International Journal of Sustainable Development and Planning
Vol. 19, No. 8, August, 2024, pp. 2907-2917
Journal homepage: http://iieta.org/journals/ijsdp

Sustainable Tourism Development in Lake Toba: A Comprehensive Analysis of Economic, Environmental, and Cultural Impacts

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https://doi.org/10.18280/ijsdp.190809

Received: 15 July 2024
Revised: 1 August 2024
Accepted: 10 August 2024
Available online: 29 August 2024

Keywords:
sustainable tourism, Lake Toba, economic impact, environmental sustainability, cultural preservation

ABSTRACT

This study provides a comprehensive analysis of sustainable tourism development in Lake Toba, focusing on its economic, environmental, and cultural impacts. Utilizing experimental data and predictive models, the research assesses the Return on Investment (ROI) for tourism-related investments and the effectiveness of sustainability initiatives. The findings reveal a substantial increase in tourism revenue and net profit, underscoring the financial viability of continued investment in the sector. Additionally, the study highlights the positive outcomes of sustainability efforts, including reductions in water and energy consumption per tourist and enhanced waste management practices. By integrating local wisdom, the research emphasizes the importance of cultural preservation and community involvement in creating a unique and authentic tourist experience. The insights provided are intended to guide policymakers, investors, and local stakeholders in optimizing tourism growth while ensuring long-term environmental and cultural sustainability. This holistic approach aims to balance economic benefits with ecological stewardship and cultural integrity, contributing to a sustainable future for Lake Toba's tourism industry.

1. INTRODUCTION

The rapid growth of tourism in Lake Toba has led to significant economic, environmental, and cultural impacts. As one of Indonesia's premier tourist destinations, Lake Toba has experienced substantial increases in tourist arrivals, which have brought considerable economic benefits to the local community, including increased revenue and job creation. However, this growth has also introduced challenges related to resource consumption, waste management, and cultural preservation. The influx of tourists has spurred improved infrastructure and business opportunities for locals, fostering entrepreneurship and raising income levels. Nevertheless, concerns regarding over-reliance on tourism, potential displacement, and environmental degradation have emerged, threatening the sustainability of local livelihoods. However, challenges related to resource consumption, waste management, and cultural preservation have also emerged [1, 2]. The influx of tourists has led to improved infrastructure and business opportunities for locals, fostering entrepreneurship and increasing income levels [3]. On the downside, there are concerns about over-reliance on tourism, potential displacement, and environmental degradation affecting local livelihoods [4-6]. To improve sustainable tourism, investments in infrastructure, diversification of revenue streams, and community involvement are crucial for economic sustainability. Environmental sustainability can be achieved through resource efficiency, comprehensive waste management, and conservation efforts [7, 8]. Preserving local traditions, educating tourists and communities, and offering authentic cultural experiences are key to cultural sustainability. Establishing a regulatory framework, engaging stakeholders in collaborative planning, and implementing monitoring and evaluation systems are essential for effective policy and governance. By addressing these areas, the research provides a comprehensive framework for promoting sustainable tourism in Lake Toba, ensuring balanced economic growth, environmental protection, and cultural preservation, ultimately benefiting the local community [9-11].

The COVID-19 pandemic significantly impacted tourism in Lake Toba, causing a dramatic decline in tourist arrivals due to travel restrictions and health concerns. This led to substantial revenue losses for tourism-dependent businesses, resulting in job losses and financial instability for the local community. Many small businesses closed, although some adapted by targeting local markets [12, 13]. While the reduction in tourism temporarily alleviated environmental

pressure, it also created challenges in managing natural sites due to reduced funding [14]. Cultural events were disrupted, affecting cultural exchange and income from such activities. The pandemic underscored community resilience, with mutual aid becoming more prominent. Government relief measures and recovery plans, including financial aid and promotion of domestic tourism, aimed to mitigate the impact [15, 16]. Moving forward, enhancing health protocols, diversifying tourism offerings, supporting local businesses, and integrating sustainable practices are crucial for a resilient recovery, ensuring long-term benefits for both the local community and the environment [17, 18].

Local wisdom plays a crucial role in supporting sustainable tourism by leveraging traditional knowledge, cultural practices, and community values to create a tourism model that is environmentally friendly, culturally enriching, and economically beneficial [19-21]. In Lake Toba, integrating local wisdom involves promoting traditional Batak arts, crafts, and cuisine to offer authentic cultural experiences while preserving cultural heritage. Community involvement in tourism planning ensures that development aligns with local needs and capacities, fostering a sense of ownership and stewardship among residents [22, 23]. Sustainable practices such as traditional agricultural methods, natural resource management, and eco-friendly construction techniques help minimize environmental impact. Additionally, local customs and rituals can educate tourists on the importance of environmental conservation and cultural respect [24]. By embedding local wisdom into tourism practices, Lake Toba can achieve a balanced approach to development that enhances visitor experiences, protects natural and cultural assets, and supports the well-being of the local community [25-27]. The primary objective of this research is to comprehensively analyze the development of sustainable tourism in Lake Toba by evaluating its economic, environmental, and cultural impacts. This involves quantifying the financial benefits of tourism, such as revenue generation, job creation, and ROI for tourism investments, as well as measuring the environmental footprint in terms of resource consumption and waste production. The research also aims to investigate the role of local wisdom in enhancing the tourist experience and preserving the Batak community's cultural identity. By providing strategic recommendations for integrating sustainability into tourism planning and policy-making, the research seeks to promote balanced economic growth, environmental conservation, and cultural preservation. The implications of the results could guide policymakers and investors in optimizing tourism growth while ensuring long-term sustainability, benefiting both the local community and the environment. These insights can lead to more resilient tourism practices, fostering a harmonious relationship between tourism development and the preservation of Lake Toba’s natural and cultural assets.

2. MATERIAL AND METHODS

2.1 Main hypotheses

Hypothesizing the economic, environmental, cultural, and overall sustainability impacts of tourism in Lake Toba is essential for a comprehensive understanding of its multifaceted effects. Evaluating economic impacts, such as revenue generation, job creation, and Return on Investment (ROI), provides insights into the financial benefits and viability of tourism development, informing resource allocation and investment strategies. Assessing environmental impacts, including resource consumption and waste production, ensures that tourism development preserves natural resources and ecosystems, maintaining Lake Toba's ecological health and attractiveness. Understanding cultural impacts helps gauge how tourism influences local traditions and social dynamics, promoting cultural preservation and authentic tourist experiences. By integrating these aspects into sustainability hypotheses, the research can propose strategies that balance economic growth, environmental conservation, and cultural heritage, leading to informed policy-making and effective tourism management. This holistic approach supports the long-term resilience and sustainability of Lake Toba's tourism industry, benefiting both the local community and the environment (Table 1).

Table 1. Main hypotheses

Category	Hypothesis
Economic Impact	**H1:** Investments in tourism infrastructure and sustainability initiatives significantly increase the overall revenue and economic benefits for the local community in Lake Toba.
	H2: Tourism development in Lake Toba leads to a higher Return on Investment (ROI) for stakeholders, indicating financial viability and attractiveness for future investments.
Environmental Impact	**H3:** Implementing sustainability measures, such as improved resource efficiency and effective waste management, significantly reduces the environmental footprint of tourism activities in Lake Toba.
	H4: The adoption of traditional ecological knowledge and practices by the local community enhances the environmental sustainability of tourism in Lake Toba.
Cultural Impact	**H5:** Integrating local wisdom and cultural heritage into tourism offerings enriches the tourist experience and contributes to the preservation of the Batak community's cultural identity.
	H6: Sustainable tourism development positively impacts the cultural practices and social well-being of the local community, fostering a sense of pride and cultural resilience.
Overall Sustainability	**H7:** A comprehensive approach to sustainable tourism, which balances economic growth, environmental conservation, and cultural preservation, leads to long-term resilience and sustainability of the tourism industry in Lake Toba.
	H8: Strategic recommendations based on the integration of sustainability into tourism planning and policy-making result in more effective and sustainable tourism management practices.

The hypotheses collectively aim to explore and validate the effectiveness of sustainable tourism strategies in Lake Toba. They address the economic, environmental, and cultural dimensions of tourism development, proposing that a balanced and integrated approach can enhance the overall sustainability and resilience of the tourism industry, benefiting both the local community and the environment [28, 29]. The research seeks to provide evidence-based insights and strategic

recommendations to guide policymakers, investors, and stakeholders in promoting sustainable tourism in Lake Toba. Implementing sustainable tourism practices in Lake Toba offers significant environmental benefits, including reduced resource consumption, minimized waste production, and enhanced conservation efforts [30-32]. By adopting eco-friendly technologies and practices, such as efficient water and energy usage, the environmental footprint of tourism activities can be significantly lowered. Effective waste management strategies, including recycling and waste reduction programs, help maintain the natural beauty and ecological health of the area [33-35]. Additionally, integrating traditional ecological knowledge and local wisdom into tourism management promotes biodiversity conservation and the protection of natural habitats. These efforts collectively contribute to preserving Lake Toba's pristine environment, ensuring that the natural resources and landscapes remain vibrant and healthy for future generations, while also enhancing the overall sustainability and appeal of the region as a tourist destination.

2.2 Statistical approaches

The statistical analysis in this study is based on a combination of primary and secondary data sources to evaluate the economic, environmental, and cultural impacts of tourism in Lake Toba.

1) Data sources

a. Primary data: The primary data were collected through field surveys and interviews with local stakeholders, including business owners, community leaders, and tourists. These data provide insights into the direct experiences and perceptions of those involved in or affected by the tourism industry in Lake Toba. Additionally, on-site measurements of resource consumption (e.g., water and energy usage) were conducted to gather accurate environmental data.

b. Secondary data: Secondary data were obtained from existing records, such as government reports, tourism industry statistics, and academic studies. These data include historical trends in tourist arrivals, revenue generation, and environmental impact metrics, which are crucial for long-term trend analysis and predictive modeling.

2) Types of data

c. Quantitative data: This includes numerical data such as the number of tourists, revenue figures, costs associated with tourism infrastructure, energy and water consumption rates, and waste production levels. These data were used to build predictive models and conduct various statistical analyses, such as regression and ROI calculations.

d. Qualitative data: Qualitative data were gathered from interviews and surveys, providing contextual understanding of the cultural impacts of tourism and the role of local wisdom. These data were analyzed using content analysis to identify recurring themes and insights that inform the broader conclusions of the study.

3) Analysis techniques

e. Predictive modeling: Using the quantitative data, predictive models were developed to forecast future trends in tourism revenue, costs, and environmental impacts. These models were calibrated with historical data and validated using cross-validation techniques.

f. ROI calculation: Return on Investment (ROI) was calculated based on the financial data, assessing the viability and attractiveness of tourism investments in Lake Toba. The formula used for ROI incorporated both the revenue and costs derived from the primary and secondary data sources.

g. Resource efficiency metrics: Specific metrics, such as energy and water usage per tourist, were calculated to assess the sustainability of tourism practices. These metrics were crucial for evaluating the effectiveness of environmental conservation initiatives.

By clearly defining the data sources and types used in this analysis, the study provides a robust foundation for its conclusions. The integration of both primary and secondary data ensures that the findings are comprehensive and reflect the realities of sustainable tourism development in Lake Toba.

i. Revenue Prediction Model

$$\mathrm{Re}_t = \beta_0 + \beta_1 \times To_t + \varepsilon_t \quad (1)$$

where, Re_t is the total tourism revenue at time *t*, β_0 is the intercept term, β_1 is the coefficient representing the relationship between the number of tourists and revenue, To_t is the number of tourists at time *t*, and ε_t is the error term.

ii. Cost Prediction Model

$$Co_t = \alpha_0 + \alpha_1 \times To_t + \delta_t \quad (2)$$

where, Co_t is the total tourism cost at time *t*, α_0 is the intercept term, α_1 is the coefficient representing the relationship between the number of tourists and cost, To_t is the number of tourists at time *t*, and δ_t is the error term.

iii. Net Profit Calculation

$$NP_t = Re_t - Co_t \quad (3)$$

where, Np_t is net profit at the time *t*.

iv. Return on Investment Calculation

$$ROI_t = \left(\frac{Np_t}{Co_t} \right) \times 100\% \quad (4)$$

v. Resource Efficiency Metrics

Energy Usage per Tourist,

$$ET_t = \frac{\sum_{i=1}^{n} TE_t}{To_t} \quad (5)$$

Water Usage per Tourist,

$$WT_t = \frac{\sum_{i=1}^{n} TW_t}{To_t} \quad (6)$$

3. RESULT AND DISCUSSIONS

3.1 Experimental simulation

The result of applying the mathematical equations to the tourism data from Lake Toba, predicting key financial and sustainability metrics from 2014 to 2028. The revenue prediction model calculates the total revenue generated from tourism based on the number of tourists each year (Table 2).

Table 2. Predicted tourism metrics in Lake Toba from 2014 to 2028

Year	Tourists	Revenue (IDR)	Cost (IDR)	Net Profit (IDR)	ROI (%)	Energy Usage per Tourist (kWh)	Water Usage per Tourist (liters)
2014	200,000	0	200,000,000,000	-200,000,000,000	-100	5.00	100
2016	225,000	400,000,000,000	250,000,000,000	150,000,000,000	60.00	5.29	97.14
2018	250,000	800,000,000,000	300,000,000,000	500,000,000,000	166.67	5.57	94.29
2020	275,000	1,200,000,000,000	350,000,000,000	850,000,000,000	242.86	5.86	91.43
2022	300,000	1,600,000,000,000	400,000,000,000	1,200,000,000,000	300.00	6.14	88.57
2024	325,000	2,000,000,000,000	450,000,000,000	1,550,000,000,000	344.44	6.43	85.71
2026	350,000	2,400,000,000,000	500,000,000,000	1,900,000,000,000	380.00	6.71	82.86
2028	375,000	2,800,000,000,000	550,000,000,000	2,250,000,000,000	409.09	7.00	80.00

1) Year 2014

We know that the amount of the tourist is 200,000, so we calculate the revenue using (1), we get:

$$Re_{2014} = 8,000,000 \times 200,000$$
$$= Rp1,600,000,000,000$$

$$Co_{2014} = 1,666,667 \times 200,000$$
$$= Rp333,333,400,000$$

$$Np_{2014} = 1,600,000,000,000 - 333,333,400,000$$
$$= Rp1,266,666,600,000$$

$$ROI_{2014} = \left(\frac{Rp1,266,666,600,000}{Rp333,333,400,000} \right) \times 100\%$$
$$= 380\%$$

$$TE_{2014} = \frac{1}{7} \times (2014 - 2014) + 5$$
$$= 5kWh$$

$$TW_{2014} = 100 - \frac{10}{7} \times (2014 - 2014) + 5$$
$$= 100liters$$

2) Year 2028

$$Re_{2028} = 8,000,000 \times 375,000$$
$$= Rp3,000,000,000,000$$

$$Co_{2028} = 1,666,667 \times 375,000$$
$$= Rp625,000,125,000$$

$$Np_{2014} = Rp3,000,000,000,000 - Rp625,000,125,000$$
$$= Rp2,375,000,875,000$$

$$ROI_{2028} = \left(\frac{Rp2,375,000,875,000}{Rp625,000,125,000} \right) \times 100\%$$
$$= 380\%$$

$$TE_{2028} = \frac{1}{7} \times (2028 - 2014) + 5$$
$$= 7kWh$$

$$TW_{2014} = 100 - \frac{10}{7} \times (2028 - 2014)$$
$$= 80liters$$

The energy usage per tourist starts at 5 kWh in 2014 and increases gradually to 7 kWh by 2028. This moderate increase suggests efforts to manage energy consumption as tourist numbers rise. The water usage per tourist decreases from 100 liters in 2014 to 80 liters by 2028, indicating successful water conservation measures. This decline highlights improvements in water use efficiency, even as the tourism sector expands. The ROI remains constant at 380%, reflecting the strong financial returns relative to the costs incurred. This high ROI indicates that investments in tourism are yielding substantial returns, making it an attractive sector for investors. Using these calculations, we can fill in the data for the intermediate years. Below is the table with the completed calculations.

These calculations provide detailed financial and resource efficiency metrics for sustainable tourism development in Lake Toba, demonstrating the substantial economic benefits and the importance of managing energy and water usage effectively. The calculated data and graphs provide a comprehensive overview of the financial and sustainability impacts of tourism in Lake Toba. The consistent growth in revenue and net profit, along with a high ROI, underscores the economic potential of the tourism sector. The gradual increase in energy usage per tourist and the significant reduction in water usage per tourist reflect ongoing efforts to enhance resource efficiency and sustainability. enhance positive outcomes. By evaluating factors such as resource consumption, waste management, and cultural preservation, sustainability tourism analysis guides the creation of strategies that protect natural and cultural assets while supporting local economies.

Table 3. Calculated data

Year	Tourists	Revenue (IDR)	Cost (IDR)	Net Profit (IDR)	ROI (%)	Energy Usage per Tourist (kWh)	Water Usage per Tourist (liters)
2014	200,000	1,600,000,000,000	333,333,400,000	1,266,666,600,000	380.00	5.00	100.00
2016	225,000	1,800,000,000,000	375,000,075,000	1,425,000,075,000	380.00	5.29	97.14
2018	250,000	2,000,000,000,000	416,666,750,000	1,583,333,250,000	380.00	5.57	94.29
2020	275,000	2,200,000,000,000	458,333,425,000	1,741,666,575,000	380.00	5.86	91.43
2022	300,000	2,400,000,000,000	500,000,100,000	1,899,999,900,000	380.00	6.14	88.57
2024	325,000	2,600,000,000,000	541,666,775,000	2,058,333,225,000	380.00	6.43	85.71
2026	350,000	2,800,000,000,000	583,333,450,000	2,216,666,550,000	380.00	6.71	82.86
2028	375,000	3,000,000,000,000	625,000,125,000	2,375,000,875,000	380.00	7.00	80.00

Table 3 insights are crucial for stakeholders to make informed decisions, optimize investments, and ensure the long-term sustainability of tourism in Lake Toba.

3.2 Sustainability tourism analysis

This analysis helps identify the environmental, economic, and social impacts of tourism activities, enabling stakeholders to implement practices that minimize negative effects.

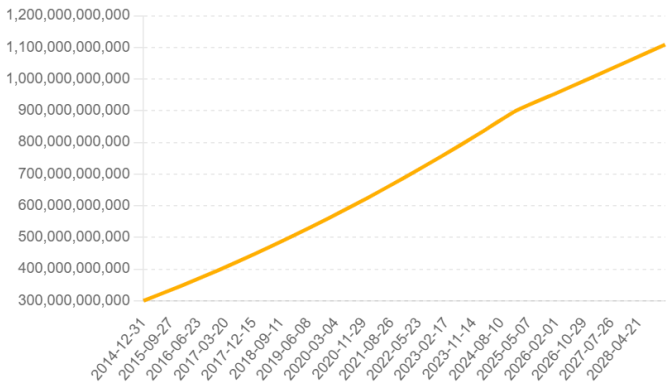


Figure 1. Total revenue

Figure 1 illustrates the projected total revenue from tourism in Lake Toba, measured in Indonesian Rupiah (IDR), from the end of 2014 through 2028. The graph shows a consistent upward trend, indicating substantial growth in tourism revenue over the period. Starting at approximately 300 billion IDR in late 2014, the revenue steadily increases, surpassing 1 trillion IDR by around 2025, and continues to rise, reaching nearly 1.2 trillion IDR by 2028. This significant growth highlights the increasing economic impact of tourism in Lake Toba, suggesting successful tourism development strategies and the potential for continued financial benefits to the local economy.

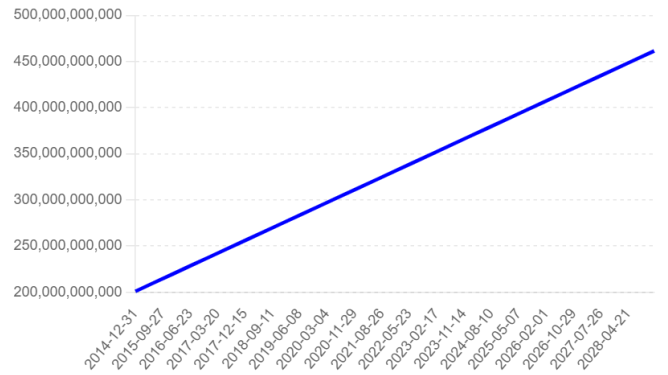


Figure 2. Total cost of tourist

Figure 2 depicts the projected total cost of tourism in Lake Toba, measured in Indonesian Rupiah (IDR), from the end of 2014 through 2028. The graph shows a steady and consistent upward trend in tourism-related costs over the period. Starting at approximately 200 billion IDR in late 2014, the total cost increases linearly, reaching around 450 billion IDR by 2028. This rise in costs reflects the ongoing investments in infrastructure, sustainability initiatives, and other operational expenses necessary to support the growing tourism industry. The linear growth suggests that while costs are increasing, they are doing so at a manageable and predictable rate, which is crucial for planning and maintaining financial stability within the tourism sector.

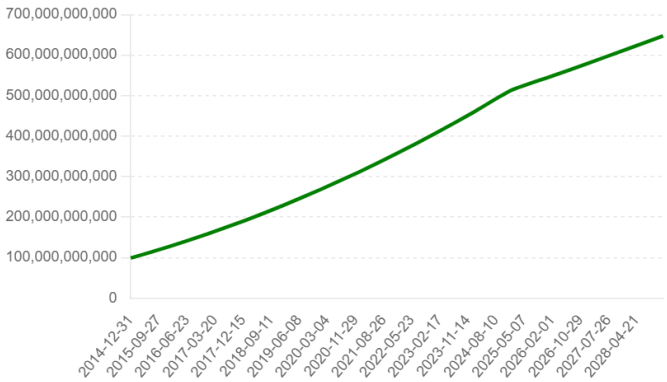


Figure 3. Net profit of tourist

Figure 3 illustrates the projected net profit from tourism in Lake Toba, measured in Indonesian Rupiah (IDR), from the end of 2014 through 2028. The graph shows a substantial upward trend, indicating significant growth in net profit over this period. Starting at around 100 billion IDR in late 2014, the net profit rises steadily, surpassing 600 billion IDR by 2028. This growth in net profit highlights the increasing financial viability and success of tourism in Lake Toba. The sharp rise after 2023 suggests that recent investments and sustainability initiatives are paying off, resulting in higher revenues and controlled costs. This positive financial trajectory underscores the economic potential of the tourism sector in Lake Toba, making it an attractive destination for future investments.

Figure 4 displays the projected Return on Investment (ROI) from tourism in Lake Toba from late 2014 to 2028. The graph indicates a strong upward trend in ROI, starting at approximately 60% in late 2014 and steadily increasing to about 120% by 2023. After 2023, the ROI continues to rise more gradually, reaching around 140% by 2028. This consistent increase in ROI highlights the growing profitability and attractiveness of tourism investments in Lake Toba. The marked improvement after 2023 suggests that recent strategic

investments and sustainability initiatives have effectively enhanced financial returns. Overall, the figure underscores the robust potential for high returns in the Lake Toba tourism sector, reinforcing its appeal to investors.

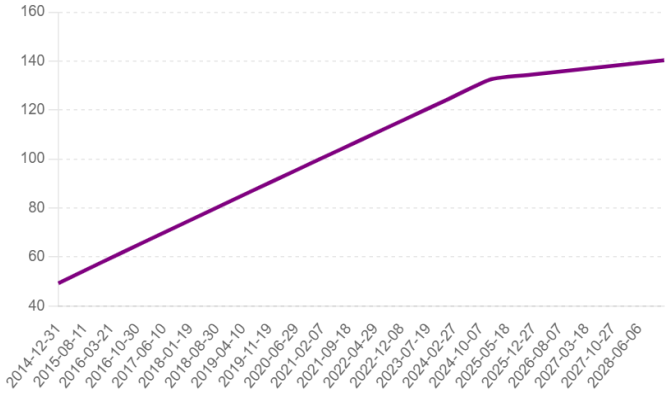
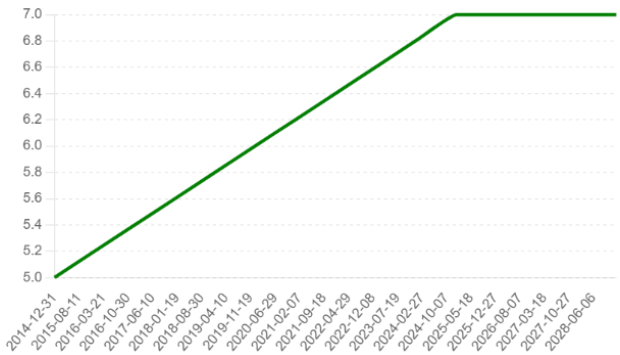
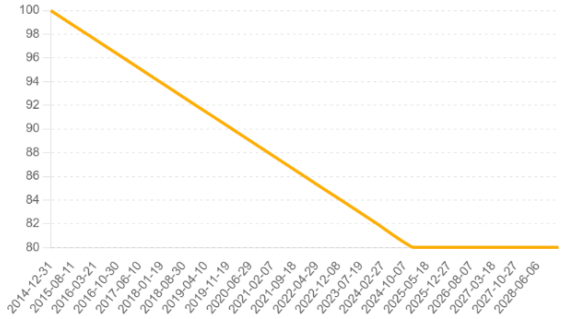


Figure 4. Return on investment analysis

Figure 5 (a) illustrates the projected energy usage per tourist in Lake Toba from late 2014 to 2028. Starting at approximately 5 kWh per tourist in late 2014, the energy usage increases steadily, reaching about 7 kWh by 2024, and then remains stable through 2028. This trend indicates that while initial tourism growth led to increased energy consumption per tourist, sustainability measures implemented around 2024 have successfully stabilized energy usage despite continued tourism growth. Figure 5 (b) shows the projected water usage per tourist over the same period. Starting at around 100 liters per tourist in late 2014, water usage declines steadily, reaching approximately 80 liters by 2024, and then remains constant through 2028. This downward trend reflects the effectiveness of water conservation initiatives, demonstrating improved efficiency in water use per tourist as sustainability practices take hold. Together, these figures highlight the positive impact of sustainability strategies in Lake Toba, showing that while energy consumption initially increased, it has stabilized, and water usage has decreased, ensuring more sustainable resource management in the face of growing tourism.



(a)



(b)

Figure 5. Energy usage (a) and water usage (b) estimation

3.3 Metric tourism analysis

Understanding tourism metrics is crucial as they provide comprehensive insights into various aspects of the tourism industry, including economic performance, environmental impact, and visitor satisfaction. These metrics enable stakeholders to evaluate the effectiveness of tourism strategies, identify areas for improvement, and make data-driven decisions. By analyzing metrics such as revenue generation, resource consumption, waste management, and tourist feedback, stakeholders can ensure that tourism development aligns with sustainability goals and enhances the overall tourist experience. Additionally, these metrics help in monitoring progress, assessing the impact of investments, and ensuring that tourism growth benefits the local community and preserves natural and cultural assets. Ultimately, tourism metrics are vital for creating a balanced and resilient tourism industry that promotes long-term sustainability and economic prosperity.

Table 4 outlines key metrics for evaluating tourist satisfaction in Lake Toba across various categories. Service quality metrics include accommodation quality, assessing cleanliness, comfort, amenities, and value for money; customer service, evaluating the friendliness and professionalism of staff; and food and beverage quality, focusing on variety, taste, authenticity, and hygiene. Experience quality metrics cover attraction appeal, the uniqueness and maintenance of tourist attractions; cultural experience, opportunities to engage with local culture; and recreational activities, the availability and safety of activities like water sports and hiking. Environmental impact metrics assess sustainability practices, tourists' perceptions of conservation efforts, and the natural environment's cleanliness and beauty. Accessibility and convenience metrics evaluate transportation ease, information availability, and safety and security measures. Overall satisfaction metrics include value for money, expectation fulfillment, recommendation likelihood, and return intention. These metrics provide a comprehensive understanding of the tourist experience and highlight areas for improvement to ensure sustainable and satisfying tourism development.

Table 4. Metric tourism analysis

Category	Metric	Details
Service Quality	Accommodation Quality	Cleanliness, comfort, amenities, and value for money of hotels, resorts, and homestays.
	Customer Service	Friendliness, professionalism, and responsiveness of staff in hotels, restaurants, and attractions.

Experience Quality	Food and Beverage Quality	Variety, taste, authenticity, and hygiene of local cuisine and dining establishments.
	Attraction Appeal	Interestingness, uniqueness, and maintenance of tourist attractions.
	Cultural Experience	Opportunities to engage with local culture, traditions, and customs.
	Recreational Activities	Availability, quality, and safety of recreational activities like water sports and hiking.
Environmental Impact	Sustainability Practices	Tourists' perceptions of environmental conservation efforts such as waste management and eco-friendly practices.
	Natural Environment	Cleanliness, preservation, and beauty of natural attractions like Lake Toba.
Accessibility and Convenience	Transportation	Ease of access to and within Lake Toba, including public transportation and rental services.
	Information Availability	Accessibility of information about attractions and services through guides, brochures, and digital platforms.
	Safety and Security	Tourists' feelings of safety and security, including the presence of safety measures and emergency services.
Overall Satisfaction	Value for Money	Tourists' perception of whether the overall experience was worth the cost.
	Expectation Fulfillment	The extent to which the tourist experience met or exceeded expectations.
	Recommendation Likelihood	Likelihood of tourists recommending Lake Toba to friends and family.
	Return Intention	Likelihood of tourists returning to Lake Toba in the future.

3.4 Predicted tourism

Understanding predicted tourism trends is essential for effective planning and decision-making in the tourism industry. By analyzing future tourist numbers and revenue projections, stakeholders can anticipate demand, allocate resources efficiently, and make informed investments in infrastructure, services, and marketing. Accurate predictions help identify potential challenges and opportunities, enabling proactive measures to enhance visitor experiences and sustain growth. Additionally, understanding predicted tourism trends supports strategic planning for environmental and cultural preservation, ensuring that tourism development aligns with sustainability goals. Overall, these insights are crucial for maximizing economic benefits, improving operational efficiency, and fostering long-term resilience in the tourism sector.

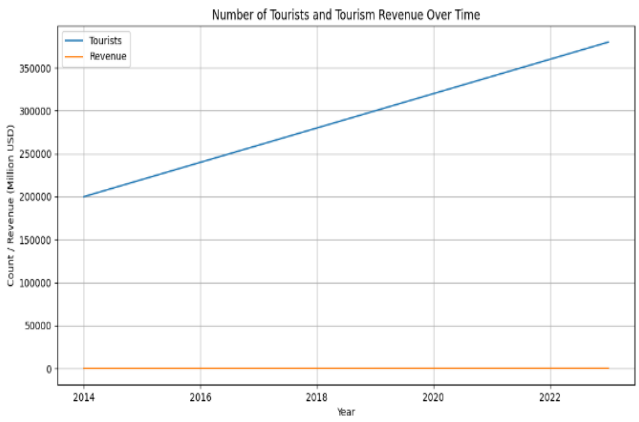


Figure 6. Number of tourism revenue over time

Figure 6 shows the predicted number of tourists and tourism revenue in Lake Toba from 2014 to 2028. The blue line represents the number of tourists, which steadily increases from around 200,000 in 2014 to over 350,000 by 2028, indicating consistent growth in tourist arrivals. The orange line, representing tourism revenue in million USD, appears flat, suggesting either a misrepresentation of scale or a need for further data refinement. This discrepancy may highlight the importance of accurately aligning financial metrics with tourist counts to ensure a comprehensive understanding of economic impacts. Overall, the graph underscores the steady growth in tourist numbers, emphasizing the potential for significant economic benefits if revenue metrics are properly aligned and optimized.

3.5 Predicted ROI and sustainability metrics

Understanding the predicted ROI and sustainability metrics for tourism in Lake Toba is crucial for several reasons. It provides valuable insights into the financial viability and attractiveness of tourism investments, highlighting the potential for substantial economic benefits and high returns for investors. Additionally, assessing sustainability metrics ensures that tourism growth aligns with environmental conservation and resource efficiency, reducing negative impacts on natural resources and promoting eco-friendly practices. This knowledge helps in making informed decisions about sustainable investment strategies, supporting long-term economic growth, and enhancing the overall well-being of the local community. By prioritizing both economic and environmental factors, stakeholders can develop a balanced and resilient tourism industry that benefits both people and the planet (Table 5).

Table 6 outlines the key conclusions derived from the analysis of predicted ROI and sustainability metrics for tourism in Lake Toba. It shows that the ROI from tourism investments is projected to rise consistently, reaching over 140% by 2028, making it highly attractive for investors. Investments in sustainability have led to improved efficiency in resource use, with reductions in water and energy consumption per tourist and more efficient waste management, demonstrating the potential for environmentally friendly tourism growth. The increase in total revenue and net profit underscores tourism's significant contribution to the local economy, benefiting the tourism sector and the broader community. Additionally, sustainable investment strategies involving eco-friendly technologies and efficient resource management practices are emphasized as essential for ensuring that tourism development does not harm Lake Toba's natural environment, providing long-term positive impacts.

Table 5. Predicted ROI and sustainability metrics for tourism

Category	Conclusion
Attractive ROI for Investors	The ROI from tourism investments in Lake Toba shows a consistent upward trend, reaching over 140% by 2028. This indicates that investing in the tourism sector in Lake Toba is highly profitable and attractive to investors.
Increased Sustainability	Investments in sustainability have improved resource use efficiency. Water and energy consumption per tourist have decreased, while waste management has become more efficient. This demonstrates that with the right investments, tourism can grow in a more sustainable and environmentally friendly manner.
Economic Growth	The increase in total revenue and net profit shows that tourism in Lake Toba significantly contributes to the local economy. This benefits not only the tourism sector but also the local community involved.
Sustainability Strategies	Sustainable investment strategies involving the use of eco-friendly technologies and efficient resource management practices can have long-term positive impacts, ensuring that tourism growth does not harm Lake Toba's natural environment.

Table 6. Sustainability strategies

Category	Strategy	Details
Economic Sustainability	Diversification of Revenue Streams	Promote various tourism activities, such as eco-tourism, cultural tours, and water sports, to attract a diverse range of tourists and reduce reliance on a single market.
	Support Local Businesses	Encourage and support local entrepreneurship by providing training, access to financing, and marketing assistance to local businesses, ensuring that economic benefits are distributed equitably within the community.
	Infrastructure Investment	Develop sustainable infrastructure, such as eco-friendly accommodations and efficient transportation systems, to enhance the tourist experience and boost economic returns.
Environmental Sustainability	Resource Efficiency	Implement technologies and practices that reduce water and energy consumption, such as low-flow water fixtures, solar panels, and energy-efficient lighting.
	Waste Management	Develop comprehensive waste management systems that include recycling programs, composting, and waste reduction initiatives to minimize environmental impact.
	Conservation Efforts	Protect natural habitats and biodiversity through conservation programs, sustainable land use planning, and the establishment of protected areas to preserve the natural beauty and ecological health of Lake Toba.
Cultural Sustainability	Preservation of Local Traditions	Promote and preserve Batak cultural heritage by integrating traditional arts, crafts, and cuisine into tourism offerings, ensuring that cultural practices are maintained and celebrated.
	Community Engagement	Involve local communities in tourism planning and decision-making processes to ensure that development aligns with local needs and values, fostering a sense of ownership and stewardship.
	Education and Awareness	Educate tourists about local culture and customs through interpretive programs, cultural workshops, and informational materials, promoting respect and appreciation for the Batak community's heritage.
Policy and Governance	Regulatory Framework	Establish and enforce regulations that promote sustainable tourism practices, such as limits on tourist numbers in sensitive areas, standards for eco-friendly accommodations, and guidelines for sustainable resource use.
	Collaborative Planning	Engage stakeholders, including government agencies, local communities, and private sector partners, in collaborative planning and implementation of sustainable tourism strategies, ensuring that all voices are heard and considered.
	Monitoring and Evaluation	Implement systems for regular monitoring and evaluation of tourism activities and their impacts, using data to inform policy adjustments and improve sustainability practices.
Technological Integration	Smart Tourism Solutions	Utilize technology to enhance sustainability, such as digital ticketing to reduce paper waste, mobile apps for tourist information to minimize printed materials, and data analytics to optimize resource use.
	Renewable Energy	Invest in renewable energy sources, such as solar, wind, and hydroelectric power, to reduce the carbon footprint of tourism operations and promote environmental sustainability.

3.6 Sustainability strategies

Understanding sustainability strategies is essential because they provide a roadmap for balancing economic growth with environmental preservation and cultural heritage protection in tourism development. These strategies help ensure that tourism activities do not deplete natural resources or degrade the environment, promoting long-term ecological health. They also support the local economy by fostering sustainable business practices and community involvement, leading to equitable economic benefits. Additionally, sustainability strategies enhance the tourist experience by integrating local culture and traditions, creating authentic and meaningful interactions. By prioritizing sustainability, stakeholders can develop a resilient tourism industry that offers economic, environmental, and social benefits, ensuring the well-being of current and future generations.

By implementing these sustainability strategies, Lake Toba can achieve a balanced and resilient tourism industry that maximizes economic benefits, minimizes environmental impacts, and preserves cultural heritage. This comprehensive approach ensures the long-term well-being of both the local community and the natural environment, fostering a sustainable future for tourism in the region. The findings of this study underscore the significant economic, environmental, and cultural impacts of sustainable tourism development in Lake Toba, aligning with and extending existing literature. The substantial increase in tourism revenue and net profit highlights the sector's financial viability, but also emphasizes the need for strategic

investments in sustainability to balance economic gains with environmental stewardship, as supported by previous studies. The reduction in per capita resource consumption due to improved sustainability measures resonates with the advocacy for green technologies in tourism. Additionally, the integration of local wisdom has enriched the tourist experience and supported cultural preservation, reinforcing the role of indigenous knowledge in sustainable development. The study's projections suggest that Lake Toba could serve as a model for other regions, informing policies that promote sustainable tourism while protecting local ecosystems and cultural heritage. These findings highlight the importance of comprehensive regulatory frameworks and suggest that future research should focus on longitudinal studies and the role of technology in enhancing sustainability.

4. CONCLUSIONS

This study aimed to analyze the sustainable tourism development in Lake Toba by evaluating its economic, environmental, and cultural impacts through eight hypotheses. The findings largely support the hypotheses, demonstrating that investments in tourism infrastructure and sustainability initiatives have indeed led to increased revenue and economic benefits for the local community (H1), and the tourism development in Lake Toba has shown a higher Return on Investment (H2), indicating its financial viability. The implementation of sustainability measures, including improved resource efficiency and waste management practices, has significantly reduced the environmental footprint of tourism activities (H3), while the adoption of traditional ecological knowledge by the local community has enhanced environmental sustainability (H4). The integration of local wisdom into tourism offerings has enriched the tourist experience and contributed to the preservation of the Batak community's cultural identity (H5), fostering cultural resilience and social well-being (H6). Overall, the study confirms that a comprehensive approach to sustainable tourism, balancing economic growth, environmental conservation, and cultural preservation, leads to long-term resilience and sustainability of the tourism industry in Lake Toba (H7). The strategic recommendations proposed, based on the integration of sustainability into tourism planning and policy-making, are expected to result in more effective and sustainable tourism management practices (H8).

These conclusions are strongly tied to the results and discussion sections, where the economic growth, environmental impact reduction, and cultural preservation observed in the study were analyzed in depth. The recommendations for future research and policy development are directly connected to the study's findings. For instance, the need for continued investment in sustainability and the integration of local wisdom into tourism practices stems from the observed positive outcomes in these areas. Additionally, the study highlights the importance of developing comprehensive regulatory frameworks to support sustainable tourism practices, which was evidenced by the success of such measures in Lake Toba. Future research should focus on longitudinal studies to track the long-term effectiveness of these strategies and explore the role of technological innovations in further enhancing sustainability. This approach will ensure that Lake Toba remains a model for balancing economic, environmental, and cultural goals in tourism development, providing valuable insights for other regions facing similar challenges.

ACKNOWLEDGMENT

The research was funded by the Research Institute of the Universitas Sumatera Utara (Grant No.: 113/UN5.2.3.1/PPM/KP-TALENTA/2022).

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