บทความวิจัย

การประยุกต์ใช้วิธี Grey-DEMATEL เพื่อระบุปัจจัยเชิงสาเหตุของการท่องเที่ยวอย่างยั่งยืน: กรณีศึกษา จังหวัดน่าน ประเทศไทย

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บทคัดย่อ

การท่องเที่ยวอย่างยั่งยืนได้กลายเป็นวาระนโยบายที่มีความสำคัญอย่างยิ่งต่อการพัฒนาภูมิภาคในประเทศเศรษฐกิจเกิดใหม่ ทว่ายังมีหลายพื้นที่ท่องเที่ยวในชนบทที่เปราะบางต่อการเติบโตอย่างไร้การควบคุม การใช้ทรัพยากรอย่างสิ้นเปลือง และการรั่วไหลของรายได้ งานวิจัยนี้มุ่งวิเคราะห์ปัจจัยเชิงสาเหตุและผลที่มีอิทธิพลต่อการท่องเที่ยวอย่างยั่งยืนในชุมชนท่องเที่ยวที่กำลังพัฒนาอย่างรวดเร็วในภาคเหนือของประเทศไทย โดยใช้หมู่บ้านสองแห่งในจังหวัดน่านเป็นกรณีศึกษา โดยอาศัยเกณฑ์ความยั่งยืน 13 ประการขององค์การการท่องเที่ยวโลกแห่งสหประชาชาติ (UNWTO) และใช้วิธีการ Grey Decision Making Trial and Evaluation Laboratory (Grey-DEMATEL) เพื่อจัดการกับความไม่แน่นอนและมุมมองที่หลากหลายของผู้มีส่วนได้ส่วนเสีย ผ่านการแปลงการประเมินแบบคู่เปรียบเทียบของผู้เชี่ยวชาญให้เป็นค่าจำนวนเกรย์แล้วสังเคราะห์เป็นเมทริกซ์ความสัมพันธ์รวมเชิงโครงสร้าง ข้อมูลได้มาจากแบบสัมภาษณ์เชิงโครงสร้างกับผู้มีส่วนได้ส่วนเสีย 13 คน ประกอบด้วยผู้นำชุมชน หน่วยงานรัฐ และผู้ประกอบการท่องเที่ยวเอกชน ผลการวิเคราะห์พบตัวขับเคลื่อนเชิงสาเหตุหลัก 5 ด้าน เรียงตามอิทธิพล ได้แก่ การสนับสนุนจากภาครัฐ การพัฒนากำลังแรงงาน การสร้างเครือข่ายระหว่างผู้ประกอบการ ความปลอดภัยของที่พัก และสื่อและการตีความทางวัฒนธรรม โดยการสนับสนุนจากภาครัฐมีค่าความเด่นและอิทธิพลสุทธิสูงสุด และส่งผลต่อผลลัพธ์เชิงเศรษฐกิจ สังคม วัฒนธรรม และสิ่งแวดล้อมตามลำดับเชิงสาเหตุ นอกจากนี้การวิเคราะห์แบบแยกกลุ่มผู้มีส่วนได้ส่วนเสียยังแสดงให้เห็นว่าปัจจัยขับเคลื่อนหลักมีความสอดคล้องกัน โดยมีความแตกต่างเชิงมุมมองระหว่างกลุ่มเพียงเล็กน้อย ข้อค้นพบดังกล่าวสามารถใช้เป็นแนวทางในการกำหนดนโยบายและมาตรการเชิงปฏิบัติ โดยมุ่งเน้นการเสริมสร้างบทบาทการสนับสนุนจากภาครัฐ การพัฒนาศักยภาพกำลังแรงงานในท้องถิ่น และการส่งเสริมความร่วมมือระหว่างผู้ประกอบการควบคู่กับการสื่อสารและตีความทางวัฒนธรรม เพื่อสนับสนุนการพัฒนาการท่องเที่ยวชนบทให้มีเสถียรภาพและยั่งยืนมากยิ่งขึ้น พร้อมทั้งชี้ให้เห็นว่าการประยุกต์ใช้ Grey-DEMATEL เป็นเครื่องมือสนับสนุนการตัดสินใจที่มีประสิทธิภาพและคุ้มค่าในบริบทที่ข้อมูลเชิงปริมาณมีจำกัด อย่างไรก็ตามข้อค้นพบยังมีข้อจำกัดจากขนาดกลุ่มตัวอย่างที่ค่อนข้างน้อยและลักษณะเฉพาะของพื้นที่ศึกษาในสองชุมชนของจังหวัดน่าน ซึ่งอาจจำกัดการประยุกต์ใช้กับแหล่งท่องเที่ยวชนบทประเภทอื่นในภูมิภาคอื่นของประเทศ

คำสำคัญ: การท่องเที่ยวอย่างยั่งยืน Grey-DEMATEL การพัฒนาชนบท การวิเคราะห์ผู้มีส่วนได้ส่วนเสีย

การอ้างอิงบทความ: พีรพงศ์ ภควณิช, ชนินาถ พลลาภ, ธีรนันทา ฤทธิ์มณี และ เจริญชัย โขมพัตราภรณ์, “การประยุกต์ใช้วิธี Grey-DEMATEL เพื่อระบุปัจจัยเชิงสาเหตุของการท่องเที่ยวอย่างยั่งยืน: กรณีศึกษา จังหวัดน่าน ประเทศไทย,” *วารสารวิชาการพระจอมเกล้าพระนครเหนือ*, ปีที่ 36, ฉบับที่ 2, หน้า 1–23, เม.ย.–มิ.ย. 2569, เลขที่บทความ 262-018156, doi: 10.14416/j.kmutnb.2026.04.002.

Research Article

A Grey-DEMATEL Approach to Identifying Causal Drivers of Sustainable Tourism: A Case Study of Nan Province, Thailand

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Abstract

Sustainable tourism has become an important policy agenda in emerging economies; however, many rural destinations remain vulnerable to uncontrolled growth, inefficient resource use, and income leakage. This study examines the causal factors influencing sustainable tourism development in two rapidly growing rural tourism communities in northern Thailand, using two villages in Nan Province as case studies. The analysis is based on the 13 sustainability criteria of the United Nations World Tourism Organization (UNWTO) and applies the Grey Decision-Making Trial and Evaluation Laboratory (Grey-DEMATEL) method to address uncertainty and diverse stakeholder perspectives. Expert judgments were transformed into grey numbers and synthesized into a total relation matrix. Data were collected through structured interviews with 13 stakeholders, including community leaders, government officials, and private tourism operators. The results identify five key causal drivers: government support, workforce development, inter-enterprise networking, accommodation safety, and cultural media and interpretation. Government support shows the highest prominence and net influence, affecting economic, social, cultural, and environmental sustainability outcomes. Stakeholder subgroup analysis reveals consistent core drivers, with only minor differences across groups. The findings offer practical implications for policy and planning, emphasizing the strengthening of government support, development of local workforce capacity, and promotion of collaboration and cultural interpretation to support more stable and sustainable rural tourism development. Nevertheless, the study is limited by the small sample size and the specific context of the two case-study communities, which may constrain the generalizability of the findings.

Keywords: Sustainable Tourism, Grey-DEMATEL, Rural Development, Stakeholder Analysis

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1. Introduction

Tourism has been identified as a significant contributor to sustainable regional development and economic transformation, particularly in rural areas with cultural and ecological value [1], [2]. In Thailand, domestic travel has increasingly shifted toward rural and secondary destinations, a trend driven by urban lifestyle changes, a desire for authentic cultural experiences, and the influence of social media-based travel culture [3], [4]. This tendency has become more pronounced in the post-pandemic period, as travelers increasingly seek less crowded, nature-based, and community-oriented experiences [5], [6]. While this surge has opened avenues for income diversification and rural revitalization, it has simultaneously introduced unintended socio-environmental consequences. These include the commodification of culture, degradation of natural resources, and inequitable distribution of tourism-derived benefits [7], [8]. Such dualities reveal the fragile balance between economic imperatives and long-term sustainability, necessitating integrated policy frameworks and grounded community engagement. Rural tourism, when thoughtfully executed, holds transformative potential beyond economic growth. It fosters sustainable livelihoods, strengthens local governance, and revitalizes indigenous knowledge systems [9]. Yet the sustainability of these gains remains contingent on how well decision-makers, stakeholders, and communities can navigate complex trade-offs across ecological, socio-cultural, and institutional domains. To this end, sustainable tourism is often framed within four interlinked pillars: economic viability, environmental integrity, sociocultural respect, and effective governance, aligned with international standards such as the Global Sustainable Tourism Council (GSTC) [10], [11] and the United Nations World Tourism Organization (UNWTO) [12]. The GSTC Destination Criteria outline a comprehensive framework across management, socio-economic equity, cultural integrity, and ecological stewardship, positioning them as a global baseline for destinations aspiring to sustainability.

While these global criteria provide a universal structure for sustainability assessment, their practical interpretation must be adapted to local realities. In the context of Thai rural tourism, issues such as cultural preservation, income seasonality, informal labor practices, environmental pressure, and limited stakeholder participation are closely aligned with the economic, socio-cultural, and environmental dimensions of the UNWTO framework. Therefore, the 13 UNWTO criteria were contextualized into indicators that reflect community-based tourism challenges in Thailand, enabling a more accurate evaluation of sustainability conditions grounded in local experience. However, practical application often diverges from theoretical ideals, particularly in emerging economies where governance structures are fragile, and tourism develops rapidly in ecologically and culturally sensitive regions. In India's Chilika Lake, for instance, a study revealed that while sustainable tourism frameworks advocate equitable livelihood enhancement and environmental preservation, fragmented authority and inadequate stakeholder engagement constrained effective implementation [13]. Similarly, in China hierarchical governance structures shaped the sustainability of cultural heritage destinations, but top-down control often limited local adaptability and community participation [14]. In Eastern Thailand, tourism-driven urbanization has intensified climate vulnerability and environmental degradation, yet governance responses have remained underdeveloped [15]. These cases highlight that while standardized frameworks offer crucial benchmarks, their success depends on adaptive, context-sensitive governance mechanisms co-produced with local stakeholders [16]–[18].

Multi-Criteria Decision-Making (MCDM) methods have emerged as useful tools to address such complexity, supporting structured deliberation across competing objectives. Techniques such as AHP, ANP, VIKOR, TOPSIS, and BWM have been applied in tourism planning to evaluate destination competitiveness, eco-resort site selection, food waste management, and sustainable transport frameworks [19]–[21]. However, conventional MCDM techniques often fall short in revealing the causal interdependencies among sustainability criteria. By contrast, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) framework provides a dynamic means of uncovering cause–effect relationships, making it particularly relevant for governance-sensitive domains like tourism [22]–[24].

Still, tourism sustainability assessments remain prone to uncertainty, stemming from fragmented data, heterogeneous stakeholder perspectives, and ambiguous policy environments. Hybrid approaches that integrate fuzzy logic or grey systems theory into MCDM have therefore gained prominence, as they enable analysis under conditions of incomplete or imprecise information. Fuzzy-DEMATEL, Grey-DEMATEL, and Spherical Fuzzy MCDM, for example, have been applied to domains such as geotourism risk management, renewable transportation planning, and rural biomass logistics [25]–[27]. Within tourism-specific applications, MCDM and DEMATEL have been used to assess eco-resort preferences, evaluate tour operator selection, and examine stakeholder perceptions in national park development [28]–[30]. Despite these advances, the application of Grey-DEMATEL in rural tourism governance remains nascent, particularly in Southeast Asia.

Grey-DEMATEL, which integrates grey numbers with causal mapping, has been successfully used in energy policy, supply chain design, and reverse logistics [31], [32]. Its suitability for rural tourism lies in its ability to incorporate diverse stakeholder perspectives without requiring complete datasets. By transforming uncertain judgments into structured causal networks, Grey-DEMATEL provides a flexible yet rigorous means of evaluating sustainability drivers under real-world conditions. Nevertheless, few studies have localized this approach within Southeast Asian tourism systems, leaving a gap in both methodology and contextual understanding [33]–[35]. The application of Grey-DEMATEL in tourism research remains very limited, particularly in rural sustainability contexts and within Southeast Asian destinations. Among existing MCDM approaches, most methods focus on ranking alternatives and assume consistent judgments. Grey-DEMATEL was selected in this study because it can model causal relationships under uncertainty and synthesize fragmented stakeholder opinions into a structured framework. This limited empirical use reflects a methodological gap, as stakeholder sustainable tourism are frequently uncertain, fragmented, and based on experiential knowledge rather than complete datasets. Addressing this gap requires an approach capable of integrating expert judgment under ambiguity. Accordingly, Grey-DEMATEL is adopted to contextualize its application in a real-world tourism setting and demonstrate how it can support causal analysis and decision-making in rural destinations.

Building on this methodological gap, the present study establishes a theoretical framework that links the UNWTO sustainability criteria with the Grey-DEMATEL procedure. The economic, socio-cultural, environmental, and governance dimensions of sustainability were contextualized for Thai rural tourism and translated into measurable indicators. Grey-DEMATEL was then employed to analyze their causal relationships under stakeholder uncertainty, providing a structured basis for decision-making in tourism governance.

To operationalize this framework, the method is applied to two rural villages in Nan Province, Thailand. Both sites represent rapidly emerging destinations where natural landscapes and cultural heritage have stimulated tourism growth while raising sustainability concerns. This study identifies key causal and effect factors shaping tourism development, prioritizes them under uncertainty, and generates tailored policy insights. The contributions are threefold 1) contextualizing Grey-DEMATEL for rural tourism governance under ambiguity 2) empirically mapping sustainability indicators against the UNWTO framework, and 3) providing actionable strategies for community-led, environmentally responsible, and economically inclusive tourism planning aligned with the United Nations Sustainable Development Goals.

Accordingly, this study is guided by three core research questions. First, it investigates the key causal and effect factors that shape sustainable tourism development in rural Thai destinations. Second, it examines how Grey-DEMATEL can be applied to manage uncertainty and reveal the interrelationships among sustainability indicators derived from the UNWTO framework. Third, it explores the policy implications that can support evidence-based, community-driven and sustainability-oriented tourism governance in emerging rural economies.

2. Materials and Methods

2.1 Study Area

Nan Province, located in northern Thailand, was selected as the study area because it represents one of the most rapidly growing rural tourism destinations in the region, yet remains underexamined in academic studies compared with well-known tourist hubs. Tourism development in Nan relies heavily on local communities and cultural resources, making it highly sensitive to sustainability challenges involving ecological pressure, market expansion, and cultural change. These characteristics make Nan an appropriate setting for examining how sustainability trade-offs emerge when tourism expands rapidly in rural areas.

Two rural villages in Nan Province were selected as case sites due to their distinctive yet comparable trajectories of tourism development. One village is a mountainous community renowned for rice terraces and scenic valleys. In recent years, the proliferation of homestays and cafés has boosted local income but also placed pressure on ecological carrying capacity and the cultural fabric of the community. The other village has pursued community-based tourism with an emphasis on ecological learning programs and cultural immersion. While this model promotes stronger local governance and resource stewardship, it still faces challenges in balancing market expansion with the safeguarding of traditional practices. Together, these two villages illustrate the broader tensions rural destinations encounter between economic diversification, cultural preservation, and environmental sustainability in emerging economies.

2.2 Factor Identification and Evaluation Design

The 13 influencing factors were adapted from internationally recognized sustainability frameworks, primarily the Global Sustainable Tourism Council (GSTC). Criteria for destinations and industry, as well as the UNWTO Indicators of Sustainable Development for Tourism Destinations. The factor list was contextualized for Nan Province and its socio-cultural setting, and subsequently validated through expert review before being analyzed using the Grey-DEMATEL method. These are listed in Table 1. A preliminary validation of the indicators was conducted through consultation with three academic experts with relevant experience in tourism research and MCDM methods. This collective expertise ensured that both the methodological structure and the local tourism context were adequately considered before applying the indicators in the stakeholder assessment.

Expert input was obtained from 13 purposively selected stakeholders, including 2 community leaders, 4 local government officials, and 7 private tourism operators. These participants play different but complementary roles within the local tourism system community engagement, governance functions, and operational service provision. Each participant had a minimum of five years of relevant experience, enabling them to contribute practical insights into sustainability challenges. Their judgments on the relationships between indicators were expressed using interval values under grey system constraints. Data were collected over a two-month period (April–May 2024) through semi-structured interviews. The interview guide consisted of general questions on current tourism challenges followed by pairwise comparisons of indicators for the Grey-DEMATEL input.

2.3 The Grey-DEMATEL Method

Grey systems theory was first introduced by Deng [36] as a methodological approach for analyzing problems in which only partial information is available. In this framework, a grey number represents a range of possible values, located conceptually between a white number which indicates complete and precise information and a black number, which reflects complete ignorance. Because most real-world decision-making problems, especially in socio-environmental domains, are characterized by uncertainty, ambiguity, and partial knowledge, grey systems theory provides a particularly valuable extension to conventional analytical models.

Table 1 UNWTO-based sustainability indicators used in the study

Factor		Description	Reference
A1	Workforce development	Training, capacity building, and skill development of tourism personnel to enhance service quality and professionalism in local communities.	GSTC Industry Criteria A4: Staff engagement & training [11]
A2	Government support	Policy formulation, funding programs, regulatory assistance, and infrastructure investment by national and local authorities to enable sustainable tourism growth.	GSTC Destination Criteria A: Effective destination management; A12 Safety & security [10]
A3	Networking among enterprises	Development of collaborative relationships among local tourism businesses, such as joint marketing, shared resources, information exchange, and cooperative initiatives, to enhance competitiveness, resilience, and sustainable practices within the destination.	GSTC Industry Criteria A10: Destination engagement [11]; Indicators of Sustainable Development for Tourism Destinations (UNWTO, 2004)
A4	Local income distribution and employment	Opportunities created by tourism for local residents in terms of fair jobs and equitable income-sharing to enhance economic inclusion.	GSTC Industry Criteria B2: Local employment [11]; Indicators of Sustainable Development for Tourism Destinations (UNWTO, 2004)
A5	Use of local raw materials and products	Promotion of local agricultural, artisanal, and manufactured goods in tourism supply chains to stimulate local economies.	GSTC Industry Criteria B3: Local purchasing; B4: Support for local entrepreneurs [11]
A6	Fair wages and working hours	Ensuring tourism employment adheres to decent labor standards, including appropriate compensation, working conditions, and worker protections.	GSTC Industry Criteria B7: Decent work [11]
A7	Safety in accommodation	Implementation of health and safety protocols in tourism lodging to protect guests and workers from physical and environmental hazards.	GSTC Destination Criteria A12 Safety & security [10]
A8	Cultural media and interpretation	Availability and quality of interpretive materials, signage, and digital media to communicate cultural significance to tourists.	GSTC Industry Criteria A9: Information & interpretation [11]
A9	Cultural preservation	Community-led initiatives to protect, restore, and promote intangible and tangible cultural assets.	GSTC Industry Criteria C2: Protecting cultural heritage; C3: Presenting culture & heritage [11]
A10	Water and wastewater management	Efficient use of water resources and safe disposal or reuse of wastewater to minimize environmental impact.	GSTC Destination Criteria D6–D9: Water use, water security, water quality, wastewater management [10]
A11	Waste management	Reduction, sorting, and eco-friendly treatment of solid waste; use of biodegradable or recyclable products.	GSTC Destination Criteria D2.4 Solid waste; D2.5 Harmful substances [10]
A12	Light and noise control	Strategies to reduce artificial lighting and sound disturbances from tourism operations, protecting both residents and ecosystems.	GSTC Destination Criteria D12: Minimize pollution (noise & light) [10]; GSTC Industry D2.6: Minimize pollution [11]
A13	Energy conservation	Use of renewable energy, energy-efficient systems, and awareness campaigns to minimize tourism's carbon footprint.	GSTC Destination Criteria D5: Energy conservation[10]; GSTC Industry D1.3: Energy conservation [11]

To account for this uncertainty, grey numbers are commonly integrated with the Decision-Making Trial and Evaluation Laboratory method, forming what is known as the Grey-DEMATEL technique. This hybrid approach enables more accurate modeling of expert judgments by capturing the ambiguity present in linguistic assessments. A critical step in applying the Grey-DEMATEL method is the transformation of grey numbers into crisp values that can be used in quantitative analysis. Each expert evaluation is initially represented as a grey number, denoted by $\otimes G = (\underline{\otimes} G, \overline{\otimes} G$ where $\underline{\otimes} G$ and $\overline{\otimes} G$ represent the lower and upper bounds of the interval. This interval must then be converted into a single value to facilitate matrix computations. The conversion process, known as the Converting Fuzzy Values into Crisp Scores (CFCS) method, consists of three main steps.

First, each grey value is normalized over all experts using Equations (1) and (2).

$$\underline{\otimes}\bar{G} = \frac{\underline{\otimes}G - \min \underline{\otimes}G}{\Delta \max, \min} \quad (1)$$

$$\bar{\otimes}\bar{G} = \frac{\bar{\otimes}G - \min \bar{\otimes}G}{\Delta \max, \min} \quad (2)$$

where $\Delta\max, \min = \max \overline{\otimes} G - \min \underline{\otimes} G$

Then, a total normalized crisp value Y is computed using Equation (3).

$$Y = \frac{\bar{\otimes}\bar{G}(1-\bar{\otimes}\,\bar{G}) + (\bar{\otimes}G \times \bar{\otimes}G)}{1-\underline{\otimes}\bar{G}+\bar{\otimes}\bar{G}} \quad (3)$$

Finally, the final crisp values are calculated using Equation (4).

$$Z = \min \underline{\otimes} G + (Y \cdot \Delta \max, \min) \quad (4)$$

This transformation ensures that the ambiguity present in the grey assessments is faithfully retained while also enabling rigorous mathematical modeling. As such, Grey-DEMATEL supported by the CFCS conversion is ideally suited to complex decision-making scenarios that require the synthesis of expert opinion under uncertainty.

Table 2 presents the linguistic terms and their corresponding grey number intervals used to capture expert judgments. Each linguistic expression of influence, ranging from "No Influence" to "Very High Influence," is represented by a grey interval value that reflects the inherent uncertainty and vagueness in human assessments. For instance, "Low to Moderate Influence" corresponds to the grey interval [0.2, 0.4], indicating that the perceived influence can vary within this range.

Table 2 Linguistic terms and corresponding grey values for expert judgments

Normal Value	Linguistic	Grey Number
0	No Influence	[0, 0]
1	Very Low Influence	[0, 0.2]
2	Low to Moderate Influence	[0.2, 0.4]
3	Moderate to High Influence	[0.4, 0.6]
4	High Influence	[0.6, 0.8]
5	Very High Influence	[0.8, 1.0]

By transforming qualitative judgments into quantitative grey values, the method ensures that subjective evaluations are systematically incorporated into the DEMATEL analysis. Subsequently, the pairwise evaluation from the first expert is presented in Table 1A. These assessments from all experts were then translated into grey numbers for computational modeling. Subsequently, the analysis proceeds according to the following grey pairwise DEMATEL steps:

Step 1: Construction of grey pairwise direct-relation matrix

Let H denote the number of respondents, experts, or decision-makers, and n denote the number of factors under consideration. Each respondent evaluates whether factor i influences factor j, where i = 1, 2, ...,n and j = 1, 2, ...,n. The grey pairwise comparison is represented as x_{ij}^h, denoting the assessment of respondent h where h = 1,2,...,H The scale ranges from 0 to 5 as shown in Table 2, with x_{ij}^h = 0. The average grey pairwise assessments are aggregated into the initial direct-relation matrix is calculated by Equation (5).

$$A = [a_{ij}]_{n\times n} \tag{5}$$

where

$$a_{ij} = \frac{1}{H}\sum_{h=1}^{H} x_{ij}^h \tag{6}$$

By applying Equation (6), the pairwise evaluations from all respondents were aggregated into the overall direct-relation matrix. The resulting crisp direct-relation matrix is presented in Table 2A.

Step 2: Normalization of grey pairwise matrix

The normalization coefficient μ is defined as the maximum between the largest row sum and the largest column sum of A, as given in Equation (7).

$$\mu = \max\left(\max_{1\le i\le n} \sum_{j=1}^{n} a_{ij}, \max_{1\le j\le n} \sum_{i=1}^{n} a_{ij} \right) \tag{7}$$

The normalized grey pairwise direct-relation matrix D is then obtained using Equation (8).

$$D = A/\mu \tag{8}$$

This ensures that all entries in D fall within the range [0, 1]. The resulting normalized direct-relation matrix is presented in Table 3A.

Step 3: Calculation of the grey pairwise total-relation matrix

To capture both direct and indirect influences, the total-relation matrix T is derived using Equation (9).

$$T = D + D^2 + D^3 + \ldots = D(I - D)^{-1} \tag{9}$$

where I is the identity matrix of size $n\times n$. The series converges since $\lim_{k\to\infty} D^k = [0]_{n\times n}$ [37].

The grey pairwise total-relation matrix is shown as Table 4A.

Step 4: Derivation of grey pairwise prominence and net effects

Let t_{ij} denote an element of T. The total influence dispatched by factor i and the total influence received by factor j are given by Equations (10) and (11), respectively.

$$c_i = \sum_{j=1}^{n} t_{ij},\ i = 1, 2, \ldots, n \tag{10}$$

$$r_j = \sum_{i=1}^{n} t_{ij},\ j = 1, 2, \ldots, n \tag{11}$$

Step 5: Grey pairwise influence-relation diagram

The Influence-Relation Diagram is constructed by plotting each factor in a two-dimensional plane. The horizontal axis represents $c_i + r_i$, the total prominence, while the vertical axis represents $c_i - r_i$, the net effect. This visualization clearly distinguishes cause from receiver factors. Additionally, the strength of grey pairwise relations between factors is captured in the net influence matrix $N = Net_{ij}$, where:

$$Net_{ij} = t_{ij} - t_{ji} \tag{12}$$

Equation (12) captures the asymmetric grey pairwise influence between factor i and factor j. For the construction of the influence–relation diagram and causal map, a threshold value was then applied to filter out negligible relationships in the total relation matrix. Consistent with common DEMATEL applications, the average of all entries in the matrix was selected as the threshold.

3. Results and Discussions

3.1 Consistency Validation of Expert Judgments

Prior to conducting the Grey-DEMATEL analysis, a consistency validation of expert judgments was performed to ensure the reliability of the direct-relation matrices. Based on the consistency validation concept of Bafail and Alamoudi [38], each expert's direct-relation matrix was compared with the aggregated matrix of the remaining experts.

A minimum correlation threshold of 0.30 was employed as the criterion for acceptable consistency. All 13 experts demonstrated corrected item–total correlations above this threshold, indicating that their judgments were consistent with the overall group pattern.

3.2 Prominence and Net Effect Scores

Table 3 reports the prominence ($c_i + r_i$) and net effect ($c_i - r_i$) of each factor. Prominence reflects the overall importance of a factor in the system, while net effect distinguishes between cause factors (positive value) and effect factors (negative value).

Table 3 Prominence and net effect scores

Factor	Prominence $c_i + r_i$	Net Effect $c_i - r_i$	Group
A2	5.674	0.649	Cause
A1	5.628	0.73	Cause
A3	5.120	0.217	Cause
A7	4.535	0.185	Cause
A8	4.439	0.496	Cause
A11	4.499	–0.035	Effect
A9	4.251	–0.087	Effect
A4	4.244	–0.328	Effect
A5	4.228	–0.227	Effect
A13	4.135	–0.25	Effect
A10	4.061	–0.491	Effect
A12	3.86	–0.245	Effect
A6	3.737	–0.614	Effect

The analysis shows that five factors: government support (A2), workforce development (A1), networking among enterprises (A3), safety in accommodation (A7), and cultural media and interpretation (A8) belong to the causal group, while the remaining eight indicators form the effect group. Among these, government support (A2) exhibited the highest prominence and strongest positive net effect, underscoring its systemic role. Workforce development (A1) and networking among enterprises (A3) followed closely, indicating that human capital and collaborative structures are key enablers of sustainability. Safety in accommodation (A7) and cultural media and interpretation (A8) also displayed positive net effects, demonstrating their importance as operational levers. Waste management (A11) appears in the

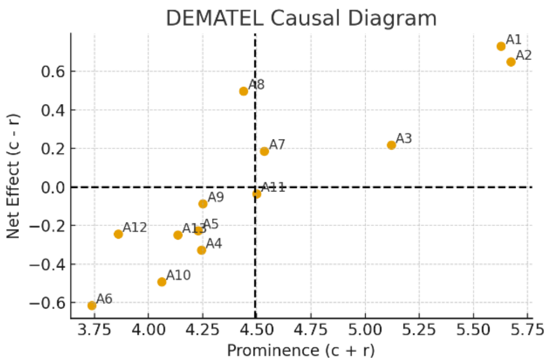

Figure 1 Influence–Relation Diagram (IRD) of sustainability factors.

effect group and shows a slight negative net effect, indicating its dependence on upstream support. Conversely, fair wages and working hours (A6) recorded the most negative net effect, while water and wastewater management (A10) also showed a strongly negative net effect, emphasizing their dependence on upstream support.

3.3 Influence–Relation Diagram

Figure 1 plots prominence against net effect, dividing the indicators into causal and effect groups. The five causal drivers are positioned in the upper half-plane, while effect factors appear below the horizontal axis.

The Influence–Relation Diagram demonstrates that government support (A2) exhibits the highest prominence and the strongest positive net effect, confirming its central role. Workforce development (A1) and networking (A3) also cluster with high prominence, reflecting their joint contribution to human and social capital. Operational standards, including safety (A7) and cultural media and interpretation (A8), further extend the causal set, while waste management (A11) appears among the effect factors, indicating that these practical levers are capable of driving systemic improvements. Conversely, equity-related outcomes such as wages (A6) and income distribution (A4), as well as environmental management practices (A10, A12, A13), remain largely dependent on these upstream interventions.

The central role of government support identified in the influence–relation diagram is consistent with evidence from other sustainable tourism contexts. Studies of rural and community based tourism often report that public sector actors provide the policy framework, financial incentives and coordination mechanisms that enable local initiatives to succeed. For example, an empirical study of Tihingan village in Bali [39] found that active government involvement, together with community participation, played a significant role in advancing sustainable tourism development at the village level. In Thailand, both the national criteria for community based tourism and case studies of CBT villages [40] highlight the importance of state agencies in setting standards and in providing funding and administrative support for local initiatives. national guidelines issued by the National Tourism Policy Committee [41] likewise highlight that effective governance and tourism specific policy instruments are key conditions for leveraging tourism as a driver of the Sustainable Development Goals. Taken together, these findings indicate that the strong driving power of government support observed in this study is not an isolated result but rather reflects a broader pattern in the literature on rural and community based tourism.

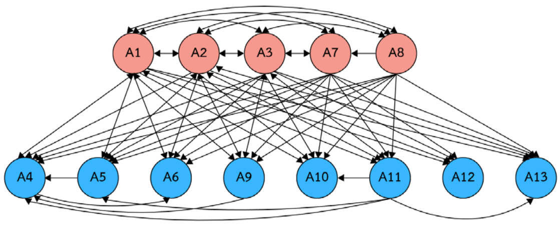

Figure 2 Causal Relationship Map of sustainability factors.

3.4 Causal Relationship Map

To visualize the structural pathways, Figure 2 presents a directed network map. Nodes in red indicate causal drivers, while nodes in blue represent effect factors. Arrows display the direction of influence.

In order to retain only meaningful causal pathways and avoid excessive network complexity, a threshold value was required to filter out very weak interactions. In this study, the threshold was determined using the mean value of all entries in the total-relation matrix, which reflects the general interaction level among factors. Only relationships stronger than this average were considered to carry sufficient influence to be visualized, while weaker links were omitted to preserve the readability of the final causal map.

In Figure 2, the calculated threshold was 0.173, meaning that only inter-factor relationships with values above this level were retained as directional links. Nodes in the upper and lower levels represent cause and effect factors, respectively, based on the prominence–relation results, while the direction of each link is determined directly from the total-relation matrix. Among these, Government support (A2) remains positioned as the central hub, engaging in mutual and reciprocal relationships with workforce development (A1), enterprise networking (A3), safety in accommodation (A7), and cultural media and interpretation (A8), as evidenced by the bidirectional links in the upper level of the diagram. In turn, these drivers propagate influence further downstream to the effect factors. For example, workforce development (A1) enhances labor standards and cultural dissemination; networking (A3) supports cultural preservation and water management; cultural media (A8) promotes both heritage protection and local product use; and safety in accommodation (A7) links directly to waste, water, and pollution control. Crucially, as the central hub, Government support (A2) exerts a broad impact across all downstream factors, reinforcing the entire framework. The map confirms that governance, capacity building, and operational standards function as interconnected levers that activate broader sustainability outcomes.

A sensitivity test was conducted by adjusting the threshold value by ±10% from the original cut-off (0.173) to verify the stability of the causal relationships. As a result, the number of visualized links in the causal map varied from approximately 50 to 110, depending on the selected threshold level. Lowering the threshold retained more links, while increasing it led to a sparser network; however, the five causal factors (A1, A2, A3, A7, A8) remained identical across all test scenarios, and government support (A2) consistently emerged as the most influential factor. These findings indicate that although the density of connections changes with the threshold level, the essential causal structure of the model remains stable. Therefore, the results are not overly sensitive to parameter selection, demonstrating that the key drivers identified in the model are robust under reasonable variations of the threshold.

3.5 Detailed Analysis of Key Drivers

Government support (A2), as the factor with the highest prominence and strongest net effect, government support is the cornerstone of rural tourism sustainability. It provides institutional capacity, regulatory enforcement, and infrastructure planning that amplify the influence of other drivers. Beyond formal governance, accessibility and visibility emerged as crucial issues. Limited public transport and high travel costs constrain inflows, reducing the impact of community initiatives. Policy measures such as subsidizing routes, coordinating shuttle services, and implementing sustainable tourism campaigns could strengthen the role of government support as a systemic enabler.

Workforce development (A1), training and capacity building significantly influence service quality, cultural dissemination, and equity outcomes. Workforce development functions not only as a social indicator but also as a causal driver of resilience. Better trained personnel internalize labor and environmental standards, creating positive spillovers that reinforce compliance and visitor trust.

Networking among enterprises (A3), enterprise networks operate as structural bridges, transmitting influence toward cultural preservation and water management. By reducing information asymmetries, harmonizing practices, and enabling collaborative marketing, networking converts isolated initiatives into systemic improvements.

Operational standards, including safety in accommodation (A7), and cultural media and interpretation (A8), show positive yet modest net effects. They function as practical levers that support system-wide improvements rather than dominant drivers. Safety in accommodation institutionalizes daily routines that ensure labor and environmental standards. Cultural media and interpretation combines high prominence with a clearly positive net tendency, highlighting its role in mobilizing community participation and stabilizing identity-affirming practices.

Dependent outcomes, Indicators such as income distribution (A4), use of local products (A5), cultural preservation (A9), energy conservation (A13), water and wastewater management (A10), light and noise control (A12), fair wages and working hours (A6), and waste management (A11) were categorized as effect factors. Their negative or modest net effects highlight their dependence on prior activation of governance, training, collaboration, and operational standards. The particularly strong negative tendencies for A6 and A10 suggest that equity and ecological outcomes are not self-starting but rely on systemic support, while A11 connects these outcomes to day-to-day environmental practices that underpin water and energy stewardship.

Building on the above discussion of the key drivers, Table 3 further clarifies their relative strength. As summarized in Table 3, government support (A2) exhibits the largest prominence and a strong positive net effect (5.674, 0.649), confirming its role as a primary driver in the system. Workforce development (A1) ranks second in prominence but attains the highest net effect (5.628, 0.730), followed by networking among enterprises (A3) (5.120, 0.217). Operational standards such as safety in accommodation (A7) and cultural media and interpretation (A8) also belong to the cause group (4.535, 0.185 and 4.439, 0.496, respectively), indicating that both basic safety and meaningful interpretation act as important levers that transmit the influence of governance and human-capital factors. By contrast, fair wages and working hours (A6) record the most negative net effect and the lowest prominence (3.737, –0.614), identifying it as a strongly dependent outcome. Water and wastewater management (A10) and income distribution (A4) also show relatively large negative net effect scores (4.061, –0.491 and 4.244, –0.328, respectively). The remaining effect indicators, namely use of local products (A5), energy conservation (A13), light and noise control (A12), cultural preservation (A9), and waste management (A11), cluster around medium to small negative net effect values (4.228, –0.227; 4.135, –0.250; 3.860, –0.245; 4.251, –0.087; and 4.499, –0.035), with waste management lying very close to the boundary between the cause and effect groups. From a practical perspective, this concentration of explanatory power in a small set of high-impact drivers (A1–A3, A7, A8), together with near-zero net effect values for some indicators (for example, A11), suggests that future applications could experiment with a more compact indicator set to reduce data collection and analysis costs while preserving the essential causal structure identified in this study.

3.6 Interpretation and Implications

The layered causal structure identified here demonstrates that governance, human capital development, enterprise collaboration, and operational standards act as upstream drivers. These activate downstream outcomes including equity, cultural preservation, and ecological management. Compared to conventional multi-criteria decision-making techniques such as AHP or TOPSIS, which primarily rank alternatives, Grey-DEMATEL offers methodological advantages by unveiling causal relationships. It captures how interventions in one domain cascade into others, enabling decision makers to target systemic leverage points rather than isolated priorities.

For policymakers, the findings imply that sustainability strategies should prioritize strengthening government capacity, workforce training, enterprise networks, and operational standards. These upstream levers generate cascading benefits across the broader system, ultimately enhancing cultural preservation, equity, and environmental stewardship. For practitioners, the study suggests a sequenced strategy: first ensure governance coherence, supportive infrastructure, and effective promotion to enhance destination accessibility and visibility, then expand workforce development and networks, followed by embedding sustainability through safety protocols, cultural dissemination, and waste routines. From a methodological perspective, the results highlight that Grey-DEMATEL is particularly well suited for participatory rural contexts where uncertainty and fragmented judgments prevail.

3.7 Subgroup Analysis by Stakeholder Group

To examine whether the causal structure identified in the overall Grey-DEMATEL model is robust across different stakeholder perspectives, the data were re-analyzed separately for three subgroups: community leaders, government officials, and private tourism operators. In the overall model, five factors (A2, A1, A3, A7, A8) are classified as causes with high prominence, while the remaining factors (A11, A9, A4, A5, A13, A10, A12, A6) act mainly as effects, with A11 located very close to the causal–effect boundary, as summarized in Table 3. This configuration indicates that A1, A2, A3, A7, and A8 play a leading role in driving the sustainability dynamics of tourism in the study area.

Across all three subgroups, as reported in Tables 4–6, the core structure of the model remains largely stable. In every group, A2 and A1 consistently appear as high-prominence causes, confirming their role as central drivers of the system rather than group-specific concerns. Similarly, A8 is classified as a causal factor in all three subgroups, and A3 appears on the causal side for community leaders and government officials, while private tourism operators perceive it slightly more as a receiving (effect) factor. These patterns echo the full-sample results, suggesting that different stakeholders broadly agree on which factors constitute the main "levers" of the system, even if they differ in the way they experience specific downstream consequences.

Among community leaders, as detailed in Table 4, the causal set comprises A2, A1, A3, A8, A13, and A11. Several factors that are causes in the overall model, such as A7, move to the effect side in this group, whereas energy conservation (A13) and waste management (A11) shift from effects in the overall model to causes. This suggests that community leaders view these environmental management indicators as structural drivers that must be addressed upstream, while they interpret outcomes associated with A7 more as consequences of other interventions and conditions.

Table 4 Prominence and net effect scores for community leaders

Factor	Prominence $c_i + r_i$	Net Effect $c_i - r_i$	Group
A2	5.232	0.370	Cause
A1	4.446	0.814	Cause
A3	4.261	1.208	Cause
A8	4.056	0.851	Cause
A13	3.842	0.387	Cause
A11	3.899	0.484	Cause
A4	3.891	–1.013	Effect
A7	3.854	–0.343	Effect
A5	3.820	–0.278	Effect
A9	3.406	–0.376	Effect
A10	3.047	–1.019	Effect
A6	2.937	–0.875	Effect
A12	2.840	–0.210	Effect

For government officials, as shown in Table 5, the causal set is somewhat broader, comprising A1, A3, A2, A9, A13, A5, and A8. This subgroup therefore promotes several factors (A5, A9, A13) that are treated as effects in the overall model into the causal category, while A7 and A11 are classified as effects. This indicates that government officials perceive social and experiential outcomes (captured by these factors) as consequences of policy and structural decisions rather than as independent levers.

For private tourism operators, as presented in Table 6, the pattern remains broadly consistent with the overall model regarding A1, A2, A7, and A8, which all appear as causes with high prominence. However, private tourism operators additionally classify A11 as a causal factor, whereas in the overall model A11 lies just on the effect side of zero. Conversely, A3, which is a cause in the full sample and in the community leader and government

Table 5 Prominence and net effect scores for government officials

Factor	Prominence $c_i + r_i$	Net Effect $c_i - r_i$	Group
A1	6.402	0.583	Cause
A3	6.046	0.208	Cause
A2	5.917	0.258	Cause
A9	5.199	0.330	Cause
A13	4.986	0.005	Cause
A5	4.963	0.272	Cause
A8	4.816	0.542	Cause
A11	5.337	–0.332	Effect
A7	4.755	–0.088	Effect
A4	4.556	–0.273	Effect
A12	4.537	–0.395	Effect
A10	4.489	–0.633	Effect
A6	4.393	–0.476	Effect

Table 6 Prominence and net effect scores for private tourism operators

Factor	Prominence $c_i + r_i$	Net Effect $c_i - r_i$	Group
A2	5.334	0.737	Cause
A1	5.310	0.642	Cause
A7	4.362	0.374	Cause
A8	4.237	0.370	Cause
A11	4.154	0.140	Cause
A3	4.515	–0.298	Effect
A4	4.118	–0.112	Effect
A10	4.081	–0.135	Effect
A9	3.912	–0.113	Effect
A5	3.879	–0.450	Effect
A13	3.706	–0.445	Effect
A12	3.635	–0.209	Effect
A6	3.605	–0.502	Effect

subgroups, is perceived by private tourism operators as slightly more of an effect. These shifts indicate that private tourism operators tend to emphasize operational and experiential aspects (represented by A7, A8, A11) as levers they can actively manipulate, while viewing more structural or contextual factors (such as A3) as conditions they must respond to rather than control.

Taken together, these subgroup results, drawn from Tables 4–6, do not contradict the overall Grey-DEMATEL model; instead, they reinforce its main structure while adding stakeholder-specific nuance. The fact that A1, A2, and A8 are consistently identified as influential causes across all groups, and that A3 behaves as a cause in two out of three subgroups, supports the robustness of the central causal backbone of the model. Differences in the classification of mid-range factors such as A5, A7, A9, A11, and A13 can be interpreted as reflecting each group's operational role and sphere of control rather than fundamental disagreement about the system. Community leaders tend to treat certain institutional or environmental variables (e.g. A13, A11) as levers; government officials view a wider set of policy-relevant variables (e.g. A5, A9, A13) as drivers while monitoring social and experiential indicators (e.g. A7, A11) as downstream outcomes; and private tourism operators emphasize factors they can adjust directly in their businesses (e.g. A7, A8, A11).

These findings confirm that the key drivers identified in the overall model are robust across both parameter changes (threshold sensitivity) and subgroup perspectives, while at the same time suggesting that implementation strategies should be differentiated by stakeholder group.

4. Conclusion

This study applied the Grey-DEMATEL method to link UNWTO based sustainability indicators with expert judgments from community leaders, government officials, and private tourism operators in two rural villages in Nan Province, Thailand. The results highlight a small set of key causal drivers, particularly government support, workforce development, networking among enterprises, safety in accommodation, and cultural media and interpretation, which strongly influence income distribution, labor conditions, cultural preservation, and environmental management.

The method yields concrete and clearly measurable outputs, including prominence and net effect scores, cause and effect grouping of the 13 indicators, and a stable causal map that remains consistent across sensitivity tests. These features allow local authorities and communities to prioritize a limited number of leverage points while still affecting a wide range of sustainability outcomes. Given that the analysis was conducted with a relatively small expert panel and modest data requirements, the study demonstrates that Grey-DEMATEL can serve as a cost-effective decision support tool for guiding rural tourism toward greater stability and sustainability. The subgroup analysis further confirms that the core causal drivers remain consistent across stakeholder groups, with only minor differences in emphasis.

Limitations and Future Research

This study has some limitations. The expert panel was relatively small and drawn from only two villages in a single province, and the analysis focused on 13 indicators that did not cover aspects such as climate risks, digital platforms, or detailed visitor behavior. In addition, the Grey-DEMATEL model relies on expert judgments rather than longitudinal performance data. Future research could compare the results or insights obtained from Grey-DEMATEL with those from other methods, such as fuzzy-DEMATEL, AHP, BWM, or structural equation modelling. Additionally, extending the framework to other rural destinations and incorporating time-based data would help examine how changes in driver indicators translate into observable sustainability outcomes. Integrating the causal results with spatial planning tools or optimization models would also support more detailed scenario analysis for rural tourism policy and investment.

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Conflicts of Interest

The authors declare no conflict of interest.

Appendix A

This appendix presents the intermediate matrices used in the Grey-DEMATEL analysis. Table 1A shows an example of the pairwise direct-relation matrix from one expert, Tables 2A and 3A report the aggregated crisp and normalized direct-relation matrices, and Table 4A summarizes the resulting total-relation matrix.

Table 1A The example of the pairwise direct-relation matrix from expert 1

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A1	0	2	4	5	5	4	3	4	4	5	5	4	4
A2	4	0	4	3	4	4	4	4	4	4	4	4	3
A3	4	4	0	4	4	3	4	4	4	4	5	4	5
A4	4	3	4	0	4	4	4	4	4	4	3	4	4
A5	4	3	3	3	0	4	3	3	3	4	4	3	4
A6	4	3	3	3	3	0	3	3	3	3	3	3	3
A7	3	3	3	3	3	3	0	3	3	3	3	3	3
A8	4	4	4	4	3	3	4	0	4	4	4	4	4
A9	3	3	3	3	3	3	3	3	0	3	3	3	3
A10	3	3	3	3	3	3	3	3	3	0	3	3	3
A11	3	3	3	3	3	3	3	3	3	3	0	3	3
A12	3	3	3	3	3	3	3	3	3	3	3	0	3
A13	4	3	3	3	3	3	3	3	3	3	3	3	0

Table 2A The overall crisp direct-relation matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A1	0.000	0.965	1.117	0.965	0.951	1.016	0.965	1.016	0.990	0.965	0.940	0.850	0.889
A2	1.044	0.000	1.070	0.892	0.828	0.968	0.968	0.994	0.968	0.917	1.019	0.994	0.867
A3	0.732	0.783	0.000	0.783	0.783	0.732	0.783	0.758	0.884	0.934	0.909	0.783	0.833
A4	0.793	0.555	0.657	0.000	0.612	0.861	0.578	0.511	0.578	0.488	0.477	0.410	0.389
A5	0.586	0.726	0.656	0.787	0.000	0.680	0.492	0.527	0.633	0.551	0.446	0.458	0.551
A6	0.712	0.552	0.570	0.675	0.460	0.000	0.478	0.270	0.324	0.377	0.324	0.324	0.298
A7	0.639	0.800	0.626	0.664	0.626	0.639	0.000	0.652	0.615	0.751	0.874	0.849	0.751
A8	0.819	0.867	0.796	0.676	0.914	0.593	0.712	0.000	0.938	0.570	0.712	0.593	0.558
A9	0.748	0.836	0.748	0.814	0.638	0.549	0.570	0.626	0.000	0.516	0.440	0.429	0.333
A10	0.566	0.669	0.566	0.364	0.420	0.398	0.578	0.386	0.364	0.000	0.681	0.464	0.773
A11	0.815	0.861	0.770	0.680	0.735	0.488	0.599	0.399	0.466	0.780	0.000	0.477	0.793
A12	0.644	0.693	0.528	0.469	0.400	0.457	0.574	0.458	0.458	0.435	0.435	0.000	0.750
A13	0.690	0.747	0.659	0.374	0.569	0.320	0.417	0.332	0.482	0.791	0.791	0.624	0.000

Table 3A The normalized direct-relation matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A1	0.000	0.083	0.096	0.083	0.082	0.087	0.083	0.087	0.085	0.083	0.081	0.073	0.076
A2	0.090	0.000	0.092	0.077	0.071	0.083	0.083	0.085	0.083	0.079	0.088	0.085	0.075
A3	0.063	0.067	0.000	0.067	0.067	0.063	0.067	0.065	0.076	0.080	0.078	0.067	0.072
A4	0.068	0.048	0.057	0.000	0.053	0.074	0.050	0.044	0.050	0.042	0.041	0.035	0.033
A5	0.050	0.062	0.056	0.068	0.000	0.058	0.042	0.045	0.054	0.047	0.038	0.039	0.047
A6	0.061	0.047	0.049	0.058	0.040	0.000	0.041	0.023	0.028	0.032	0.028	0.028	0.026
A7	0.055	0.069	0.054	0.057	0.054	0.055	0.000	0.056	0.053	0.065	0.075	0.073	0.065
A8	0.070	0.075	0.068	0.058	0.079	0.051	0.061	0.000	0.081	0.049	0.061	0.051	0.048
A9	0.064	0.072	0.064	0.070	0.055	0.047	0.049	0.054	0.000	0.044	0.038	0.037	0.029
A10	0.049	0.057	0.049	0.031	0.036	0.034	0.050	0.033	0.031	0.000	0.059	0.040	0.066
A11	0.070	0.074	0.066	0.058	0.063	0.042	0.051	0.034	0.040	0.067	0.000	0.041	0.068
A12	0.055	0.060	0.045	0.040	0.034	0.039	0.049	0.039	0.039	0.037	0.037	0.000	0.065
A13	0.059	0.064	0.057	0.032	0.049	0.028	0.036	0.029	0.041	0.068	0.068	0.054	0.000

Table 4A The total-relation matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A1	0.189	0.271	0.277	0.253	0.248	0.249	0.245	0.233	0.246	0.252	0.250	0.226	0.240
A2	0.271	0.193	0.273	0.247	0.238	0.244	0.244	0.231	0.244	0.248	0.255	0.237	0.238
A3	0.218	0.226	0.159	0.211	0.207	0.199	0.204	0.188	0.211	0.222	0.219	0.196	0.209
A4	0.180	0.165	0.170	0.110	0.156	0.174	0.151	0.136	0.151	0.148	0.147	0.132	0.136
A5	0.167	0.180	0.173	0.175	0.108	0.162	0.147	0.140	0.157	0.156	0.147	0.138	0.151
A6	0.151	0.140	0.140	0.143	0.123	0.084	0.123	0.099	0.111	0.119	0.114	0.106	0.109
A7	0.193	0.208	0.192	0.184	0.178	0.176	0.125	0.166	0.174	0.191	0.200	0.186	0.187
A8	0.213	0.220	0.212	0.193	0.208	0.180	0.189	0.120	0.206	0.184	0.194	0.172	0.177
A9	0.185	0.194	0.186	0.183	0.166	0.157	0.158	0.153	0.111	0.158	0.152	0.140	0.139
A10	0.153	0.164	0.153	0.129	0.132	0.127	0.142	0.118	0.125	0.100	0.155	0.129	0.159
A11	0.198	0.205	0.196	0.179	0.181	0.159	0.167	0.141	0.157	0.188	0.124	0.152	0.184
A12	0.160	0.167	0.152	0.139	0.132	0.134	0.143	0.125	0.134	0.137	0.137	0.091	0.158
A13	0.171	0.179	0.170	0.139	0.152	0.130	0.138	0.122	0.142	0.173	0.172	0.149	0.105

References

[1] L. Yanan, M. A. Ismail, and A. Aminuddin, "How has rural tourism influenced the sustainable development of traditional villages? A systematic literature review," *Heliyon*, vol. 10, no. 4, 2024, Art. no. e25627, doi: 10.1016/j.heliyon.2024.e25627.

[2] V. Kumar, T. Agarwala, and S. Kumar, "Rural tourism as a driver of sustainable development: A systematic review and future research agenda," *Tourism Review*, vol. 81, no. 3, pp. 1101–1120, 2026, doi: 10.1108/TR-03-2024-0172.

[3] V. T. King and M. J. G. Parnwell, "World heritage sites and domestic tourism in Thailand: Social change and management implications," *South East Asia Research*, vol. 19, no. 3, pp. 381–420, 2011, doi: 10.5367/sear.2011.0055.

[4] N. Kontogeorgopoulos and A. Churyen, "Homestay tourism and the commercialization of the rural home in Thailand," *Asia Pacific Journal of Tourism Research*, vol. 20, no. 1, pp. 29–50, 2015, doi: 10.1080/10941665.2013.852119.

[5] C. Chansuk, T. Arreeras, and C. Chiangboon, "Using factor analyses to understand the post-pandemic travel behavior in domestic tourism through a questionnaire survey," *Journal of Hospitality and Tourism Insights*, vol. 16, 2022, Art. no. 100691, doi: 10.1016/j.trip.2022.100691.

[6] S. Laparojkit and M. Suttipun, "The causal factors influencing repurchase intentions of local tourists in Thailand during COVID-19 crisis," *Journal of Tourism Futures*, vol. 8, no. 3, pp. 309–324, 2022, doi: 10.1108/JTF-05-2021-0122.

[7] X. Fang, Y. Wu, L. Xia, Z. Wang, W. Ni, Y. Zhang, and Y. Liu, "Vulnerability analysis of socio-ecological systems on small islands from the perspective of fisheries and tourism: A case study of Zhoushan Gouqi Island," *Journal of Cleaner Production*, vol. 473, 2024, Art. no. 143550, doi: 10.1016/j.jclepro.2024.143550.

[8] Y. Zhang and Q. Ali, "Socio-economic determinants of sustainable tourism and their nexus with energy, environment, and economy (3Es): A panel data analysis," *Energy Strategy Reviews*, vol. 56, 2024, Art. no. 101577, doi: 10.1016/j.esr.2024.101577.

[9] S. Suriyankietkaew, K. Krittayaruangroj, S. Thinthan, and S. Lumlongrut, "Creative tourism as a driver for sustainable development: A model for advancing SDGs through community-based tourism and environmental stewardship," *Environmental and Sustainability Indicators*, vol. 27, 2025, Art. no. 100828, doi: 10.1016/j.indic.2025.100828.

[10] Global Sustainable Tourism Council (GSTC). (2013). GSTC destination criteria. Global Sustainable Tourism Council. [Online]. Available: https://www.gstcouncil.org/gstc-criteria.

[11] Global Sustainable Tourism Council (GSTC). (2016). GSTC industry criteria. Global Sustainable Tourism Council. [Online]. Available: https://www.gstcouncil.org/gstc-criteria.

[12] United Nations World Tourism Organization (UNWTO). (2004). Indicators of sustainable development for tourism destinations: A guidebook. [Online]. Available: https://www.e-unwto.org/doi/book/10.18111/9789284407262.

[13] B. Dash and G. Balamurugan, "Sustainable tourism, livelihood and coastal governance: Chilika

lake, India," *Ocean & Coastal Management*, vol. 245, 2024, Art. no. 107128, doi: 10.1016/j.ocecoaman.2024.107128.

[14] H. Wang, B. Zhang, and H. Qiu, "How a hierarchical governance structure influences cultural heritage destination sustainability: A context of red tourism in China," *Journal of Hospitality and Tourism Management*, vol. 50, pp. 128–136, 2022, doi: 10.1016/j.jhtm.2022.02.002.

[15] V. Nitivattananon and S. Srinonil, "Enhancing coastal areas governance for sustainable tourism in the context of urbanization and climate change in eastern Thailand," *Advances in Climate Change Research*, vol. 10, no. 3, pp. 142–155, 2019, doi: 10.1016/j.accre.2019.03.003.

[16] R. Nunkoo, "Governance and sustainable tourism: What is the role of trust, power and social capital?," *Journal of Destination Marketing & Management*, vol. 6, no. 4, pp. 277–285, 2017, doi: 10.1016/j.jdmm.2017.10.003.

[17] R. Vantola, E. Luoma, T. Parviainen, and A. Lehikoinen, "Sustainability manifesting as a multi-material and -sited network effect: How boat-sourced sewage management facilities serve as governance artefacts advancing sustainability in nautical tourism," *Marine Pollution Bulletin*, vol. 173, 2021, Art. no. 113114, doi: 10.1016/j.marpolbul.2021.113114.

[18] Y. Zhang, H. Tat, and Z. Zhang, "Sustainable development in the tourism sector: The impact of environmental, social, and governance performance on operational efficiency a multilevel analytical approach," *Sustainable Futures*, vol. 9, 2025, Art. no. 100923, doi: 10.1016/j.sftr.2025.100923.

[19] G. Carra, A. Pellegrino, M. Tomasella, and A. Lué, "Sustainable cycle-tourism for society: Integrating multi-criteria decision making and land use approaches for route selection," *Sustainable Cities and Society*, vol. 94, 2023, Art. no. 104905, doi: 10.1016/j.scs.2023.104905.

[20] H. A. Antwi, D. K. Kumi, and M. Addai, "Enhancing the sustainability of food waste management practices in emerging economies' hospitality industry through SECA multi-criteria group decision-making," *International Journal of Hospitality Management*, vol. 121, 2025, Art. no. 104233, doi: 10.1016/j.ijhm.2025.104233.

[21] J. Niemsakul, S. Hiranmahapol, J. Janmontree, H. Zadek, and K. Ransikarbum, "Analysis of barriers for hydrogen-fueled logistics under integrated sustainability: A DEMATEL-TOWS framework," *Journal of Cleaner Production*, vol. 445, 2025, Art. no. 145720, doi: 10.1016/j.jclepro.2025.145720.

[22] P. Jiang, W. Wang, Y. C. Hu, Y. J. Chiu, and S. J. Tsao, "Pattern classification using tolerance rough sets based on non-additive grey relational analysis and DEMATEL," *Grey Systems: Theory and Application*, vol. 10, no. 3, pp. 251–272, 2020, doi: 10.1108/GS-05-2020-0062.

[23] K. G. Nalbant, "A methodology for personnel selection in business development: An interval type 2-based fuzzy DEMATEL-ANP approach," *Heliyon*, vol. 9, no. 12, 2023, Art. no. e23698, doi: 10.1016/j.heliyon.2023.e23698.

[24] A. Zuñiga-Collazos, E. J. Galvez-Albarracin, F. Vera-Jaramillo, and L. V. Patiño-Giraldo,

"Digitalization, innovation, sustainability and performance: A causal analysis applied to tourism MSMEs," *International Journal of Innovation Studies*, vol. 9, no. 1, pp. 46–59, 2025, doi: 10.1016/j.ijis.2024.12.001.

[25] S. A. M. Abandansari, P. Ghasemi, A. Attar, F. Goodarzian, and S. A. Ahmadi, "A hybrid biomass supply chain optimization approach using sequential adaptive fuzzy inference learning: Insights from a cogeneration system in Europe," *Results in Engineering*, vol. 19, 2025, Art. no. 105261, doi: 10.1016/j.rineng.2025.105261.

[26] S. Sultan, A. Almaktoom, R. Kaur, and T. Rashid, "Optimizing renewable transportation framework by an extended spherical fuzzy rough multi-criteria group decision making method," *Applied Soft Computing*, vol. 146, 2025, Art. no. 113599, doi: 10.1016/j.asoc.2025.113599.

[27] K. Zorlu, S. Polat, V. Dede, and A. Yılmaz, "Measuring degradation risk levels of resources in sustainable geotourism development: A Multi-criteria Decision Making (MCDM) approach under spherical fuzzy environments," *International Journal of Geoheritage and Parks*, vol. 11, 2025, Art. no. 100235, doi: 10.1016/j.ijgeop.2024.11.011.

[28] Ö. F. Görçün, M. Baskan, and E. Aydın, "Strategic tour operator selection in the tourism sector using a quantum picture fuzzy rough set-based multi-criteria decision-making approach," *Engineering Applications of Artificial Intelligence*, vol. 126, 2025, Art. no. 110793, doi: 10.1016/j.engappai.2025.110793.

[29] C. Mutanga, G. S. Masunga, O. D. Kolawole, R. Gondo, and J. Mbaiwa, "Media framing of stakeholders' perceptions on the sustainability of tourism development at Chobe National Park Riverfront in Botswana: Insights for sustainable tourism planning," *Scientific African*, vol. 19, 2025, Art. no. e02876, doi: 10.1016/j.sciaf.2025.e02876.

[30] M. Sukrana, A. S. M. Mohibul, and M. R. Kabir, "Investigating the influence of the push and pull factors in eco-resort selection to promote sustainable tourism in Bangladesh," *Sustainable Futures*, vol. 9, 2025, Art. no. 100619, doi: 10.1016/j.sftr.2025.100619.

[31] J. Jeong, L. García-Moruno, J. Hernández-Blanco, and A. Sánchez-Ríos, "Planning of rural housings in reservoir areas under (mass) tourism based on a fuzzy DEMATEL-GIS/MCDA hybrid and participatory method for Alange, Spain," *Habitat International*, vol. 57, pp. 143–153, 2016, doi: 10.1016/j.habitatint.2016.07.008.

[32] C. L. Lin, "Establishing environment sustentation strategies for urban and rural/town tourism based on a hybrid MCDM approach," *Current Issues in Tourism*, vol. 23, no. 19, pp. 2360–2395, 2020, doi: 10.1080/13683500.2019.1642308.

[33] M. Behboudian, S. Anamaghi, R. Kerachian, and Z. Kalantari, "Comparison of three group decision-making frameworks for evaluating resilience time series of water resources systems under uncertainty," *Ecological Indicators*, vol. 154, 2024, Art. no. 111269, doi: 10.1016/j.ecolind.2023.111269.

[34] A. Madanaguli, A. Dhir, R. P. Joseph, N. Albishri, and S. Srivastava, "Environmental sustainability practices and strategies in the rural tourism

and hospitality sector: A systematic literature review and suggestions for future research," *Scandinavian Journal of Hospitality and Tourism*, vol. 23, no. 1, pp. 1–28, 2023, doi: 10.1080/15022250.2023.2174179.

[35] Y. Xiang, B. Zhang, Y. Hou, and F. Li, "Identifying the specific features, determinants, and suitability of green homestay inn distribution in rural China," *Journal of Rural Studies*, vol. 119, 2025, Art. no. 103760, doi: 10.1016/j.jrurstud.2025.103760.

[36] J. L. Deng, "Control problems of grey systems," *Systems & Control Letters*, vol. 1, no. 5, pp. 288–294, 1982, doi: 10.1016/S0167-6911(82)80025-X.

[37] C.-W. Hsu, T.-C. Kuo, S.-H. Chen, and A. H. Hu, "Using DEMATEL to develop a carbon management model of supplier selection in green supply chain management," *Journal of Cleaner Production*, vol. 56, no. 1, pp. 164–172, 2013, doi: 10.1016/j.jclepro.2011.09.012.

[38] O. Bafail and M. Alamoudi, "Prioritizing worker-related factors of safety climate using fuzzy DEMATEL analysis," *Systems*, vol. 13, no. 5, 2025, Art. no. 383, doi: 10.3390/systems13050383

[39] I. G. P. Nugraha, I. P. G. Parma, M. D. P. Agustina, and P. N. Hutnaleontina, "The role of government and community participation in realizing sustainable tourism development in Tihingan Village, Bali, Indonesia," *Journal of Infrastructure, Policy and Development*, vol. 8, no. 8, 2024, Art. no. 4621, doi: 10.24294/jipd.v8i8.4621.

[40] P. Phupuak, S. Choenkwan, and A. T. Rambo, "Factors affecting the sustainability of community-based tourism in a Phu Thai village in Northeast Thailand," *Journal of Humanities and Social Sciences Nakhon Phanom University*, vol. 13, no. 2, pp. 17–33, 2023.

[41] National Tourism Policy Committee, Criteria for Thailand's Community-Based Tourism Development. National Tourism Policy Committee, Feb. 2019.