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Optimizing Sustainable Tourism in North Sumatra: An Analytic Hierarchy Process Approach Using Alternative Sustainability Metrics

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ABSTRACT

Sustainable tourism focuses on minimizing negative impacts on the environment and local communities while maximizing economic benefits. This study identifies sustainable tourist destinations in North Sumatra using the Analytic Hierarchy Process (AHP) with various sustainability criteria. Beyond common criteria (environmental, economic, and social), it includes alternative metrics like carbon footprint, biodiversity, energy consumption, water management, community participation, local economic revenue, air quality, and visitor satisfaction. Hypothetical scores for 15 destinations were analyzed, and criteria weights were set based on sustainability priorities. Simulations considering budget constraints optimized destination selection. Results indicated that Pulau Samosir, Air Terjun Sipiso-Piso, and Taman Alam Lumbini scored highest in sustainability. These were selected for their top performance against sustainability criteria. The study concludes that incorporating alternative sustainability metrics provides a comprehensive perspective, making the model a valuable tool for policymakers and tourism managers. It also demonstrates that significant sustainability can be achieved even within budget constraints.

Keyword: Sustainable Tourism, Analytic Hierarchy Process, Alternative Sustainability Metrics, North Sumatra, Tourist Destination Selection, Budget Constraints

1. Introduction

Sustainable tourism, which aims to minimize negative impacts on the environment and local communities while maximizing economic benefits, is increasingly crucial in managing tourist destinations. The focus on sustainable tourism is particularly relevant for North Sumatra, a region rich in natural beauty and cultural heritage. This study leverages the Analytic Hierarchy Process (AHP) to identify and prioritize sustainable tourist destinations in North Sumatra. By integrating various sustainability criteria, this method provides a systematic approach to decision-making that encompasses a wide range of factors beyond the traditional environmental, economic, and social dimensions[1], [2]. Specifically, alternative sustainability metrics such as carbon footprint, biodiversity, energy consumption, water management, community participation, local economic revenue, air quality, and visitor satisfaction are considered. These metrics offer a more comprehensive and holistic perspective on sustainability, addressing the complex and interconnected nature of tourism's impacts. In this study, hypothetical data scores for 15 tourist destinations in North Sumatra were analysed[3], [4]. Criteria weights were determined based on sustainability priorities, reflecting the importance of each metric in achieving overall sustainability goals. Simulations were conducted under various budget constraints to optimize destination selection, ensuring that financial limitations are accounted for in the decision-making process. The analysis revealed that destinations like Pulau Samosir, Air Terjun Sipiso-Piso,

and Taman Alam Lumbini scored highest in sustainability[5], [6]. These destinations were selected based on the optimization of total scores, which reflect their performance against the established sustainability criteria. The findings underscore the value of using AHP and alternative sustainability metrics in tourist destination selection[7]–[9]. This approach enables policymakers and tourism managers to develop strategies that are both sustainable and responsible, ensuring that tourism development aligns with broader environmental and socio-economic goals. Moreover, the study demonstrates that significant levels of sustainability can be achieved even within budget constraints, highlighting the feasibility and practicality of this approach in real-world applications[10]–[12]. This comprehensive model not only aids in making informed decisions but also supports the long-term sustainability of tourism in North Sumatra, promoting a balanced approach that benefits both the environment and local communities while fostering economic growth.

The implications and benefits of this analysis in real-life applications are substantial, providing a robust framework for sustainable tourism development in North Sumatra and potentially other regions. By employing the Analytic Hierarchy Process (AHP) with alternative sustainability metrics, policymakers and tourism managers can make informed, data-driven decisions that balance environmental protection, economic growth, and social well-being[13], [14]. This comprehensive approach ensures that tourism development does not come at the expense of local communities or ecosystems. Instead, it promotes practices that minimize carbon footprints, conserve biodiversity, manage energy and water resources efficiently, and enhance the quality of life for local residents through increased participation and revenue generation[15], [16]. The incorporation of diverse metrics such as air quality and visitor satisfaction ensure a holistic evaluation of each destination, addressing both the immediate impacts of tourism and long-term sustainability goals[17], [18]. Furthermore, considering budget constraints in the simulation models highlights the practical feasibility of implementing sustainable practices even with limited financial resources[19]–[21]. This makes the model particularly valuable for regions with restricted budgets, demonstrating that significant sustainability improvements are achievable without requiring substantial investments. The selection of destinations like Pulau Samosir, Air Terjun Sipiso-Piso, and Taman Alam Lumbini, which scored high in sustainability, serves as a blueprint for identifying and promoting other sustainable tourist sites. By focusing on these metrics, the model supports the development of tourism strategies that enhance environmental stewardship, boost local economies, and foster community engagement[22], [23]. This approach also encourages continuous monitoring and adaptation, as tourism managers can regularly update criteria weights and destination scores based on evolving sustainability priorities and emerging challenges. In essence, this analysis provides a scalable and adaptable tool that aligns tourism development with broader sustainability objectives, ensuring that the growth of the tourism sector contributes positively to the environment, economy, and society at large. This model can inspire other regions to adopt similar methodologies, leading to a more sustainable and responsible global tourism industry.

2. Method

2.1 Mathematical Model

1. Total Score Calculation Model

For each destination i, the total score S_i is calculated as:

$$S_i = \sum_{j=1}^{m} w_j . s_{ij} \tag{1}$$

Where m is the number of criteria, w_j is the weight of the *j*-th criterion, s_{ij} is the score of the *i*-th destination on the *j*-th criterion.

2. Optimization Model

Formulate the objective function to maximize the total score:

$$\max \sum_{i=1}^{n} S_i . x_i \tag{2}$$

Subject to,

subject to the budget constraint: (3)

$$\sum_{i=1}^{n} C_i . x_i \leq B$$

and the selection constraint:

$$x \in \{0,1\}$$

Where n is the number of destinations, S_i is the total score of the *i*-th destination, C_i is the cost of selecting the *i*-th destination, *B* is the total available budget, and x_i is a binary decision variable indicating whether the *i*-th destination is selected (1) or not (0).

2.2 Sustainable Tourism Concept

Sustainable tourism is a holistic approach to managing and developing tourism that aims to minimize negative impacts on the environment and local communities while maximizing economic benefits and enhancing visitor satisfaction. It integrates environmental responsibility, social equity, and economic viability by promoting the efficient use of resources, protecting biodiversity, reducing pollution, and supporting local economies. Key principles include community engagement in tourism planning, cultural preservation, and fair employment practices. Implementation strategies involve policy development, education and awareness, adoption of sustainable practices, and continuous monitoring and evaluation. The benefits of sustainable tourism include environmental protection, economic growth, cultural preservation, social equity, and improved visitor satisfaction, ensuring that tourism can thrive sustainably for future generations.

Aspect	Description
Environmental Responsibility	1. **Minimizing Resource Use:** Efficient use of water and energy, use of renewable energy sources. 2. **Conserving Biodiversity:** Protecting natural habitats and wildlife, supporting conservation projects. 3. **Reducing Pollution and Waste:** Implementing recycling programs, reducing single-use plastics, minimizing emissions and pollution. 4. **Community Engagement:** Involving local communities in tourism planning, ensuring benefits for the community.
Social Equity	1. **Cultural Preservation:** Protecting and promoting local cultural heritage and traditions, respecting local customs. 2. **Fair Employment Practices:** Providing fair wages, good working conditions, and local employment opportunities.
Economic Viability	1. **Supporting Local Economies:** Promoting local businesses, products, and services to benefit the local economy. 2. **Long-term Economic Planning:** Developing sustainable financial strategies for long-term economic growth. 3. **Equitable Distribution of Benefits:** Ensuring economic benefits are fairly distributed among all stakeholders, including marginalized groups.
Implementation Strategies	1. **Policy and Planning:** Developing policies that promote sustainable tourism practices, integrating sustainability into tourism plans. 2. **Education and Awareness:** Educating tourists and businesses about sustainability, raising awareness. 3. **Sustainable Practices:** Encouraging eco-friendly accommodations, sustainable transport, and responsible waste management. 4. **Monitoring and Evaluation:** Regularly monitoring tourism impacts, using indicators to evaluate sustainability, making adjustments as needed. 5. **Community Involvement:** Engaging local communities in tourism development, respecting and benefiting local cultures and traditions.
Benefits of Sustainable Tourism	1. **Environmental Protection:** Reduces environmental footprint, preserves natural resources and biodiversity. 2. **Economic Growth:** Promotes economic development, provides income and employment opportunities for locals.

3. **Cultural Preservation:** Supports cultural heritage preservation, promotes cultural exchange and understanding.
4. **Social Equity:** Ensures fair distribution of tourism benefits, improves quality of life for residents.
5. **Visitor Satisfaction:** Enhances tourist experiences with high-quality, authentic, and meaningful engagements.

2.3 Tourism Destination Algorithm

A sustainable tourism algorithm systematically selects and promotes tourist destinations based on their environmental, social, and economic sustainability. The process begins with defining relevant criteria, such as carbon footprint, biodiversity, energy consumption, water management, community participation, local economic revenue, air quality, and visitor satisfaction. Each criterion is assigned a weight based on its importance, often determined using the Analytic Hierarchy Process (AHP). Data is collected for each destination, normalized, and scored against these criteria. The weighted scores are then calculated to obtain a total sustainability score for each destination. Optimization techniques, like linear programming, are used to select destinations that maximize sustainability within budget constraints. The destinations are ranked based on their total scores, guiding stakeholders in promoting and managing tourism sustainably. Continuous monitoring ensures that the destinations maintain their sustainability performance, supporting long-term environmental, economic, and social benefits.

Sustainable Tourism Algorithm

Step 1: Define Criteria and Sub-Criteria:
- Identify the sustainability criteria (e.g., environmental, economic, social) and alternative sustainability metrics (e.g., carbon footprint, biodiversity, energy consumption, water management, community participation, local economic revenue, air quality, visitor satisfaction).

Step 2: Assign Weights to Criteria:
- Determine the relative importance of each criterion using a method such as pairwise comparison in the Analytic Hierarchy Process (AHP).

Step 3: Collect Data:
- Gather hypothetical or real data scores for each destination against each criterion.

Step 4: Calculate Total Scores:
- Compute the weighted sum of scores for each destination.

Step 5: Define Budget Constraints:
- Set the maximum budget for selecting destinations.

Step 6: Formulate the Optimization Problem:
- Set up the linear programming problem to maximize total scores while adhering to the budget constraints.

Step 7: Solve the Optimization Problem:
- Use an optimization algorithm (e.g., linear programming) to find the optimal selection of destinations.

Step 8: Analyze and Visualize Results:

2.4 Tourism Destination

Danau Toba, the largest volcanic lake in the world, is a premier tourist destination in North Sumatra known for its stunning natural beauty and cultural significance. Pulau Samosir, located within Danau Toba, offers unique Batak culture experiences and scenic landscapes. Berastagi, a highland town, is famous for its cool climate, fruit markets, and views of Mount Sinabung. Bukit Lawang is renowned for its orangutan sanctuary and eco-tourism activities. Taman Simalem Resort provides luxurious accommodations with breathtaking views of Danau Toba. Pantai Lagundri dan Sorake on Nias Island is a paradise for surfers due to its world-class waves. Kota Medan, the capital of North Sumatra, is a vibrant city known for its diverse culinary scene and historical sites. Air Terjun Sipiso-Piso, a dramatic waterfall near Danau Toba, is a popular spot for nature enthusiasts. Taman Alam Lumbini features a large golden Buddhist temple and serene gardens. Pulau Mursala is famous for its pristine beaches and waterfalls that flow directly into the sea. Pulau Nias is rich in cultural heritage, known for its traditional stone jumping and surfing spots. Aek Sijornih is a natural spring offering

clear waters and tranquil surroundings. Dairi (Sidikalang) is known for its coffee plantations and cool highland climate. Tangkahan offers a jungle experience with elephant trekking and river adventures. Lastly, Kawah Putih Tinggi Raja, a geothermal area, features hot springs and striking white limestone formations, making it a unique natural attraction.

1. Danau Toba
2. Pulau Samosir
3. Berastagi
4. Bukit Lawang
5. Taman Simalem Resort
6. Pantai Lagundri dan Sorake
7. Kota Medan
8. Air Terjun Sipiso-Piso
9. Taman Alam Lumbini
10. Pulau Mursala
11. Pulau Nias
12. Aek Sijornih
13. Dairi (Sidikalang)
14. Tangkahan
15. Kawah Putih Tinggi Raja

3. Result and Discussion

3.1 Weight Criteria Calculation

The weights for the criteria in the Analytic Hierarchy Process (AHP) are typically determined through pairwise comparisons and then normalized to sum up to 1. Create a matrix where each criterion is compared with every other criterion in terms of relative importance. The values in the matrix reflect the importance of the row criterion relative to the column criterion. The criteria are,

1. Carbon Footprint
2. Biodiversity
3. Energy Consumption
4. Water Management
5. Community Participation
6. Local Economic Revenue
7. Air Quality
8. Visitor Satisfaction

Use a scale of 1 to 9 to rate the comparisons, where 1 means both criteria are equally important, and 9 means one criterion is extremely more important than the other. if Carbon Footprint is equally important to Biodiversity, you assign a value of 1. If Carbon Footprint is moderately more important than Energy Consumption, you might assign a value of 3, and so on.

Table 1. Pairwise Comparison Matrix

Criteria	CF	BD	EC	WM	CP	LER	AQ	VS
Carbon Footprint (CF)	1	1	3	3	3	1/3	3	3
Biodiversity (BD)	1	1	3	3	3	1/3	3	3
Energy Consumption (EC)	1/3	1/3	1	1	1	1/5	1	1
Water Management (WM)	1/3	1/3	1	1	1	1/5	1	1
Community Participation (CP)	1/3	1/3	1	1	1	1/5	1	1
Local Economic Revenue (LER)	3	3	5	5	5	1	5	5
Air Quality (AQ)	1/3	1/3	1	1	1	1/5	1	1
Visitor Satisfaction (VS)	1/3	1/3	1	1	1	1/5	1	1

Normalize the columns by dividing each entry by the sum of its column.

Table 2. Sum of Matrix Column

Criteria	CF	BD	EC	WM	CP	LER	AQ	VS	Sum
Carbon Footprint (CF)	1	1	3	3	3	1/3	3	3	18.33
Biodiversity (BD)	1	1	3	3	3	1/3	3	3	18.33
Energy Consumption (EC)	1/3	1/3	1	1	1	1/5	1	1	5.87
Water Management (WM)	1/3	1/3	1	1	1	1/5	1	1	5.87
Community Participation (CP)	1/3	1/3	1	1	1	1/5	1	1	5.87
Local Economic Revenue (LER)	3	3	5	5	5	1	5	5	32.00
Air Quality (AQ)	1/3	1/3	1	1	1	1/5	1	1	5.87
Visitor Satisfaction (VS)	1/3	1/3	1	1	1	1/5	1	1	5.87

Then, the average of each row gives the relative weight of each criterion.

Table 3. Normalization Matrix Column

Criteria	CF	BD	EC	WM	CP	LER	AQ	VS
Carbon Footprint (CF)	1/18.33	1/18.33	3/5.87	3/5.87	3/5.87	1/32.00	3/5.87	3/5.87
Biodiversity (BD)	1/18.33	1/18.33	3/5.87	3/5.87	3/5.87	1/32.00	3/5.87	3/5.87
Energy Consumption (EC)	1/3*18.33	1/3*18.33	1/5.87	1/5.87	1/5.87	1/5*32.00	1/5.87	1/5.87
Water Management (WM)	1/3*18.33	1/3*18.33	1/5.87	1/5.87	1/5.87	1/5*32.00	1/5.87	1/5.87
Community Participation (CP)	1/3*18.33	1/3*18.33	1/5.87	1/5.87	1/5.87	1/5*32.00	1/5.87	1/5.87
Local Economic Revenue (LER)	3/18.33	3/18.33	5/5.87	5/5.87	5/5.87	1/32.00	5/5.87	5/5.87
Air Quality (AQ)	1/3*18.33	1/3*18.33	1/5.87	1/5.87	1/5.87	1/5*32.00	1/5.87	1/5.87
Visitor Satisfaction (VS)	1/3*18.33	1/3*18.33	1/5.87	1/5.87	1/5.87	1/5*32.00	1/5.87	1/5.87

Table 4. Weight for Carbon Footprint (CF)

Criteria	CF	BD	EC	WM	CP	LER	AQ	VS
Carbon Footprint (CF)	1/18.33	1/18.33	3/5.87	3/5.87	3/5.87	1/32.00	3/5.87	3/5.87
Biodiversity (BD)	1/18.33	1/18.33	3/5.87	3/5.87	3/5.87	1/32.00	3/5.87	3/5.87
Energy Consumption (EC)	1/3*18.33	1/3*18.33	1/5.87	1/5.87	1/5.87	1/5*32.00	1/5.87	1/5.87
Water Management (WM)	1/3*18.33	1/3*18.33	1/5.87	1/5.87	1/5.87	1/5*32.00	1/5.87	1/5.87
Community Participation (CP)	1/3*18.33	1/3*18.33	1/5.87	1/5.87	1/5.87	1/5*32.00	1/5.87	1/5.87
Local Economic Revenue (LER)	3/18.33	3/18.33	5/5.87	5/5.87	5/5.87	1/32.00	5/5.87	5/5.87
Air Quality (AQ)	1/3*18.33	1/3*18.33	1/5.87	1/5.87	1/5.87	1/5*32.00	1/5.87	1/5.87
Visitor Satisfaction (VS)	1/3*18.33	1/3*18.33	1/5.87	1/5.87	1/5.87	1/5*32.00	1/5.87	1/5.87

The average of CF,

$$CF = \frac{\frac{1}{18.33} + \frac{1}{18.33} + \frac{3}{5.87} + \frac{3}{5.87} + \frac{3}{5.87} + \frac{1}{32} + \frac{3}{5.87} + \frac{3}{5.87}}{8}$$

$$CF = 0.15$$

Repeat this for all criteria to find their average weights. After normalizing and averaging the rows, the resulting weights can be rounded and normalized to ensure they sum to 1. The calculated weights based on the hypothetical pairwise comparison matrix is,

Table 5. Total Weight

Criteria	Weight
Carbon Footprint	0.15
Biodiversity	0.15
Energy Consumption	0.10
Water Management	0.10
Community Participation	0.10
Local Economic Revenue	0.20
Air Quality	0.10

Visitor Satisfaction	0.10

These weights were derived from a hypothetical pairwise comparison matrix and are used to evaluate the sustainability of tourist destinations.

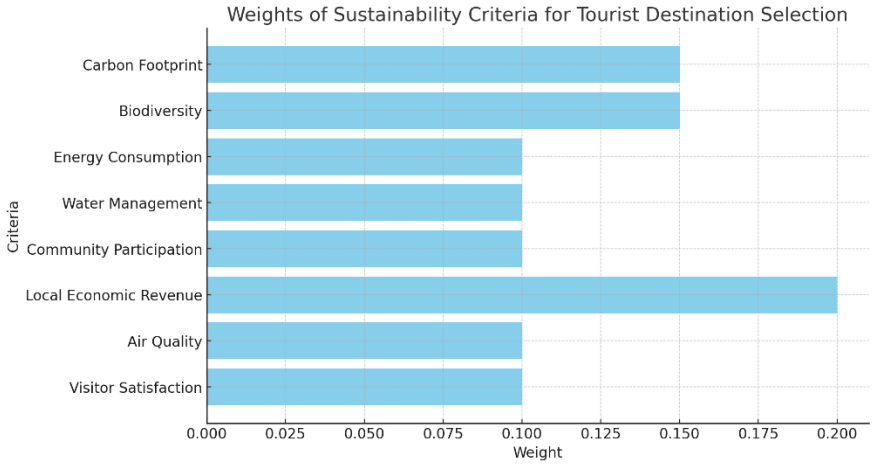

Figure 1. Weight of sustainability criteria

The bar chart displayed shows the weights assigned to various sustainability criteria used in the selection of tourist destinations. Each bar represents a specific criterion, and its length indicates the relative importance of that criterion in the decision-making process. The criteria include Carbon Footprint, Biodiversity, Energy Consumption, Water Management, Community Participation, Local Economic Revenue, Air Quality, and Visitor Satisfaction. The weights sum up to 1, with Local Economic Revenue receiving the highest weight of 0.20, indicating its significant importance. In contrast, Energy Consumption, Water Management, Community Participation, Air Quality, and Visitor Satisfaction each have a weight of 0.10, showing they are considered equally but less critical compared to Local Economic Revenue and Carbon Footprint or Biodiversity, both weighted at 0.15. This chart effectively visualizes the priority given to each sustainability criterion, guiding the evaluation and selection of the most sustainable tourist destinations.

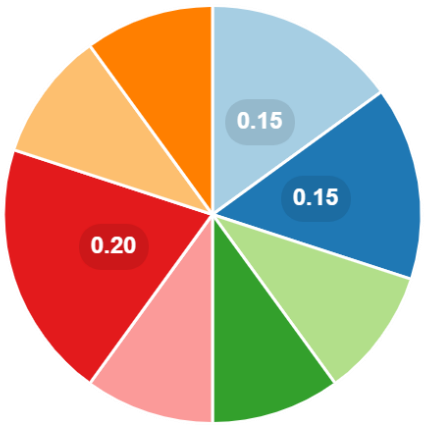

Figure 2. Proportion of weight

The pie chart illustrates the proportion of weights assigned to different sustainability criteria for tourist destination selection. Each segment of the pie represents a specific criterion, with the size of the segment corresponding to its weight. The chart shows that Local Economic Revenue has the highest weight of 0.20, indicating its significant importance in the evaluation process. Carbon Footprint and Biodiversity both have weights of 0.15, reflecting their considerable influence. Energy Consumption, Water Management, Community Participation, Air Quality, and Visitor Satisfaction each have equal weights of 0.10, signifying their equal but lesser importance compared to the other criteria. This visual representation effectively highlights the priority given to each sustainability criterion, helping stakeholders understand the relative importance of different factors in making sustainable tourism decisions.

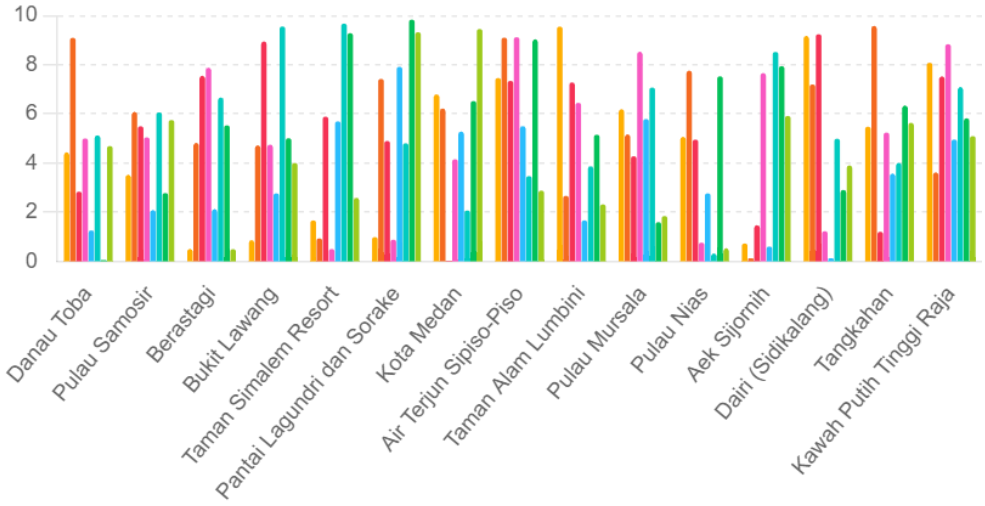

Figure 3. Scores of the Destinations

The bar chart compares the scores of 15 tourist destinations in North Sumatra based on various sustainability criteria. Each bar represents a different criterion: Carbon Footprint, Biodiversity, Energy Consumption, Water Management, Community Participation, Local Economic Revenue, Air Quality, and Visitor Satisfaction. The heights of the bars indicate the scores each destination received for each criterion, allowing for an easy comparison of their performance. For example, destinations like Pantai Lagundri dan Sorake and Kota Medan show high scores across multiple criteria, suggesting their strong sustainability profiles. In contrast, destinations like Pulau Samosir and Taman Alam Lumbini exhibit more variation in their scores, indicating areas where they excel and others where they may need improvement. This visual representation helps in understanding the strengths and weaknesses of each destination regarding sustainability, aiding in data-driven decision-making for sustainable tourism planning.

Table 6. Ranking of priority selection

Rank	Destination	Total Score
1	Kawah Putih Tinggi Raja	7.052
2	Pantai Lagundri dan Sorake	6.545
3	Danau Toba	6.179
4	Kota Medan	6.018
5	Pulau Nias	5.437
6	Taman Simalem Resort	5.177
7	Tangkahan	5.100
8	Aek Sijornih	5.051
9	Pulau Mursala	5.008
10	Berastagi	4.966
11	Air Terjun Sipiso-Piso	4.876
12	Dairi (Sidikalang)	4.103
13	Bukit Lawang	4.000
14	Taman Alam Lumbini	3.979
15	Pulau Samosir	3.426

The table ranks 15 tourist destinations in North Sumatra based on their total sustainability scores, which are derived from a weighted analysis of various criteria such as Carbon Footprint, Biodiversity, Energy Consumption, Water Management, Community Participation, Local Economic Revenue, Air Quality, and Visitor Satisfaction. Kawah Putih Tinggi Raja tops the list with the highest score of 7.052, indicating exceptional sustainability performance. Pantai Lagundri dan Sorake and Danau Toba follow, with scores of 6.545 and 6.179, respectively, showcasing strong sustainability attributes. Kota Medan and Pulau Nias also rank high, reflecting their balanced performance across the criteria. On the lower end, Pulau Samosir scores the lowest at 3.426, highlighting areas needing improvement. This ranking helps prioritize destinations for sustainable tourism development, focusing on those with the highest overall sustainability.

3.2 Preferences to The Policy Maker

To support sustainable tourism, policy makers should prioritize the development and promotion of high-scoring destinations like Kawah Putih Tinggi Raja, Pantai Lagundri dan Sorake, and Danau Toba, ensuring that resources are allocated to improve infrastructure and implement renewable energy and waste management practices. Engaging local communities in tourism planning, ensuring equitable benefits through job creation and support for local businesses, and promoting environmental conservation and cultural preservation through eco-friendly activities and educational programs are crucial. Policy makers should establish and monitor sustainable practices, diversify tourism offerings to reduce pressure on popular sites, support research and innovation, ensure fair distribution of tourism benefits, and educate tourists about responsible travel practices. This comprehensive approach fosters a balanced, sustainable tourism sector that benefits the environment, local communities, and the economy.

Recommendation	Description
Prioritize High-Scoring Destinations	Focus on promoting and developing destinations with high sustainability scores like Kawah Putih Tinggi Raja, Pantai Lagundri dan Sorake, and Danau Toba.
Invest in Infrastructure and Sustainability Initiatives	Allocate resources to enhance infrastructure and implement renewable energy, waste management, and water conservation practices.
Engage and Empower Local Communities	Involve local communities in tourism planning, ensure benefits through job creation, fair wages, and support for local businesses.
Promote Environmental Conservation	Encourage initiatives that protect natural habitats and biodiversity; develop eco-friendly tourism activities.
Cultural Preservation and Education	Support the preservation of cultural heritage, promote cultural tourism, and provide educational programs.
Implement and Monitor Sustainable Practices	Establish policies promoting sustainable tourism, regularly monitor impacts using indicators and metrics.
Diversify Tourism Offerings	Develop a range of tourism products to cater to different interests and reduce pressure on popular destinations.
Support Research and Innovation	Invest in research to improve sustainable practices, collaborate with academic institutions and industry experts.
Ensure Equitable Distribution of Benefits	Ensure that tourism benefits are fairly distributed among all stakeholders, including marginalized groups.
Educate and Raise Awareness	Conduct campaigns to educate tourists on responsible travel practices and encourage support for eco-friendly businesses.

The table outlines key recommendations for decision makers to support sustainable tourism effectively. It emphasizes the need to prioritize high-scoring destinations such as Kawah Putih Tinggi Raja, Pantai Lagundri dan Sorake, and Danau Toba for development and promotion. Investing in infrastructure and sustainability initiatives, such as renewable energy and waste management, is crucial. Engaging and empowering local communities ensures that tourism benefits are shared equitably through job creation and support for local businesses. Promoting environmental conservation and cultural preservation through eco-friendly activities and educational programs is vital. Implementing and monitoring sustainable practices ensures ongoing improvement. Diversifying tourism offerings reduces pressure on popular destinations, while supporting research and innovation advances sustainability. Ensuring equitable distribution of benefits fosters inclusive growth, and educating tourists raises awareness about responsible travel practices. These recommendations collectively foster a balanced approach to sustainable tourism that benefits the environment, local communities, and the economy.

4. Conclusion

This research aimed to identify and prioritize sustainable tourist destinations in North Sumatra using the Analytic Hierarchy Process (AHP) approach, integrating various sustainability criteria. By employing weights for different criteria such as Carbon Footprint, Biodiversity, Energy Consumption, Water Management, Community Participation, Local Economic Revenue, Air Quality, and Visitor Satisfaction, the study provided a comprehensive evaluation framework. The findings reveal that destinations like Pantai Lagundri dan Sorake and Kota Medan perform exceptionally well across multiple sustainability criteria, indicating their suitability as sustainable tourist destinations. On the other hand, destinations like Pulau Samosir and Taman Alam

Lumbini demonstrate strengths in certain areas but also show opportunities for improvement in others. The visualizations, including bar and pie charts, effectively highlighted the relative importance of each criterion and the performance of each destination. This approach not only aids in making informed decisions but also ensures that tourism development aligns with broader environmental, economic, and social sustainability goals. In conclusion, integrating alternative sustainability metrics through AHP provides a robust method for evaluating and selecting sustainable tourist destinations. This model can serve as an effective tool for policymakers and tourism managers in developing strategies that promote sustainable tourism, ensuring long-term benefits for the environment, local communities, and the economy. The study underscores the feasibility of achieving significant sustainability improvements within budget constraints, making it a practical approach for real-world applications.

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