INTEGRATING SMART AND GREEN INNOVATION FOR SUSTAINABLE GEOTOURISM DEVELOPMENT: A CASE STUDY OF TOBA CALDERA UNESCO GLOBAL GEOPARK, INDONESIA

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Abstract

The integration of smart and green innovation has become essential in advancing sustainable geo-tourism development, particularly within UNESCO Global Geopark areas. This study aims to explore how digital technologies and environmentally responsible practices can synergistically enhance the sustainability of the Toba Caldera UNESCO Global Geopark in Indonesia. Using a qualitative-descriptive approach supported by field observations, stakeholder interviews, and secondary data analysis, this research identifies current smart initiatives such as digital visitor management systems, virtual geotourism platforms, and eco-friendly infrastructure and examines their impact on environmental preservation, community empowerment, and visitor experience. The findings reveal that while technological adaptation has improved information accessibility and operational efficiency, the success of sustainable geo-tourism heavily depends on community participation and consistent environmental education. Several challenges were also identified, including limited digital literacy among local communities and insufficient coordination between public and private sectors. Integrated Smart-Green GeoTourism Framework that combines technological innovation, environmental stewardship, and social inclusivity to achieve long-term destination sustainability. The study concludes that the Toba Caldera Geopark has strong potential to serve as a national model for sustainable geo-tourism when smart and green innovations are harmoniously implemented. Policy support, community involvement, and capacity building are recommended to strengthen this integration and ensure the continuous preservation of Indonesia's geoheritage within a globally competitive tourism landscape.

Keywords: Smart Tourism Innovation; Green Tourism Development; Sustainable GeoTourism; Community Empowerment; Toba Caldera UNESCO Global Geopark.

A. INTRODUCTION

Tourism has evolved into one of the most dynamic global industries, yet it faces increasing pressure to align with the principles of sustainability and digital transformation. Over the past decade, the concept of geo-tourism which emphasizes the conservation of geological heritage, local culture, and environmental integrity has gained international recognition as a pathway toward sustainable regional development (Dowling & Newsome, 2018; Farsani et al., 2021). Simultaneously, the rise of smart tourism innovation has transformed how destinations are managed, experienced, and sustained, leveraging digital technologies to optimize visitor experiences while minimizing ecological footprints (Gretzel et al., 2015; Buhalis, 2020). The convergence between smart and green innovation represents a paradigm shift in destination management. Smart technologies such as Internet of Things (IoT), Geographic Information

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Systems (GIS), and virtual tourism platforms can enhance data-driven decision-making, improve resource efficiency, and strengthen environmental monitoring (UNWTO, 2023). Meanwhile, green innovation focuses on eco-friendly infrastructure, renewable energy use, and community-based environmental stewardship, promoting long-term ecological balance and social inclusion (OECD, 2022). When integrated effectively, these two dimensions can create a resilient, adaptive, and inclusive geo-tourism model that aligns with the Sustainable Development Goals (SDGs), particularly Goals 11 (Sustainable Cities and Communities) and 15 (Life on Land).

In the Indonesian context, Toba Caldera UNESCO Global Geopark (UGGp) serves as a living laboratory for implementing smart and green strategies in tourism management. The geopark recognized globally for its volcanic landscape and cultural richness faces complex challenges in balancing tourism growth with environmental preservation and community welfare (UNESCO, 2024). Although several smart initiatives have been introduced, including digital visitor management systems, virtual reality-based promotion, and green infrastructure projects, their integration remains partial and fragmented. This condition underscores the need for a comprehensive framework that connects technological innovation, environmental stewardship, and local empowerment within a unified sustainability model. To illustrate the conceptual relationship between smart tourism and green innovation in achieving sustainable geo-tourism, Table 1 summarizes their key characteristics, alignment with the Sustainable Development Goals (SDGs), and potential impacts on destination sustainability.

Table 1. The Intersection of Smart and Green Innovation in Sustainabe Geo-Tourism Development

Innovation Focus	Key Characteristics	Relevant Sustainable Development Goals (SDGs)	Expected Impact on Geotourism
Smart Tourism Innovation	Utilization of digital tools, data analytics, IoT, and virtual tourism to optimize destination management and enhance visitor experiences	SDGs 9: Industry, Innovation and Infrastructure, SDGs 11: Sustainable Cities and Communities	Improves data-driven decision-making, enhances accessibility, and increases efficiency in resource use
Gren Innovation	Eco-friendly infrastructure, renewable energy adoption, waste reduction, and conservation-based tourism practices	SDGs 12: Responsible Consumption and Production, SDGs 13: Climate Action, SDGs 15: Life on Land	Minimizes environmental degradation, promotes eco-conscious behavior, and supports biodiversity protection
Integrated Smart-Green Approach	Synergy between technological advancement and environmental ethics	SDGs 17: Partnership for the Goals	Builds resilience, inclusivity, and long-term destination sustainability through multi-stakeholder collaboration

Source: Adapted from UNWTO (2023), OECD (2022), and Buhalis (2020).

As shown in Table 1, the integration of technological advancement and environmental responsibility creates a synergistic pathway toward more resilient and inclusive geo-tourism destinations. This framework forms the foundational perspective of the present study, particularly in the context of the Toba Caldera UNESCO Global Geopark. Therefore, this study aims

to explore how the integration of smart and green innovations can strengthen the sustainability of Toba Caldera Geopark by addressing ecological, socio-cultural, and managerial dimensions. To achieve this, a qualitative-descriptive method was employed, combining field observations, stakeholder interviews, and secondary data analysis to identify key strategies and challenges in implementing smart and green geo-tourism initiatives. The research emphasizes the importance of synergy between technology and environmental ethics to ensure that destination development not only enhances competitiveness but also safeguards geoheritage and community well-being. The findings of this study are expected to contribute to the broader discourse on sustainable geo-tourism transformation and provide actionable insights for policymakers, destination managers, and local stakeholders across Indonesia and beyond.

B. RESEARCH METHOD

To achieve the research objectives, this study employed a qualitative–descriptive approach, which allows for an in-depth exploration of the relationship between smart and green innovations in the sustainable management of Toba Caldera UNESCO Global Geopark (UGGp). The study combined field observations, semi-structured interviews, and secondary data analysis to obtain a comprehensive understanding of current practices, stakeholder perceptions, and existing challenges. The research was conducted from January to August 2025, focusing on three primary stakeholder groups: (1) local government and Geopark management units, (2) community-based tourism groups, and (3) private sector operators engaged in eco-tourism and digital innovation initiatives. Data collection involved on-site observations at selected geosites (Sigulatti, Hutaginjang, and Balige areas), interviews with 15 key stakeholders, and document analysis from official reports, policy papers, and sustainability frameworks by UNESCO and the Ministry of Tourism and Creative Economy of Indonesia. Triangulation was used to ensure data credibility, combining multiple sources and perspectives for validation. To provide a concise overview of the research process and methodological structure, Table 2 summarizes the essential components of this study, including the approach, data sources, analytical techniques, and validation methods.

Table 2. Research Design Overview

Component	Description
Approach	Qualitative-Descriptive
Location	Toba Caldera UNESCO Global Geopark, North-Sumatera, Indonesia
Duration	January – August 2025
Participants / Subjects	Local government, geopark management, tourism entrepreneurs, and community groups
Data Collection Techniques	Field observation, semi-structured interviews, document analysis
Instruments Used	Observation checklist, interview guide, secondary data templates
Data Analysis Method	Thematic content analysis (Miles & Huberman, 2014)
Validation Technique	Data triangulation and member checking

Source: Author's compilation (2025).

As summarized in Table 2, the study adopted a multi-source and iterative data collection process to ensure both contextual accuracy and analytical depth. Each methodological element was designed to capture the dynamic interaction between technological innovation, environmental management, and community participation in the Geopark area. To illustrate the

sequential process of this research and ensure replicability, Figure 1 presents the step-by-step flow of activities—from data gathering to analysis and framework formulation.

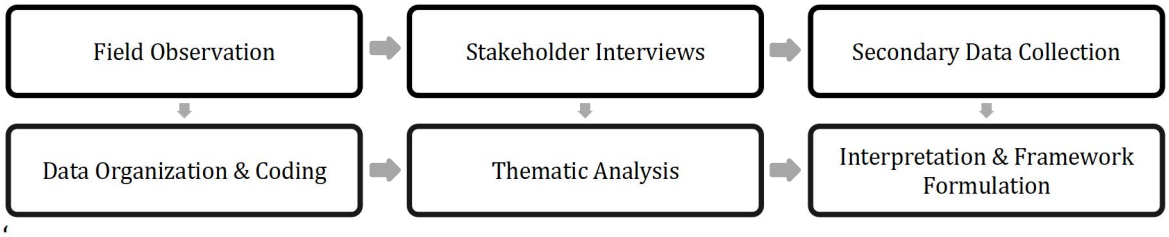

Figure 1. Research Procedure Flow.

As depicted in Figure 1, the research procedure followed a linear–iterative cycle, enabling the researcher to continuously refine interpretations and strengthen the validity of the findings through feedback and triangulation. Data were analyzed using thematic content analysis, following Miles and Huberman's (2014) three-step process: data reduction, data display, and conclusion drawing/verification. Codes and categories were developed inductively to capture emerging themes related to smart innovation, green practices, and community participation.

C. FINDINGS AND DISCUSSION

This study explored how the integration of smart and green innovations contributes to the sustainability of Toba Caldera UNESCO Global Geopark (UGGp). The results are presented based on three key dimensions derived from the thematic analysis: (1) Smart Innovation Practices, (2) Green and Environmental Initiatives, and (3) Community Empowerment and Governance Synergy.

3.1 Smart Innovation Practices

Findings from field observations and interviews indicate that the Toba Caldera Geopark has adopted several digital-based initiatives aimed at improving visitor management and destination promotion. These include the implementation of digital visitor tracking systems, QR-based geosite information, and the development of a virtual geotourism platform accessible via mobile applications. These initiatives have significantly improved information accessibility and visitor experience personalization, aligning with the global trend of smart destination management (Gretzel et al., 2015; UNWTO, 2023). However, digital adoption remains uneven among community-based tourism operators due to limited digital literacy and infrastructure support. To summarize the key smart innovation findings, Table 3 presents the main initiatives, their objectives, and their observed impacts on destination sustainability.

Table 3. Summary of Key Smart-Green GeoTourism Findings in Toba Caldera UGGp

Dimension	Initiative / Strategy	Observed Impact	Challenges Identified
Smart Innovation	Digital visitor management system, QR information points, virtual tour apps	Improved visitor experienced, enhanced data accuracy for management	Low digital literacy among local guides, limited internet coverage
Green Innovation	Solar-powered lighting, waste segregation stations, eco-lodge certification	Reduced carbon footprint, cleaner geosite environments	Limited maintenance budgets, need for stronger enforcement
Community Empowerment	Training for local tourism	Increased participation,	Inconsistent

Dimension	Initiative / Strategy	Observed Impact	Challenges Identified
	groups, community-based waste program, local craft digital marketplace	strengthened local economy	engagement, lack of coordination between sectors

Source: Field observation and stakeholder interviews (2025).

As shown in Table 3, the integration of digital and environmental practices has produced measurable improvements in operational efficiency and environmental management. However, the challenges identified particulary regarding digital literacy and cross-sector coordination remain key barriers to achieving full integration.

3.2 Green and Environmental Initiatives

The second finding highlights the progress made in adopting green innovation practices. Several geosites, such as Sigulatti and Hutaginjang, have implemented renewable energy-based lighting systems, while community groups initiated waste management programs supported by local NGOs. These efforts demonstrate alignment with the UN SDGs 12 and 13 (Responsible Consumption and Climate Action). Interview data revealed that visitors perceive these eco-friendly features as enhancing the authenticity of their experience. This supports findings by Farsani et al. (2021), who emphasized that eco-conscious infrastructure directly strengthens the value of geoheritage sites. Nevertheless, the sustainability of these green initiatives depends on consistent funding and long-term monitoring. Respondents noted that maintenance of eco-facilities often declines after initial project funding ends, suggesting a need for integrated policy and local ownership.

3.3 Community Empowerment and Governance Synergy

The third dimension relates to social and governance factors. The findings underscore that community engagement is a determining factor in the success of smart–green integration. Community-based tourism groups (Kelompok Sadar Wisata or Pokdarwis) in the Toba area have actively participated in environmental campaigns, digital promotion, and cultural interpretation. However, coordination between government agencies, private sector, and community groups remains fragmented. Some digital systems developed by local innovators are not integrated into the official Geopark database, leading to data duplication and inefficiency. This gap echoes previous studies (OECD, 2022; UNESCO, 2024) that highlight the need for multi-stakeholder alignment in sustainable tourism governance.

3.4 Integrated Smart–Green GeoTourism Framework

To consolidate the empirical results and connect them with the study objectives, Figure 2 illustrates the proposed Integrated Smart–Green GeoTourism Framework developed from this research.

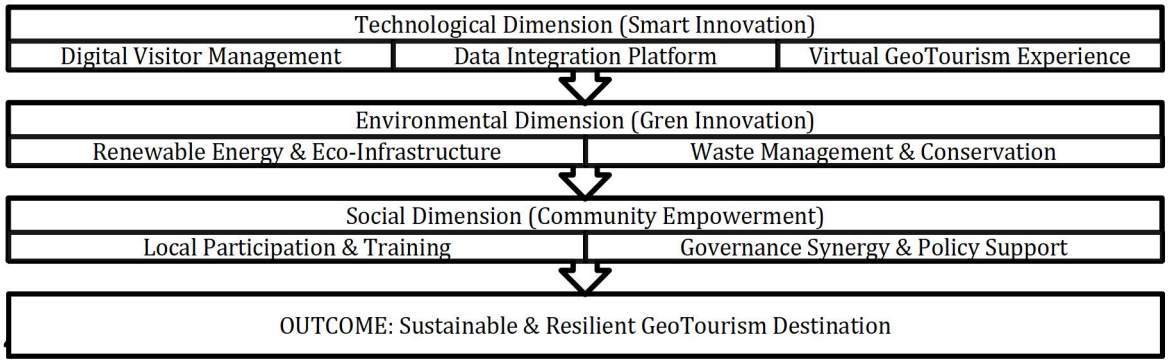

Figure 2. Integrated Smart-Green GeoTourism Framework for Toba Caldera UGGp.

As illustrated in Figure 2, the framework positions smart innovation as the enabler, green innovation as the foundation, and community empowerment as the driver of sustainability. This aligns with Buhalis (2020) and UNWTO (2023), who noted that digital and environmental integration can only succeed when supported by social inclusivity and local participation.

3.5 Discussion Summary

The findings collectively confirm that smart and green innovations, when implemented synergistically, can significantly enhance both the operational and ecological dimensions of geotourism. However, the results also indicate that technological advancement alone is insufficient without strong community engagement and governance coordination. These results are consistent with prior studies by Dowling & Newsome (2018) and Farsani et al. (2021), who emphasized that sustainable geotourism development requires multi-dimensional integration. Yet, the present study adds new insight by framing a practical integration model (Figure 2) tailored for a UNESCO Global Geopark context a contribution not extensively explored in previous research.

4 CONCLUSION

This study set out to explore how the integration of smart and green innovations can enhance the sustainability of the Toba Caldera UNESCO Global Geopark (UGGp). The findings confirm that the combined application of digital technologies, eco-friendly infrastructure, and community participation provides a holistic pathway toward sustainable geo-tourism development. Smart initiatives have improved information accessibility and operational efficiency, while green practices have strengthened environmental stewardship and reduced the ecological footprint of tourism activities. Most importantly, local community engagement has proven to be the cornerstone that connects technological advancement with social and environmental responsibility. The research concludes that the synergy between smart innovation, green innovation, and community empowerment represents an essential triad for achieving long-term sustainability in geopark management. When implemented collectively, these dimensions create a self-reinforcing system where technology supports efficiency, green practices ensure environmental balance, and community participation drives inclusivity and resilience.

Beyond its empirical contributions, this study also presents a conceptual framework (Figure 2) that can serve as a replicable model for other UNESCO Global Geoparks or sustainable tourism destinations in developing regions. The framework highlights that sustainability in geo-tourism should not be viewed as a technological goal alone but as a socially integrated transformation that aligns with national and global sustainability agendas such as the UN SDGs 11, 12, and 15. However, several limitations remain. The study's qualitative scope focused primarily on stakeholder perceptions and observed practices within selected geosites; therefore, future research is encouraged to apply mixed-method approaches combining spatial data analytics, visitor behavior analysis, and environmental impact assessment to strengthen quantitative validation. In addition, future studies should explore policy alignment and inter-agency coordination in sustaining digital and environmental innovation across broader tourism networks in Indonesia.

Ongoing collaborative projects between UNESCO, Politeknik Pariwisata Medan, and local government agencies are currently developing pilot programs for smart eco-infrastructure and digital heritage education in the Toba Caldera region. These initiatives are expected to build upon the findings of this study and provide real-time evidence of how integrated innovations can reinforce geoheritage conservation and socio-economic resilience. In summary, the Toba Caldera

Geopark demonstrates a strong potential to become a national benchmark for smart and green tourism integration. Sustaining this achievement will depend on continuous policy support, technological adaptation, and inclusive community empowerment to ensure that Indonesia's geoheritage continues to thrive within an increasingly competitive and environmentally conscious global tourism landscape.

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