.

Despite the progress made in the quantitative evaluation of sustainable development in scenic areas, several limitations remain due to the ongoing evolution of tourism and digital transformation:

The indicator system does not include emerging fields such as smart tourism and green finance, making it difficult to fully reflect tourism sustainability in the digital era.

The data primarily relies on traditional statistics and surveys, lacking real-time and dynamic adaptability.

The depth of interdisciplinary integration is limited, as the study has not yet incorporated GIS spatial analysis techniques and policy tool coordination mechanisms.

Future research will focus on the following directions:

Enhancing the evaluation system: Introducing indicators related to digital transformation and carbon tax policies to improve the framework's forward-looking capabilities and global applicability.

Technological innovation: Utilizing big data, artificial intelligence, and social media data to develop a dynamic monitoring platform and improve the timeliness of evaluations.

Deepening interdisciplinary integration: Combining geographic information science and ecological methodologies to explore synergies between GIS technology and carbon tax policies for optimizing the STI model.

Expanding empirical applications: Extending the framework to diverse contexts such as ecologically fragile areas and cultural heritage sites to validate its universality and develop targeted strategies.

As the tourism industry undergoes digital transformation and further advances toward sustainable development goals, future research should continue to deepen theoretical discussions, technological innovations, and policy practices. Strengthening interdisciplinary collaboration and improving data acquisition and analysis capabilities will promote the healthy and sustainable development of tourism, contributing greater insights and efforts toward achieving the United Nations Sustainable Development Goals.

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