



Full-Length Research Article

Sustainability Status of Kalitalang Ecotourism in Mount Merapi National Park Using Multidimensional Scaling

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ABSTRACT

Kalitalang Ecotourism is a natural tourism object in the Mount Merapi National Park (TNGM) region, jointly managed by local communities and conservation area operators. It lies within Mount Merapi's highest volcanic hazard zone, and features steep terrain that may pose safety risks to visitors. Visitor numbers increased markedly from 59,144 in 2024 to 182,856 in 2025 following its official designation as a natural tourism object in December 2024, potentially intensifying environmental pressures. The destination has also faced governance challenges during the transition toward a more formal tourism management arrangement under TNGM, underscoring the need to balance conservation objectives with local community interests. Despite these challenges, no previous multidimensional sustainability assessment has been conducted. This study's novelty lies in providing such an assessment for Kalitalang Ecotourism. This study aims to assess the sustainability status of Kalitalang Ecotourism management using the Rap-Ecotourism method based on multidimensional scaling, through an organized and transparent attribute matrix covering five dimensions: ecology, economy, social, law and institutions, and accessibility and infrastructure. Data were gathered through field observations, structured interviews using interview guidelines, questionnaires, and secondary sources. The results reveal that Kalitalang Ecotourism's sustainability level falls into the moderately sustainable category (65.33%). The ecological dimension scored 80.67% and was classified as highly sustainable, while accessibility and infrastructure (66.96%), legal and institutional (71.30%), social (62.23%), and economic (69.45%) dimensions were classified as moderately sustainable. Optimizing sensitive attributes through adaptive management and temporal monitoring is a key recommendation to improve Kalitalang Ecotourism's sustainability. To better capture local economic consequences, future research should replace the Regional Original Revenue or *Pendapatan Asli Daerah* (PAD) contribution attribute with tourism sector economic growth.

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1. Introduction

Kalitalang Ecotourism is one of five natural tourism objects or *Objek Wisata Alam* (OWA) managed under the auspices of Mount Merapi National Park (TNGM). As a conservation area, TNGM serves as a center for research, education, and nature tourism (Muhamad 2018). This national park covers an area of approximately 6,410 ha and was officially designated by Decree

of the Minister of Forestry Number SK.134/Menhut-II/2004. TNGM comprises four ecosystem types, ranging from lowland to subalpine, and serves as an important water catchment area while supporting high biodiversity, including 81 tree and 74 orchid species. Based on the eruption history of TNGM, approximately 73% (4,728.19 ha) of the forest area has been directly affected by pyroclastic flows. These ecological characteristics highlight the importance of implementing ecotourism in accordance with conservation principles. According to [Fennell \(2008\)](#), ecotourism is a type of sustainable, nature-based travel that is low-impact, non-consumptive, ethically managed, locally focused, and contributes to conservation efforts. As a result, Kalitalang Ecotourism's management must improve the local economy and significantly promote environmental conservation.

Kalitalang is growing quickly as a travel destination. Locals first utilized the region to gather animal feed daily. In 2017, village youth took the initiative to build photo spots, which later expanded alongside social media-driven tourism trends and rising visitor numbers ([Muhammad and Widarjono 2023](#)). During the same period, several locations in Central Java and the Special Region of Yogyakarta (DIY) showed a similar trend ([Disbudparekraf Central Java 2017](#); [Dispar DIY 2017](#)). With the formal clearance to open the Kalitalang Nature Tourism Object (OWA) in December 2024, Kalitalang was officially recognized as a conservation-based nature tourism destination under the coordination of the TNGM ([Pradopo 2024](#)).

The sustainable management of Kalitalang faces both ecological and governance challenges. Located within Mount Merapi's highest volcanic hazard zone, or *Kawasan Rawan Bencana* (KRB III), the destination has steep terrain that may pose safety risks to visitors. In addition, visitor numbers increased markedly from 59,144 in 2024 to 182,856 in 2025 following its official designation as a Natural Tourism Object in December 2024, potentially intensifying environmental pressures. Governance challenges also emerged after Kalitalang was designated a utilization zone in 2021. Tourism activities had developed informally through community initiatives. Subsequent spatial management policies implemented by TNGM required several tourism facilities to be adjusted or closed for conservation and visitor safety reasons. These changes generated tensions between local communities and authorities (TNGM), leading to a prolonged negotiation process regarding management responsibilities and benefit-sharing arrangements. To address this, sustainable tourism indicators (STIs) serve as evaluation and monitoring tools by simplifying and aggregating information on environmental, social, and economic conditions to inform decision-making ([Miller and Torres-Delgado 2023](#)). Therefore, a multidimensional quantitative approach is needed to more fully describe the destination's condition ([Yuedi et al. 2023](#)).

International studies have increasingly highlighted the importance of sustainable ecotourism management in national parks and other conservation areas. An ecotourism sustainability assessment framework for the Khangchendzonga Biosphere Reserve was developed using a hierarchical system of principles, criteria, indicators, and verifiers established through Delphi and participatory approaches, highlighting the importance of structured sustainability assessment in conservation areas ([Ashok et al. 2017](#)). Likewise, a study in Bulusan Volcano Natural Park, Philippines, showed that ecotourism supports biodiversity conservation and local socio-economic development while also creating challenges related to increasing visitor numbers and maintaining high-quality visitor experiences ([Rebuya 2020](#)). More broadly, a recent systematic review of ecotourism in volcanic regions identified governance, conservation, stakeholder participation, and community impact as recurring themes, while highlighting the limited use of explicit theoretical or quantitative sustainability frameworks in such settings ([Kamaluddin et al. 2025](#)). Collectively,

these studies underscore the need for a structured, multidimensional sustainability assessment to support evidence-based management in volcanic national parks, including Mount Merapi National Park.

This study's selection of sustainability dimensions is grounded in the sustainable development framework proposed by Brundtland (1987), which emphasizes balancing ecological, economic, and social needs to ensure that current development does not compromise future generations' ability to meet their own needs. Kuhlman and Farrington (2010) reinforce this perspective, arguing that sustainability requires balancing environmental conservation and economic development rather than prioritizing one over the other. In the context of ecotourism, effective governance and adequate infrastructure must support these three sustainability pillars to ensure tourism development is implemented responsibly and sustainably. In line with these theoretical foundations, this study adopted the sustainability dimension framework from Sutata et al. (2024). Accordingly, the study assessed sustainability using five dimensions: ecology, economy, social, law and institutions, and accessibility and infrastructure.

One method for assessing the sustainability of nature-based destinations is multidimensional scaling (MDS), developed by Rapfish's Rap-Ecotourism. Several studies show that MDS effectively assesses the sustainability of nature-based destinations by integrating several key dimensions (Ardiansyah et al. 2024; Hakim et al. 2022). However, limitations remain, particularly regarding the lack of detailed operational definitions, attribute-specific data collection procedures, and explicit scoring criteria that may affect assessment consistency and the ability to replicate the analysis (Bakri et al. 2023; Kusdiyantoro et al. 2023; Sutata et al. 2024; Warlina and Sodikin 2025; Yunandar et al. 2025). Furthermore, although Kalitalang Ecotourism has been studied from several other angles, such as its development feasibility (Pratama and Umrotun 2024; Triwahyuningsih et al. 2025), socio-economic impact (Muhammad and Widarjono 2023), entrepreneurship strategy (Triwahyuningsih et al. 2026), camping-ground governance (Arbainah et al. 2025), visitor satisfaction (Salsabilla 2025), and social-media marketing (Salsabilla and Suryaningtyas 2026), none has assessed its sustainability across the ecological, economic, social, institutional, and infrastructural dimensions using the MDS approach. Based on these conditions, this study aims to assess the sustainability status of Kalitalang Ecotourism using the MDS approach through a modified Rap-Ecotourism method, compiling a structured, transparent assessment matrix as a basis for replicable analysis.

2. Materials and Methods

2.1. Description of the Study Area

The Kalitalang Ecotourism Site is located in Balerante Village, Kemalang District, Klaten Regency, Central Java Province. Geographically, the study site is centered at coordinates 7°34'51.87" S and 110°27'42.94" E. The Kalitalang Ecotourism Site is located in a conservation forest area managed by the National Park Management Section (*Seksi Pengelolaan Taman Nasional/SPTN*) Region II.

Kalitalang's ecological characteristics are strongly influenced by Mount Merapi's volcanic activity, resulting in a distinctive landscape of volcanic materials, steep slopes, and panoramic views of the mountain. The land cover is mainly natural vegetation, with *Acacia decurrens* as the dominant species that has regenerated in areas affected by volcanic disturbances. These ecological

and landscape characteristics are important assets for nature-based tourism but require appropriate management to remain sustainable. Tourism activities also interact with local community livelihoods, particularly through traditional resource utilization such as livestock fodder collection, reflecting the continued relationship between local communities and the conservation area. Furthermore, its location within KRB III, with the trekking boundary at Post 4 approximately 3 km from the summit of Mount Merapi, poses challenges for sustainable tourism management due to volcanic hazards.

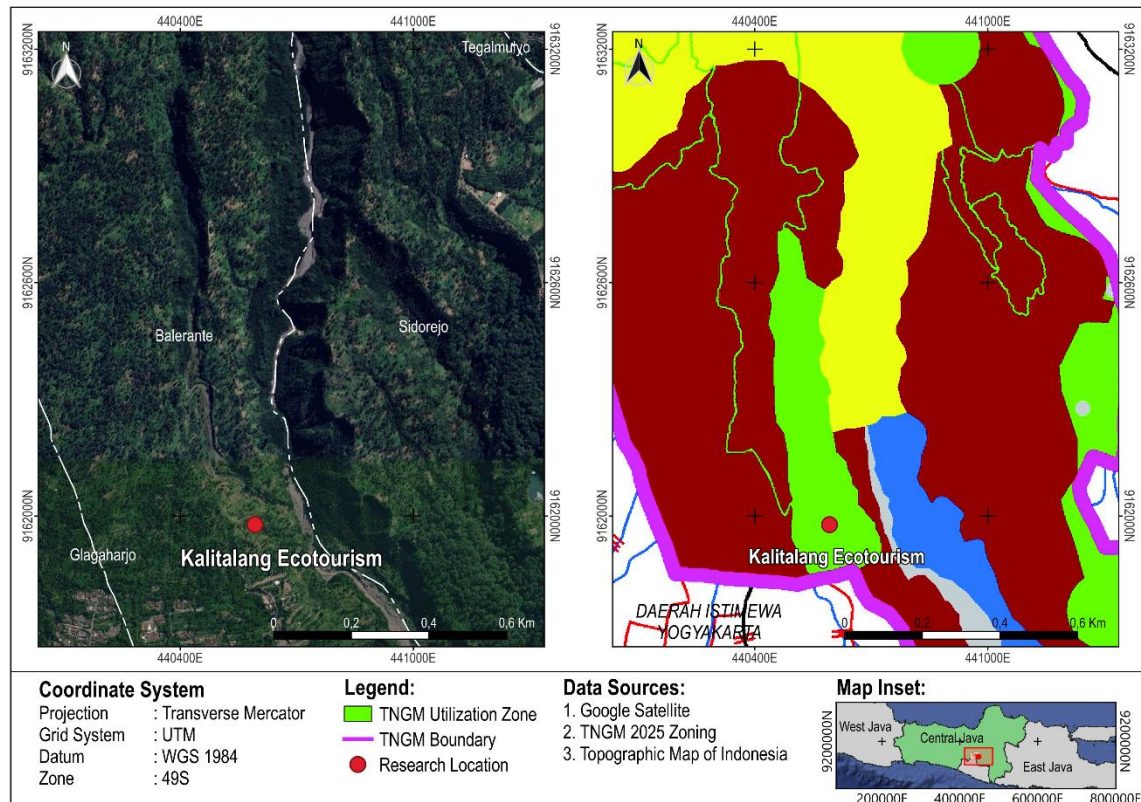


Fig. 1. Map of the research location at the Kalitalang Ecotourism Site.

2.2. Population and Sample

This study's population consists of tourists, local communities, operators of the Tourism Awareness Group (*Kelompok Sadar Wisata/Pokdarwis*), and operators of Mount Merapi National Park (TNGM). The tourist sample was selected using accidental sampling, involving visitors encountered on-site who met the criteria as information sources (Memon et al. 2025). This sampling technique was used because the tourist population was mobile and continuously changing, making it difficult to establish a complete sampling frame during the survey period. The minimum tourist sample size was determined using the Krejcie and Morgan (1970) formula based on the visitor population:

$$S = \frac{X^2 NP \times (1-P)}{e^2 (N-1) + X^2 P (1-P)} \quad (1)$$

where S is the required sample size, X^2 is the chi-square value at the 95% confidence level (3.84, equivalent to $Z = 1.96$), N is the population size (7,804 visitors, calculated from the average number of visitors recorded in November during 2022–2024), P is the assumed population

proportion (0.50), and e is the margin of error (0.10). This calculation yielded a minimum required sample size of 95 respondents.

Based on this formula, the minimum required sample size was 95 respondents. Therefore, this study included 100 tourist respondents. After being selected through accidental sampling, respondents were screened to ensure that they belonged to the target population based on three inclusion criteria: possessing a valid entrance ticket, currently visiting Kalitalang Ecotourism, and being at least 17 years old.

Respondents from the operator and local communities were selected through purposive sampling because these groups possess specific knowledge and roles related to ecotourism management. A total of seven local community members and fifteen operator representatives (Pokdarwis and TNGM) were selected based on predefined criteria. Operator criteria included Pokdarwis and TNGM members actively involved in managing Kalitalang Ecotourism. Local community respondents were residents of Balerante, Sidorejo, and Glagaharjo villages who directly engage in economic activities or use resources within the Kalitalang Ecotourism area and benefit from ecotourism activities.

2.3. Data Collection

This study combines primary and secondary data. The researchers collected primary data through field observations, structured interviews guided by interview guidelines, and questionnaires administered from November to December 2025. This period was selected because it coincided with relatively high visitor numbers, supporting sufficient tourist respondents and enabling comprehensive observation of ecotourism management and tourism activities. Meanwhile, secondary data were drawn from various related sources to supplement data requirements during data processing. Land-cover data were derived from Sentinel-2 Harmonized Surface Reflectance imagery accessed through Google Earth Engine. Imagery acquired between September 2024 and April 2025 with a spatial resolution of 10 m was used to generate a cloud-free median composite image. Land-cover classification used the Random Forest algorithm and was verified through ground checks to ensure the results reflected actual conditions in the study area.

Data collection aimed to assess sustainability across five dimensions. A score range of 0 to 3 was used to assess each attribute, with 0 indicating poor condition and 3 indicating good condition, as adapted from [Sutata et al. \(2024\)](#). As shown in **Table 1**, the sustainability status assessment matrix was further developed in a more organized and methodical manner after being adopted from [Sutata et al. \(2024\)](#). A combination of primary and secondary sources was used to collect data for each attribute, with sampling strategies and populations tailored to each attribute. The concept of sustainability, which emphasizes meeting present needs without compromising future generations' ability to meet their own needs, serves as the basis for developing attributes in the sustainability matrix ([Brundtland 1987](#)). Sustainable ecotourism management requires a balance between resource use and conservation. According to [Kuhlman and Farrington \(2010\)](#), sustainability lies at the nexus of weak and strong sustainability, providing direct social and economic benefits while preserving the environment for future generations. This balance can only be achieved through fair, participatory, and accountable governance, supported by adequate infrastructure and institutions.

Table 1. Sustainability status assessment matrix

Dimension/Attribute	Data Collection	Assessment Explanation	Score
A. Ecological Dimension			
1. Clean water availability in and around the tourism area	Observation	Inspecting (1) Water sources, (2) Sustainability of supply, and (3) Distribution.	0 = Water unavailable, unsustainable, and not distributed; 1 = Water available from outside the area, unsustainable, and limited distribution; 2 = Water available from local or outside sources that are sustainable with limited distribution; 3 = Water available from local or natural sources that are sustainable and well-distributed.
2. Waste management	Observation	The existence of facilities (trash bins, storage tanks) and management (collection, cleaning, disposal, processing).	0 = No facilities or management available; 1 = Limited facilities and no management implementation; 2 = Complete facilities and limited management implementation; 3 = Complete facilities and management implementation available.
3. Preservation of natural landscape	^a Questionnaire	Condition of the authenticity and beauty of the landscape (topography, vegetation, panorama).	0 = Very damaged or unnatural; 1 = Quite much changed, looks less natural; 2 = Still quite natural, only a few changes; 3 = Very natural, beauty and authenticity are well maintained.
4. Tree species diversity	Observation	Number of tree species with diameter > 20 cm.	0 = Number of individuals <5 trees; 1 = Number of individuals 5–20 trees; 2 = Number of individuals 21–35 trees; 3 = Number of individuals >35 trees.
5. Management of biodiversity	Secondary data: TNGM management documents (Balai Taman Nasional Gunung Merapi, 2024, 2025a, 2025b)	Existence of biodiversity management plans, implementation levels, and documentation of results.	0 = No plan; 1 = There is a plan, but it has not been implemented; 2 = There is a plan, and it has been implemented well; 3 = There is a plan, it has been implemented, and the results of biodiversity management are documented.
6. Presence of nuisance wildlife for tourists	^{a,b} Questionnaire	Presence of wildlife and the level of disturbance to tourist comfort and activities.	0 = Present, highly disturbing and threatening; 1 = Present, frequently disturbing but not threatening; 2 = Present, neither disturbing nor threatening; 3 = No disturbing or threatening wildlife present.
7. Exploitation rate of tourism areas	^a Questionnaire	The level of development of tourism facilities, the areas utilized, and the pressure on the area's environmental conditions.	0 = Very high exploitation; intensive development and activities are damaging the environment; 1 = High exploitation; most of the area is utilized and puts great pressure on the environment; 2 = Moderate exploitation; only part of the area is utilized, pressure is still manageable; 3 = Low or no exploitation; utilization is limited and does not put significant pressure on the environment.
8. Land cover (vegetation)	Secondary data: Sentinel-2 Surface Reflectance Image (S2-SR Harmonized) and Area of Interest (AOI) data	Percentage of the tourism area covered by dense vegetation.	0 = ≤25% dense vegetation cover; 1 = >25–50% dense vegetation cover; 2 = >50–75% dense vegetation cover; 3 = >75% dense vegetation cover.

Dimension/Attribute	Data Collection	Assessment Explanation	Score
B. Economic Dimension			
1. Income increase for local communities	^c Interview guide	Monthly income of local communities from ecotourism activities compared to the 2025 regional minimum wage (UMR).	0 = Less than 1 million; 1 = 1 million to UMR; 2 = Equal to UMR; 3 = More than UMR.
2. Contribution to regional original revenue (PAD)	Secondary data: No PAD contribution (tourism revenue is managed as village original income or PADes)	Contribution of tourism to PAD based on the ratio of income to regional maintenance costs.	0 = Does not exist and tourism utilization causes damage; 1 = None; 2 = Existing, the proportion between income and maintenance costs illustrates the fulfillment of all cost needs to preserve the area; 3 = There is, the proportion between income and maintenance costs illustrates that obtaining profits can also fulfill all the cost needs to maintain its sustainability.
3. Job opportunities for local communities	^c Interview guide and ^b Questionnaire	Conditions for job opportunities, considering impacts (labor competition and the dominance of external labor).	0 = Increased job opportunities around tourist attractions, but has an impact; 1 = Decreased job opportunities around tourist attractions, but has an impact; 2 = Decreased job opportunities around tourist attractions, but has no impact; 3 = Increased job opportunities around tourist attractions, but has no impact.
4. Business diversification	^{b,c} Interview guide	The development of various types of businesses around tourist attractions by considering the impacts of 1) Social pressure from unhealthy competition and the struggle for business land, 2) Environmental pressure from waste, water quality, and unsafe physical buildings.	0 = Increased business diversity, but has an impact; 1 = Decreased business diversity, but has an impact; 2 = Decreased business diversity, but has no impact; 3 = Increased business diversity, but has no impact.
5. Tourism retribution	^a Questionnaire	The existence of tourism levies and the reasonableness of their rates for tourism area services.	0 = None; 1 = Exist, needs review (rates do not match the services/facilities provided); 2 = Exist, rates are appropriate and not yet fully commensurate with the facilities or experience provided; 3 = Exist, rates are appropriate and fully commensurate with the facilities or experience provided.
6. Increased tourist purchasing power	^b Interview guide	There is an increase in tourists' purchasing power for tourism services, including photography, accommodation and culinary services.	0 = None; 1 = Exist, tourists use ≤ 1 type of tourism service (≤ 1 time per month); 2 = Exist, tourists use > 1 type of tourism service (every week); 3 = Exist, tourists use > 1 type of tourism service (almost every day).
7. Tourist visitation rate	Secondary data: Tourism visitation records, rainfall correction factor (CF), slope CF, temperature CF, sunshine duration CF, soil sensitivity CF, and AOI	The number of tourists visiting a tourist area over a given period is determined by the ratio of visits to the real carrying capacity (RCC).	0 = Very high, number of visits $> 100\%$ of the RCC value; 1 = Low, number of visits $< 33\%$ of the RCC value; 2 = Moderate, number of visits $33\text{--}66\%$ of the RCC; 3 = High, number of visits $\geq 66\text{--}100\%$ of the RCC.

Dimension/Attribute	Data Collection	Assessment Explanation	Score
8. Availability of capital/funding sources	^b Interview guide	Availability of capital or funding sources to support tourism activities and regional development.	0 = None; 1 = Insufficient capital, no development of facilities and infrastructure; 2 = Insufficient capital, there is little development of facilities and infrastructure; 3 = Sufficient capital, there is development of facilities and infrastructure.
C. Social Dimension			
1. Education level	Secondary data: Balerante Village education data	The formal education level of the majority of the people in Balerante Village is based on the largest population group.	0 = Elementary School; 1 = Junior High School; 2 = Senior High School; 3 = Bachelor's Degree or higher.
2. Local unemployment rate	Secondary data: Balerante Village employment data	The unemployment rate is determined by the status of not working or not yet working.	0 = High (Unemployment >20%); 1 = Medium (Unemployment 10–20%); 2 = Low (Unemployment 5–10%); 3 = Very low (Unemployment <5%).
3. Environmental knowledge of tourists	^a Questionnaire	The level of tourists' understanding of 1) Environmental conditions, such as safe and dangerous terrain points, and 2) Nature tourism ethics: throwing rubbish in its place, using enough water, and not damaging facilities.	0 = Does not know safe/dangerous points and does not understand travel etiquette at all; 1 = Knows a small part of the safe points or the etiquette is partially applied; 2 = Knows most of the safe points and the etiquette is generally applied; 3 = Knows all the safe points and the etiquette is generally applied.
4. Education and training for operators	^b Questionnaire	Availability of education and training to manage natural resources and serve visitors.	0 = None; 1 = Exists, but training is very rare and unplanned (occasionally, not routinely); 2 = There is training, but it cannot support the improvement of human resources and the improvement of further competencies; 3 = There is training, but it can support the improvement of human resources and the improvement of further competencies.
5. Community involvement in area management	^c Interview guide	Community participation in planning and decision-making for managing tourism areas.	0 = Community is not involved in planning or decision-making; 1 = Community is involved in planning, but not in decision-making; 2 = Community is not involved in planning, but is involved in decision-making; 3 = Community is involved in planning and is involved in decision-making.
6. Existence of local wisdom	^b Interview guide and ^b Questionnaire	Cultural practices that are directly related to the existence of the area (for example, certain days are considered bad or local beliefs regarding prohibitions).	0 = None; 1 = Exists but not well maintained; 2 = Exists and is well maintained but not well documented; 3 = Exists and is well maintained and documented.
7. Potential conflicts	^{b, c} Interview guide	The level of potential social and environmental conflict is based on the clarity of: 1) Division of roles, 2) Authority, and 3) Benefits.	0 = 1) Roles: unclear or overlapping, 2) Authority: fully controlled by one party without community involvement, 3) Benefits: no community share, no transparency, leading to open conflict; 1 = 1) Roles: being discussed but no clear agreement, 2) Authority: unregulated, 3) Benefits: distribution between community and

Dimension / Attribute	Data Collection	Assessment Explanation	Score
8. Level of security	Observation	Guarantees of tourist safety (zero accidents) include: (1) The availability of safety instructions, such as signs for safe routes during trekking and evacuation mechanisms in the event of a warning of Merapi activity; (2) Easy access to early warning information or guidance from officers in the event of increased Merapi activity; and (3) Attention and supervision from officers regarding tourist safety.	operators perceived as unfair with no transparency; 2 = 1) Roles: clear and implemented by mutual agreement, 2) Authority: regulated in official partnerships involving operators and community, 3) Benefits: distribution perceived as unfair but there is transparency; 3 = 1) Roles: clear and implemented by mutual agreement, 2) Authority: regulated in official partnerships, 3) Benefits: shared fairly and transparently. 0 = 1) Safety instructions: none, 2) Early warning information: not available, 3) Attention and supervision: none; 1 = 1) Safety instructions: some points exist but there are no evacuation procedures, 2) Early warning information: can be obtained from officers but is not readily available to tourists, 3) Attention and supervision: not yet available; 2 = 1) Safety instructions: complete throughout the route with clear evacuation procedures, 2) Early warning information: easily accessible or quickly conveyed by officers, 3) Attention and supervision: still limited; 3 = 1) Safety instructions: complete throughout the route with clear evacuation procedures, 2) Early warning information: easily accessible or quickly conveyed by officers, 3) Attention and supervision: carried out throughout the tourist area.
D. Legal and Institutional Dimension			
1. Availability of formal management regulations	^b Interview guide	The existence and level of optimization of formal regulations governing the management of tourist areas.	0 = No regulations; management without legal basis, uncertain and inconsistent; 1 = Regulations exist, but are minimal and not fully implemented, uncertainty remains; 2 = Regulations are clear and sufficiently implemented, there are minor deficiencies; 3 = Regulations are clear and consistently implemented, there are minor deficiencies that can still be addressed.
2. Policy making involves the community	^{b, c} Interview guide	The level of local community involvement in the process of formulating tourism area management policies.	0 = Does not involve local communities; 1 = Exists, local communities are passive, and some accept the tourism area management policy; 2 = Exists, local communities are active, and some accept the tourism area management policy; 3 = Exists, local communities are active and wholly accept the tourism area management policy.
3. Level of community compliance with rules	^b Interview guide	Level of community compliance with regulations and agreements for managing tourist areas.	0 = No compliance (complete disregard for rules); 1 = Low compliance (rules are not followed with supervision, violations occur frequently despite minimal awareness); 2 = Moderate compliance (most rules are followed with supervision, violations still occur); 3 = High compliance (all rules are followed with supervision, resulting in infrequent violations).

Dimension/Attribute	Data Collection	Assessment Explanation	Score
4. Coordination between stakeholders	^{b, c} Interview guide	The level of cooperation and coordination between related parties (government, community, operators, private sector) in managing the area.	0 = There is no cooperation or coordination between parties; 1 = There is cooperation and coordination, but it is limited (without any real follow-up); 2 = There is unstructured cooperation and coordination; the program runs smoothly with collaboration between parties; 3 = There is structured cooperation and coordination, the program runs smoothly with collaboration between parties.
5. Division of roles among institutions/groups	^{b, c} Interview guide	Clarity and balance in the division of roles between institutions or groups in managing tourist areas.	0 = Unclear roles and overlapping authority; 1 = Unbalanced roles and weak collaboration (some overlap); 2 = Clear and balanced roles; strong collaboration (some overlap); 3 = Clear and balanced roles; strong collaboration (no overlap).
6. Law enforcement	^{b, c} Interview guide	The existence and implementation of law enforcement or regulations in tourist areas.	0 = None; 1 = Exist, no supervision, if there is a violation, there is never a warning; 2 = Exist, there is supervision, any violations that are seen will be warned by the operator; 3 = Exist, there is supervision, any violations that are seen will be warned by the operator, and the rules are communicated before various parties enter the area.
7. Guidance and counseling	^{b, c} Interview guide	The existence of guidance and counseling activities for the community and tourism stakeholders regarding tourism management.	0 = None; 1 = Exist, rarely (≤ 1 time/year, participants are only tourism actors); 2 = Exist, quite adequate (≥ 1 time/year, participants are only tourism actors); 3 = Exist, adequate (≥ 1 time/year, participants are tourism actors and the community).
8. Monitoring and evaluation of ecotourism management	^{b, c} Interview guide	The existence and frequency of monitoring and evaluation activities for the management of tourist areas.	0 = None; 1 = Exist, unscheduled, no follow-up; 2 = Exist, unscheduled (baseline evaluation and partial corrective action); 3 = Exist, scheduled (evaluation with data and optimal corrective action).
E. Accessibility and Infrastructure Dimension			
1. Facilities and infrastructure	^b Interview guide and observation	Availability of 1) parking space, 2) toilets, 3) street lighting, 4) security posts, 5) worship facilities, 6) rest areas.	0 = Few facilities are functioning or available (0–1 facility); 1 = Available and partially functioning (2–3 facilities); 2 = Available and adequately functioning (4–5 facilities); 3 = Available and fully functioning (6 facilities).
2. Access to transportation	^a Questionnaire and Observation	Accessibility and ease of access to tourist locations.	0 = No transportation access available. All types of vehicles cannot enter the tourist site; 1 = Limited access available, only two-wheeled vehicles can enter. The road is potholed and difficult to navigate on two lanes; 2 = Access available for two-wheeled vehicles and light vehicles, with a smooth road condition and passable on two lanes.; 3 = Access available for two-wheeled vehicles, light vehicles, and large vehicles, with a smooth road condition and passable on two lanes.

Dimension/Attribute	Data Collection	Assessment Explanation	Score
3. Access to information	^a Questionnaire and Observation	Availability and ease of access to tourist information, such as directions and information boards.	0 = None, difficult to access; 1 = Available, difficult to access (1–2 signs, hidden location, outdated condition); 2 = Available, easily accessible (signs in the main area, accurate/up-to-date information, no digital format yet); 3 = Available, very easy (signs evenly distributed throughout the area, accurate/up-to-date information, digital format available).
4. Communication access	^a Questionnaire and Observation	Availability and ease of access to communication networks, such as cellular and internet connectivity for mobile devices, in tourist areas.	0 = None; 1 = Limited (weak signal throughout the area); 2 = Easily accessible (stable in the main area); 3 = Very easily accessible (strong and stable throughout the area).
5. Tourism promotion	^b Questionnaire and Observation	Intensity and consistency of promotional style through social media.	0 = None; 1 = Promotion is conducted very infrequently (1–2 times a year), but inconsistently; 2 = Promotion is conducted regularly (every month), but inconsistently; 3 = Promotion is conducted regularly (every month) and consistently.
6. Electricity availability	^b Interview guide and Observation	Availability of electricity for 1) toilet lighting, 2) camping areas, 3) security posts, 4) prayer facilities, 5) public electricity, and 6) food stalls.	0 = 0–1 facilities have electricity; 1 = 2–3 facilities have electricity; 2 = 4–5 facilities have electricity; 3 = 6 facilities have electricity.
7. Health facilities	^b Interview guide and Observation	Availability and suitability of first-aid equipment (wound or bleeding treatment and medication), and the ability of emergency personnel to provide emergency assistance.	0 = No first aid kit and not trained in emergency response; 1 = First aid kit is available but incomplete and not trained in emergency response; 2 = First aid kit is available and trained in emergency response; 3 = Complete first aid kit is available and trained in emergency response.
8. Facility maintenance	^b Interview guide and Observation	Availability and implementation of public facility maintenance activities.	0 = None; damaged facilities are neglected and unfit for use; 1 = Exists; implemented when major damage occurs, resulting in minor damage being ignored; 2 = Exists; implemented in some facilities or with minor damage; 3 = Exists, carried out in all facilities and always in proper condition.

Notes: The dimensions and attributes in this matrix are adapted from [Sutata et al. \(2024\)](#) with modified assessment and scoring criteria. Codes: a = tourist respondents with the sample size determined using the [Krejcie and Morgan \(1970\)](#) formula, b = operator respondents, and c = local community respondents.

The sustainability index for each dimension and the multidimensional index were calculated using MDS in Rap-Ecotourism, which produces values on a scale of 0–100, ranging from “bad” to “good,” as shown in **Table 2**.

Table 2. Sustainability level categories (Pitcher 1999)

Index value (%)	Category (sustainability status)	Explanation
0.00–25.00	Bad (Unsustainable)	Most sustainability attributes are in unfavorable conditions.
25.01–50.00	Poor (Less Sustainable)	Several sustainability attributes remain in unfavorable conditions, while some aspects are favorable.
50.01–75.00	Fair (Moderately sustainable)	Many sustainability attributes are in favorable conditions, although improvements are still needed in several aspects.
75.01–100.00	Good (Highly Sustainable)	Most sustainability attributes are in favorable conditions and support sustainable management.

3. Results and Discussion

3.1. Sustainability Attribute Scoring Results

The assessment of sustainability attributes was based on the matrix presented in **Table 1**. Scores from various data sources were combined using a mode to produce a single representative value for each attribute, which was then used as input to the MDS analysis. Field observations constituted one of the primary data sources used to assess several sustainability attributes. Representative findings from these observations are presented in **Fig. 2**.

Based on field observations (**Fig. 2**), waste management facilities are available, but their implementation remains limited, as evidenced by waste at several tourist activity points. Safety signs along tourist routes support the tourist safety system. Maintenance of public facilities still includes signs that are in poor condition. All observation results are also included as data sources in the sustainability attribute assessment, with some results presented in **Fig. 2**.

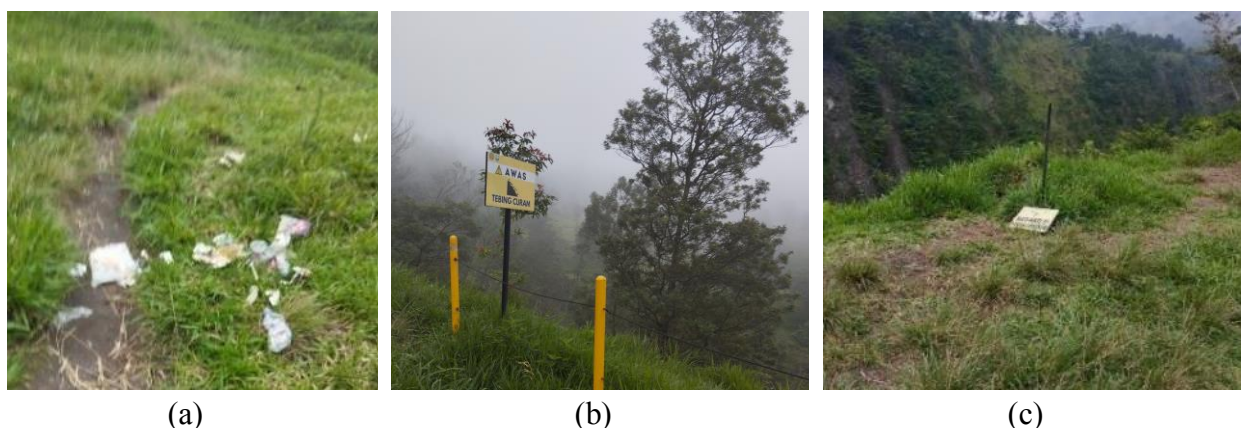


Fig. 2. Field observation findings related to (a) cleanliness, (b) safety, and (c) maintenance of the area.

3.2. Kalitalang Ecotourism Sustainability Index

The sustainability attribute scores were subsequently analyzed using the Rap-Ecotourism method, yielding sustainability index values for each dimension, as presented in **Fig. 3**.

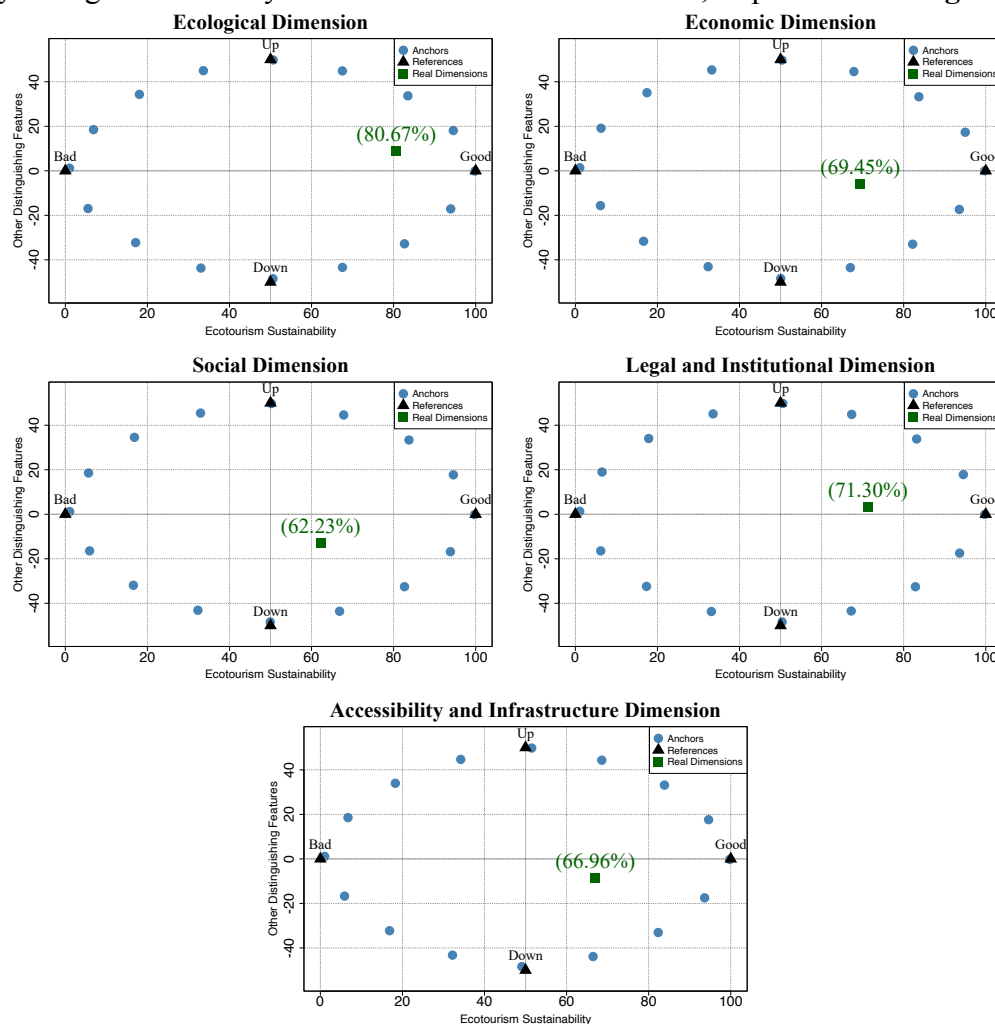


Fig. 3. Sustainability status of Kalitalang Ecotourism across each dimension.

The ecological dimension achieved the highest sustainability index (80.67%), indicating that ecological conditions in the study area are better maintained than the economic, social, legal and institutional, and accessibility and infrastructure dimensions. This high score aligns with Mount Merapi National Park's management objectives, which prioritize conserving water resources, native flora and fauna, and the sustainable use of volcanic ecosystem potential ([Balai Taman Nasional Gunung Merapi 2024](#)). This conservation-oriented management has helped maintain the area's ecological integrity despite increasing tourism activities. This result is reflected in favorable conditions for several ecological attributes, including clean water availability in and around the tourism area, preservation of the natural landscape, tree species diversity, biodiversity management, and the tourism area's exploitation rate. These attributes demonstrate that the natural resources supporting ecotourism remain relatively well preserved. [Sutata et al. \(2026\)](#) reported similar patterns, finding that the ecological dimension achieved the highest sustainability index (73.00%) among nature-based tourism destinations within the TNGM area. Likewise, the ecological dimension was also identified as the highest-performing sustainability dimension in Bukit Tiga Puluh National Park, with a sustainability index of 91.68% ([Sadad and Yoswaty 2022](#)).

These consistent findings indicate that ecological sustainability generally outperforms other sustainability dimensions in national park ecotourism, reflecting the effectiveness of conservation-oriented management in maintaining ecosystem integrity.

In contrast, the social dimension recorded the lowest sustainability index (62.23%), indicating that it requires greater improvement than the other sustainability dimensions in Kalitalang Ecotourism. Although this value is higher than the social sustainability index of 45.81% reported for Mount Rinjani National Park (Sadikin et al. 2020), the social dimension remained lower than the ecological dimension in both studies. In Kalitalang, the relatively lower social performance was mainly associated with local communities' low education levels and the local unemployment rate, which received the lowest scores among the social attributes. These findings reflect the socio-economic characteristics of the communities surrounding Kalitalang, where local livelihoods were historically dominated by agriculture, livestock farming, and sand mining before ecotourism development. At the same time, tourism has gradually expanded employment opportunities and community capacity-building initiatives (Muhammad and Widarjono 2023). Consistent with these developments, the proportion of residents with primary education or less has gradually decreased, and the unemployment rate has declined slightly between 2023 and 2025 (Pemerintah Desa Balerante 2025). However, these improvements have not yet been sufficient to raise the sustainability scores of the education level and local unemployment rate attributes.

3.3. MDS Results and Monte Carlo Analysis with a 95% Confidence Level

Monte Carlo analysis tested the stability of the MDS results. A delta between the MDS and Monte Carlo values below 5% indicates stable analysis results, with smaller differences indicating greater confidence in the ordination results (Widyawati et al. 2024). As shown in **Table 3**, the Monte Carlo analysis produced delta values ranging from 0.14% to 1.73% across all sustainability dimensions, all below the acceptable threshold of 5%. These results indicate that the MDS ordination is stable and that the estimated sustainability indices reliably assess Kalitalang Ecotourism's sustainability status.

3.4. Validation Test

The obtained sustainability index values then need to be tested to assess the fit of the analysis model used. Model fit is determined using *S-stress* and the coefficient of determination (R^2). An *S-stress* value below 0.25 is considered acceptable (Pitcher 1999). The lower the *S-stress* value, the better the model fits the data (Supriatna et al. 2024). An R^2 value is acceptable if it is close to 1, meaning the attributes used to assess the dimensions can reflect sustainability (Kavanagh and Pitcher 2004). The validation test results in **Table 4** show *S-stress* values of 0.12–0.15 and R^2 values of 0.95–0.96. These values indicate that the model fits well and meets the acceptable criteria for sustainability analysis.

Table 3. MDS results and Monte Carlo analysis with 95% confidence level

Dimensions	Sustainability index (%)	Monte Carlo (%)	Delta (%)	Sustainability status	Explanation
Ecology	80.67	78.94	1.73	Highly Sustainable	Most sustainability attributes are in favorable conditions and support sustainable management.
Economics	69.45	68.40	1.05	Moderately sustainable	Many sustainability attributes are in favorable conditions, although improvements are still needed in several aspects.
Social	62.23	62.10	0.14	Moderately sustainable	Many sustainability attributes are in favorable conditions, although improvements are still needed in several aspects.
Law and Institutions	71.30	70.23	1.07	Moderately sustainable	Many sustainability attributes are in favorable conditions, although improvements are still needed in several aspects.
Accessibility and Infrastructure	66.96	66.11	0.85	Moderately sustainable	Many sustainability attributes are in favorable conditions, although improvements are still needed in several aspects.
Multi-dimensional	65.33	64.46	0.87	Moderately sustainable	Many sustainability attributes are in favorable conditions, although improvements are still needed in several aspects.

Note: Delta (%) is the difference between the sustainability index and the Monte Carlo.

Table 4. Validation test results

Dimensions	<i>S-stress</i>	<i>R</i> ²
Ecology	0.14	0.95
Economics	0.14	0.95
Social	0.14	0.95
Law and Institutions	0.15	0.95
Accessibility and Infrastructure	0.15	0.95
Multidimensional	0.12	0.96

3.5. Leverage Analysis

Fig. 4 presents the leverage analysis results, showing each attribute's relative influence on the sustainability index. Attributes with higher RMS values have a greater influence on changes in the sustainability index and are priority variables for sustainability improvement. In the ecological dimension, land cover was identified as the most sensitive ecological attribute (RMS = 5.11). The land-cover classification achieved an overall accuracy of 91.08% and a kappa coefficient of 84.62%, indicating that the dataset was sufficiently reliable to represent vegetation conditions in the study area. The attribute received a score of 1 because dense vegetation covered only 35.98% of the total area, while sparse vegetation dominated 55.68%. Based on the established scoring criteria, this proportion indicates that vegetation cover contributes to erosion and runoff control, although its ecological function has not yet reached an optimal condition (Zhang et al. 2022). As the most sensitive ecological attribute, changes in vegetation cover can substantially influence the ecological sustainability index.

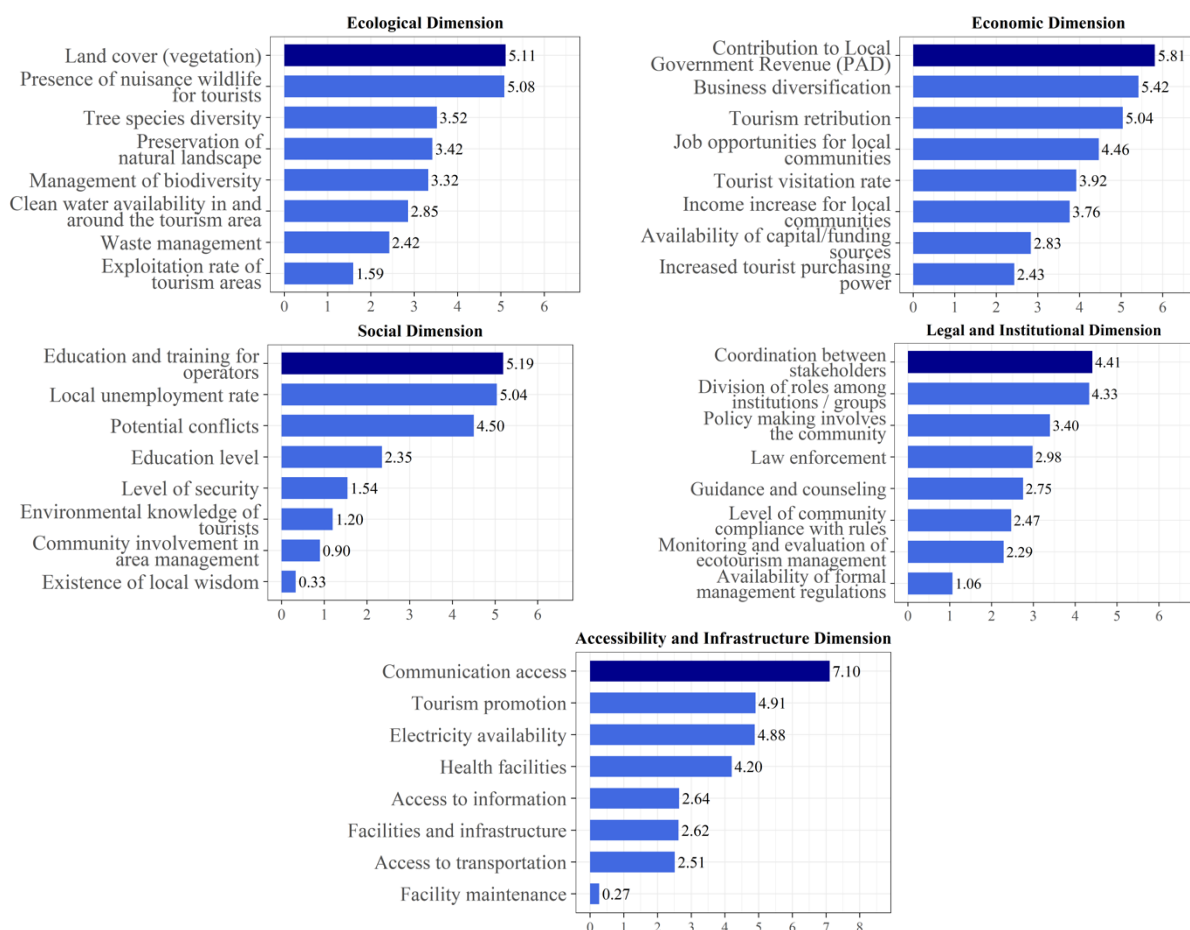


Fig. 4. Sensitivity analysis for each sustainability dimension based on root mean square change in ordination when a selected attribute is removed (on sustainability scale 0 to 100).

Leverage analysis for the economic dimension indicates that PAD contribution (RMS = 5.81) is a sensitive attribute. PAD contribution reflects the link between tourism development and regional economic performance (Simorangkir et al. 2024). However, at Kalitalang Ecotourism, tourism revenue is still managed as village original income (PADes) by the tourism group (Pokdarwis), so its contribution to regional PAD is not optimal.

Leverage analysis for the social dimension indicates that the education and training attribute for operators (RMS = 5.19) is a sensitive attribute. Education and training influence operator performance and service quality, as reflected in Pokdarwis' ability to coordinate with the TNGM, understand role allocation and respond to safety and waste management issues. These findings align with [Tah and Goswami \(2025\)](#), who emphasized the role of education and training in improving management performance and tourist experience.

Leverage analysis on the legal and institutional dimensions indicates that inter-stakeholder coordination (RMS = 4.41) is a sensitive attribute. Coordination among stakeholders plays a crucial role in supporting ecotourism sustainability across environmental, economic, and community welfare dimensions ([Mulyani et al. 2021](#)). Effective institutional collaboration further strengthens governance for sustainable natural resource management ([Banuwa et al. 2025](#)). Kalitalang Ecotourism management involves collaboration between local communities, the tourism awareness group (Pokdarwis), and the National Park (TNGM) through operational coordination and communication mechanisms for tourism services. This is consistent with findings from another Indonesian national park, where social capital and forestry extension officers strengthened community participation in conservation partnership programs ([Suswadi et al. 2024](#)).

Leverage analysis on the accessibility and infrastructure dimensions indicates that communication access (RMS = 7.10) is the most sensitive attribute. Communication access is crucial because coordination, information dissemination, and emergency response at tourist destinations depend heavily on effective communication systems ([Danzi et al. 2025](#)). Moreover, adequate accessibility and supporting facilities are essential for improving tourism performance and destination sustainability ([Hasibuan et al. 2025](#)). At Kalitalang Ecotourism, communication access remains limited due to poor cellular coverage and reliance on Wi-Fi networks at the Pokdarwis and TNGM posts. These limitations could hinder rapid response and emergency visitor safety management.

3.6. Sustainability Status of Kalitalang Ecotourism

The results of each dimension were analyzed multidimensionally to obtain the sustainability index value for Kalitalang Ecotourism. **Fig. 5** shows a sustainability index value of 65.33% for Kalitalang Ecotourism (moderately sustainable). This value indicates that the ecotourism management system has operated sustainably in supporting the sustainability dimension but has not yet reached the highly sustainable category. For comparison, Boonpring Ecotourism reported a multidimensional sustainability index of 59.76%, which was also classified as moderately sustainable ([Hakim et al. 2022](#)). In the Boonpring study, all sustainability dimensions were classified as moderately sustainable, with ecological, economic, and human resource indices of 54.46%, 63.79%, and 61.03%, respectively ([Hakim et al. 2022](#)). Similarly, the multidimensional sustainability index obtained in the present study reflects the combined performance of all assessed dimensions, where the relatively high ecological index (80.67%) was moderated by comparatively lower indices for the social, economic, legal and institutional, and accessibility and infrastructure dimensions.

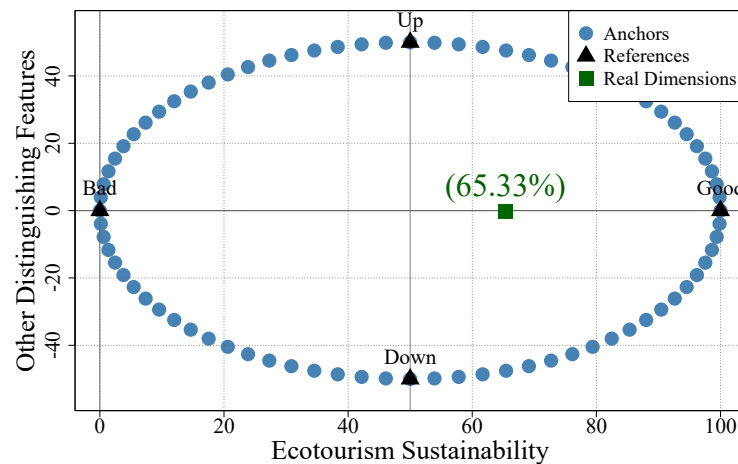


Fig. 5. Multidimensional sustainability status of Kalitalang Ecotourism.

The kite diagram (**Fig. 6**) summarizes the sustainability indices for all dimensions and shows each dimension's relative performance. The ecological dimension exhibited the highest sustainability index, followed by the legal and institutional, economic, accessibility and infrastructure, and social dimensions. Overall, the kite diagram indicates an imbalance in sustainability performance across dimensions, with ecological sustainability performing better than the others.

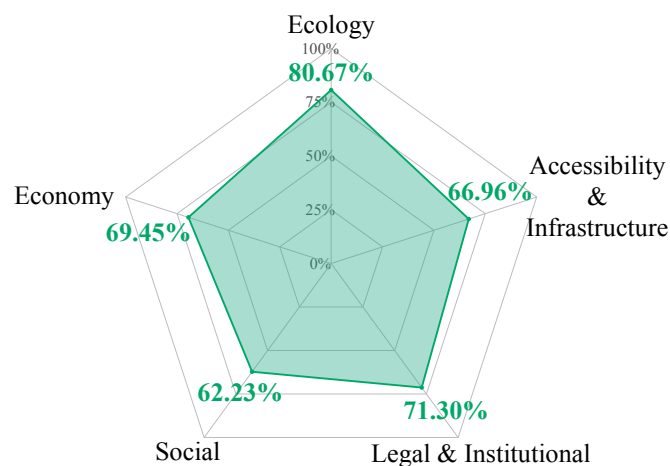


Fig. 6. Kite diagram of Kalitalang Ecotourism sustainability.

4. Conclusions

Based on an MDS analysis using the Rap-Ecotourism method, Kalitalang Ecotourism's sustainability status is 65.33% (moderately sustainable). This indicates that many assessed sustainability attributes are in favorable conditions, although several attributes still require improvement to achieve a highly sustainable status. Sensitive attributes identified in the leverage analysis include land cover (vegetation), PAD contribution, operator education and training, stakeholder coordination, and communication access. These attributes should be prioritized in adaptive management strategies and temporal monitoring to optimize sustainability. Further research is recommended to replace the PAD contribution attribute with economic growth from the tourism sector, given the PAD indicator's limitations in capturing the economic impact of tourism activities.

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Author Contributions

A.D.: Conceptualization, Methodology, Software, Formal Analysis, Writing – Original Draft Preparation; R.S.: Conceptualization, Methodology, Supervision; T.A.: Validation, Resources, Writing – Review and Editing; W.W.: Validation, Review and Editing.

Conflict of Interest

The authors declare no conflict of interest.

Declaration of Generative AI And AI-Assisted Technologies in the Manuscript Preparation

Not applicable.

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