The impact of institutional economics on carrying capacity and sustainable tourism of the subak landscape as a World Cultural Heritage site: A Bayesian network approach

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Abstract

This study aims to analyze the probability of sustainable tourism in Subak Pulagan. Specifically, it examines the probabilistic impact of optimizing tourist visits on tourism carrying capacity and sustainable tourism within the Subak Pulagan landscape. The analysis was conducted using the Bayesian Network (BN) approach to develop a sustainable tourism model that integrates components of institutional economics, destination support factors, carrying capacity, and the World Cultural Heritage (WCH) designation as interrelated variables. Tourism in Subak Pulagan has strong potential for development through village tourism and rural tourism approaches. However, it is crucial to prevent overuse of the carrying capacity, as excessive tourist numbers could undermine the sustainability of tourism in the area. The findings indicate that a significant increase in tourist visits is likely to have a substantial impact on physical and environmental capacities. In contrast, the WCH designation and its associated recognition have not yet made a significant contribution to the sustainable tourism development of Subak Pulagan. As a policy implication, it is recommended to strengthen preventive measures to manage tourism carrying capacity—particularly in the physical and environmental dimensions—to ensure that tourism development supports both heritage preservation and long-term sustainability.

Keywords: *Bayesian network; Institutional economics; Subak landscape; Sustainable tourism; World Cultural Heritage*

JEL Classification: R11, R58, Z10, Z32, Z38

INTRODUCTION

Agriculture and tourism are the two main sectors supporting Bali's economy. Based on their contributions to Bali's economy, these sectors consistently dominate (Widhianthini, 2022). During the Covid-19 pandemic (2020–2021), the share of the agricultural sector increased, while that of the tourism sector declined. Figure 1 illustrates

that the shares of tourism (proxied by accommodation and food service activities) and agriculture in the Gross Regional Domestic Product (GRDP) of Bali Province tend to exhibit an inverse pattern. This suggests that the two sectors have the potential to affect one another negatively (Artini et al., 2020), while also having the capacity to complement one another (Purwahita et al., 2021). Agriculture can thus serve as a buffer, given the tourism sector's vulnerability to global shocks and crises (Kurniawati, 2022).

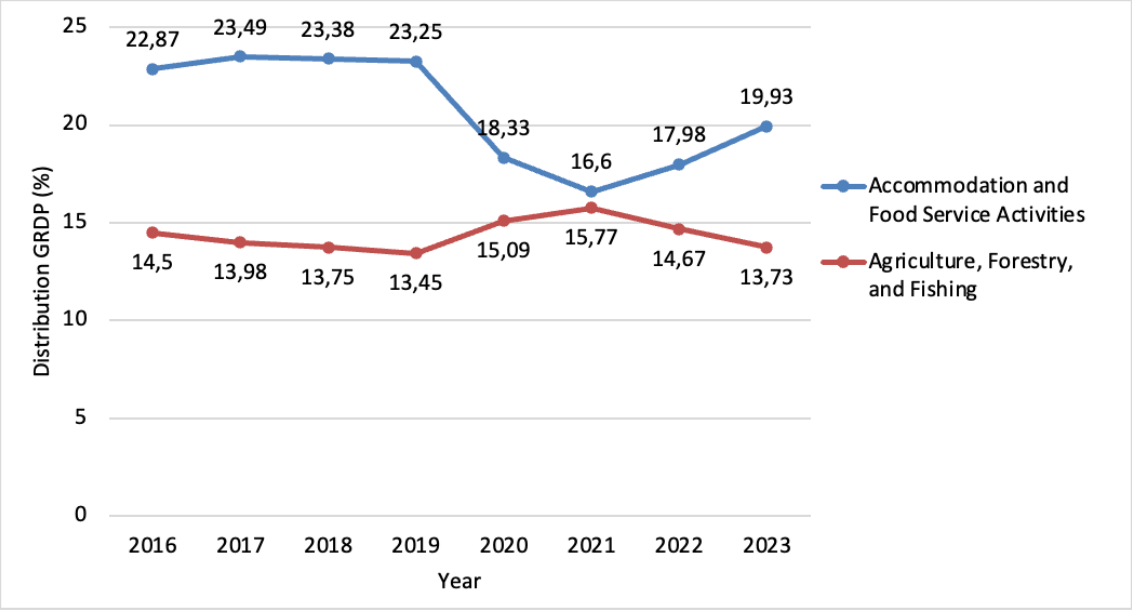

Figure 1. Trend in the share of the agriculture and tourism sectors in Bali's GRDP
Source: Statistics of Bali Province, 2024

The agricultural sector in Bali not only provides food and employment but also fulfills important socio-cultural functions (Widhianthini, 2022). As one of the foundational pillars of Bali's economy (Sutjana, 2012), agriculture is deeply intertwined with Balinese culture, particularly through the philosophical concept of *Tri Hita Karana*, which remains relevant and widely practiced today (Hasana, 2022; Lestari et al., 2015). The institution at the heart of Bali's culture-based agricultural system is subak (Suasih et al., 2024; Zen et al., 2024). Subak is widely recognized as a traditional organization that manages irrigation systems in Bali (Yuliana, 2017). Beyond this, it plays a strategic role in ensuring agricultural sustainability, encompassing social, environmental (Doddy et al., 2024), and economic dimensions (Budiasa, 2010).

The recognition of Balinese agriculture and subak is reflected in UNESCO's designation of Bali's cultural landscape as a World Heritage site (Mas'ad, 2019). This cultural landscape includes rural areas, terraced rice fields with subak irrigation systems, temples, and shrines. It embodies the Tri Hita Karana philosophy, which teaches that happiness, prosperity, and peace can be achieved only through harmony among God, humans, and nature. The principles of this philosophy reveal an extraordinary interconnection between the spiritual, human, and natural realms. The temples—iconic elements of the landscape—serve as venues for traditional ceremonies and reflect the Balinese aspiration to maintain harmony with the divine. Meanwhile, religious and social organizations, including subak, an irrigation institution, serve as channels for fostering cooperation and social cohesion. The development of Bali's landscape—such as temple location selection, architectural design, irrigation construction, and terraced field formation—demonstrates a sustained commitment to environmental harmony.

In 2012, UNESCO inscribed the cultural landscape of Bali Province as a World Cultural Heritage site. Figure 2 presents a map of Bali Island and the designated heritage locations, including Ulun Danu Batur Temple and Lake Batur (A), the Pakerisan Watershed (DAS) (B), Lake Buyan, Lake Tamblingan, and the Catur Angga Batukaru area (C), as well as the Pura Taman Ayun site (D), covering a total area of 20,974.70 hectares.

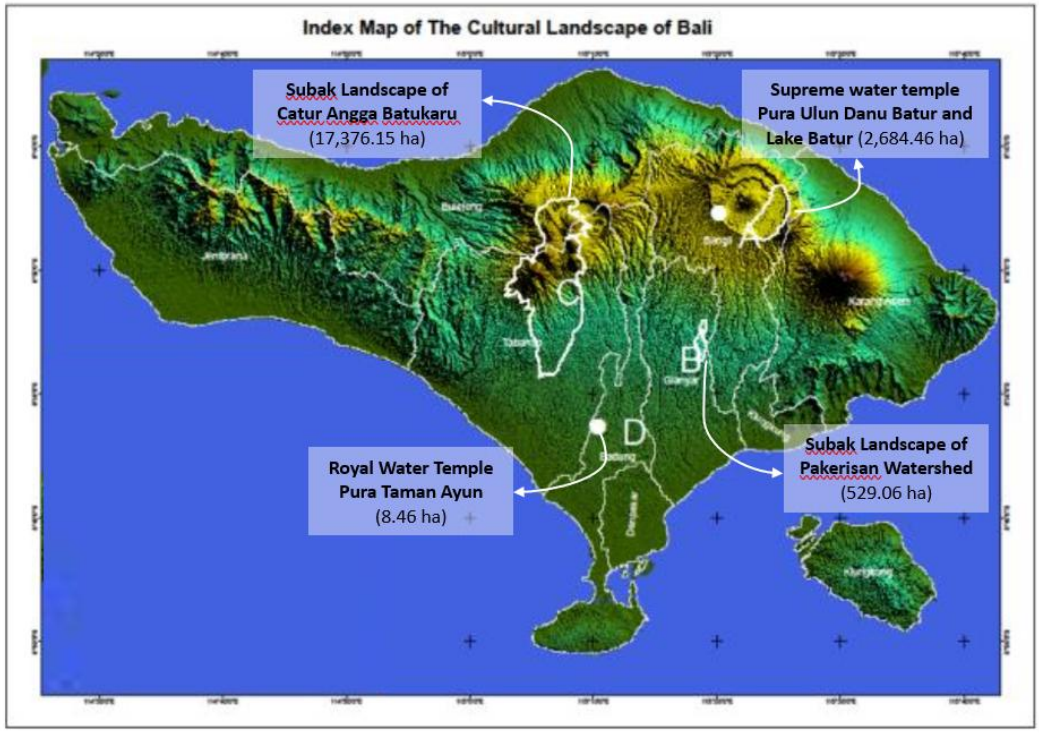

Figure 2. Map of Bali Island and World Cultural Heritage areas – subak cultural landscape of Bali
Source: Suasih et al., 2024

The Pakerisan Watershed area comprises three subak systems—Subak Pulagan, Subak Kulub Atas, and Subak Kulub Bawah—with Subak Pulagan being the largest. As a World Heritage site, the conversion of rice fields in this area is prohibited. Nevertheless, most farmers in Bali are smallholders who face challenges such as low productivity and limited access to capital (Barokatuminalloh et al., 2018; Mahpudin, 2020). This issue requires collective attention from both the government and the community to enhance farmers' welfare and preserve the sustainability of the rice field ecosystem.

Tampaksiring Village, which administers the Subak Pulagan area, has been designated as a tourism village, with the expectation that tourism will develop specifically within Subak Pulagan. The subak system holds significant tourism potential due to its rice field landscapes, religious rituals, agricultural products, and the social life of farmers (Mas'ad, 2019). However, transforming this area into an ecotourism destination necessitates the development of community-based tourism facilities aligned with sustainable principles. The main challenge is that tourism facility development within a heritage site can also threaten its cultural integrity.

Although the subak landscape received UNESCO recognition in 2012, empirical evidence shows that farmers have yet to experience substantial economic benefits. Sarita et al. (2013) found that while 86.6% of farmers in Subak Pulagan perceived the

designation positively, these perceptions did not translate into tangible improvements in income or livelihoods. Similarly, Taylor (2016) reported that in Jatiluwih—another UNESCO-recognized subak area—financial gains from tourism often failed to reach farmers due to institutional and administrative bottlenecks. A more recent Bayesian Network analysis by Suasih et al. (2024) emphasized that maximizing farmers' profits is essential to achieving agricultural sustainability in Subak Pulagan, yet this remains an unmet goal despite international recognition.

Previous studies have not applied probabilistic modeling to assess tourism sustainability within subak systems. This research contributes by developing a probabilistic framework using Bayesian Networks to evaluate the tourism carrying capacity of cultural heritage sites. It offers added value by applying the Bayesian Network approach to model tourism sustainability through institutional economic components—a perspective rarely explored in the context of subak.

Although Bayesian Networks have been used in environmental and tourism research (e.g., Hsu et al., 2012; Zhang et al., 2024), their application has seldom examined the interaction between institutional economic variables and tourism sustainability in heritage agricultural landscapes. This study addresses that gap by focusing on Subak Pulagan—a uniquely governed socio-ecological system—thereby providing context-specific insights into sustainable tourism modeling.

Previous research has employed Bayesian Networks in tourism decision-support systems and environmental risk assessments. For instance, Hsu et al. (2012) developed a Bayesian Network–based intelligent recommendation system that integrates visitor preferences and site attributes for tourist attraction planning. Similarly, Norouzi Isfahani et al. (2023) proposed an advanced nature-based tourism model using Bayesian Networks to analyze the influence of environmental, economic, and social subsectors on sustainability. However, these studies primarily focused on tourism behavior or environmental variables, without incorporating institutional economic factors such as governance structures or community participation. This study fills that gap by integrating such institutional variables into a probabilistic Bayesian Network framework to model sustainable tourism in the socio-ecological heritage system of Subak Pulagan.

Institutional economics, a branch of economics emphasizing the crucial role of institutions in shaping economic performance, recognizes that social rules and constraints influence economic behavior when they are effectively enforced (North, 2005; Yonay, 1998; Hodgson, 2013; Arwani & Priyadi, 2024). Markets alone often fail to self-correct and achieve equilibrium (Györy, 2020), prompting the emergence of institutional economics as a distinct field (Leeson, 2015; Richter, 2011). Within this framework, three key points stand out. First, economics increasingly incorporates sociological, political, anthropological, and psychological factors into its analyses (Young & Kaufman, 2006; Vu, 2010). Orthodox economics—typically static and market-focused—has come to recognize that many economic decisions occur outside of market structures (Luca, 2015), as non-economic considerations frequently influence economic choices (Nalle & Ismail, 2024). Second, governments must regulate to prevent oligopolistic dominance that harms smaller entities (Jo & Tae-Hee, 2018; Arwani & Priyadi, 2024), while also fostering collaboration among weaker economic actors through cooperative arrangements (Vargas-Hernández, 2008). Additionally, governments bear responsibility for ensuring public sector efficiency and maintaining a balance between oligopolistic and competitive private enterprises (Dooren et al., 2014). Third, unlike neoclassical economics, institutional economics emphasizes that humans design and employ institutions to resolve social and

economic conflicts (Toboso, 2006).

Several studies have highlighted the state's regulatory role in addressing market failures, ensuring fair distribution of tourism benefits, and controlling environmental degradation through formal governance mechanisms (Bramwell, 2011). Conversely, other scholars underscore the importance of informal community institutions—such as customary norms, local leadership, and cooperative networks—in managing tourism sustainably from the bottom up (de Bruyn & Fernández Alonso, 2012). This study integrates both perspectives by modeling the interaction between formal and informal institutions in Subak Pulagan's tourism governance, recognizing that effective sustainability often arises from the synergy between state regulation and community-based management.

Sustainable tourism refers to tourism that fully considers social, environmental, and economic impacts—both present and future—while meeting the needs of visitors, the industry, the environment, and local communities (Vitriani et al., 2017; Huseynli, 2022). The development of sustainable tourism must preserve the authenticity of host communities' socio-cultural values, safeguard cultural heritage and traditions, and promote cross-cultural understanding and tolerance (Hubner et al., 2022). It should also optimize the use of environmental resources—key elements in tourism development—by maintaining essential ecological processes and conserving natural heritage and biodiversity (Sadikin, 2023). Moreover, sustainable tourism must ensure long-term economic viability by providing stable employment and income opportunities for local communities (Nurlisa Ginting et al., 2020; Sushanti et al., 2019).

Achieving sustainable tourism requires enhancing visitor satisfaction and ensuring meaningful tourist experiences (Ratih & Noer, 2024; Kusumah, 2024; Hadassa, 2024), while simultaneously increasing awareness of sustainability and promoting responsible tourism practices (UNEP and UNWTO, 2015). This concept is central to improving the quality of life for local communities (Khairina & Anggraini, 2023) and preserving environmental quality. Sustainable tourism development should not only focus on increasing tourist numbers but also on balancing environmental and socio-cultural considerations.

Previous research on sustainable tourism has consistently emphasized the *profit–people–planet* triad. Environmental dimensions (Wiwattanakantang & To-im, 2014; Blancas, 2011), ecological considerations (Choi & Sirakaya, 2006), and environmental education in local tourism management (Astawa et al., 2018) have been key areas of focus. Economically, tourism should create jobs and improve community welfare (Wiwattanakantang & To-im, 2014; Blancas, 2011; Choi & Sirakaya, 2006; Astawa et al., 2018) while ensuring sound tourism management (Wiwattanakantang & To-im, 2014). The socio-cultural aspect involves local community participation in managing tourism in line with international sustainability principles (Astawa et al., 2018). Hence, sustainable tourism must account for economic (profit), social (people), and environmental (planet) dimensions.

By integrating these perspectives, this study contributes to the literature by applying a Bayesian Network approach to model tourism sustainability through institutional economic components—a method rarely employed in the context of Subak Pulagan. Specifically, the study aims to analyze the probability of sustainable tourism in Subak Pulagan, focusing on how optimizing tourist visits influences tourism carrying capacity and sustainability. The Bayesian Network approach is advantageous for constructing intuitive models that can simulate and handle incomplete data through probabilistic integration (Kisioglu & Topcu, 2011; Suharso & Djunaidy, 2013).

METHODS

Bayesian Network approach

The Bayesian Network (BN), also referred to as the Belief Bayesian Network (BBN), is a causal probabilistic network (Suasih et al., 2024). In this study, the BN approach is employed to assess the sustainability of tourism in Subak Pulagan, a World Cultural Heritage site, with particular attention to the influence of social capital.

Broadly, a BN comprises two main components: qualitative and quantitative. The qualitative component represents the relationships among variables through a Directed Acyclic Graph (DAG), while the quantitative component consists of probabilistic data organized in Conditional Probability Tables (CPTs). Figure 3 illustrates the basic structure of a BN comprising three variables.

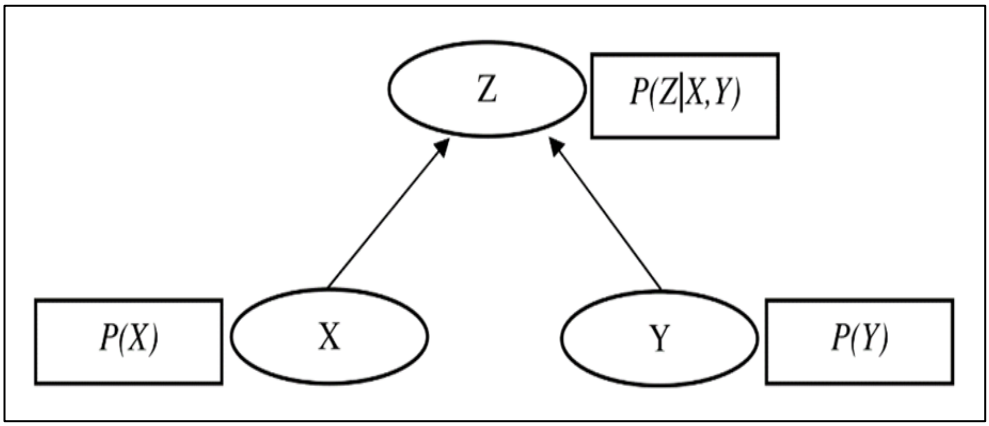

Figure 3. Basic structure of BN
Source: Chakraborty et al., 2016; Suasih et al., 2024

Variables X and Y serve as the *parent variables* of variable Z, making Z the *child variable*. The probability distribution of any variable depends solely on its parent variables and can be expressed as follows for *n* nodes (Chakraborty et al., 2016):

$$P(X_1, \dots, X_n) = \prod_{i=1}^{n} P\left(X_i \middle| P_a(X_i)\right) \quad \text{.....(1)}$$

where $Pa(X_i)$denotes the set of parent nodes of X_i. Based on Figure 3, Equation (1) can be reformulated as (Chakraborty et al., 2016):

$$P(Z) = P(Z|X,Y)\ x\ P(X)\ x\ P(Y) \quad \text{.....(2)}$$

Identifying variables in the BN structure

The BBN modeling procedure begins with identifying and mapping variables within the network structure according to probabilistic relationships (Hoshino et al., 2016). The variables included in the BN are categorized into objectives, interventions, intermediate factors, controlling factors, and implementation factors. Objectives represent the outcomes that the system seeks to influence. Interventions refer to actions implemented to achieve those objectives. Intermediate factors are variables that cannot be directly modified by interventions but can be controlled. Implementation factors are variables that influence the success of interventions in both the present and the future.

Figure 4 illustrates the interactions among variables within the BN structure.

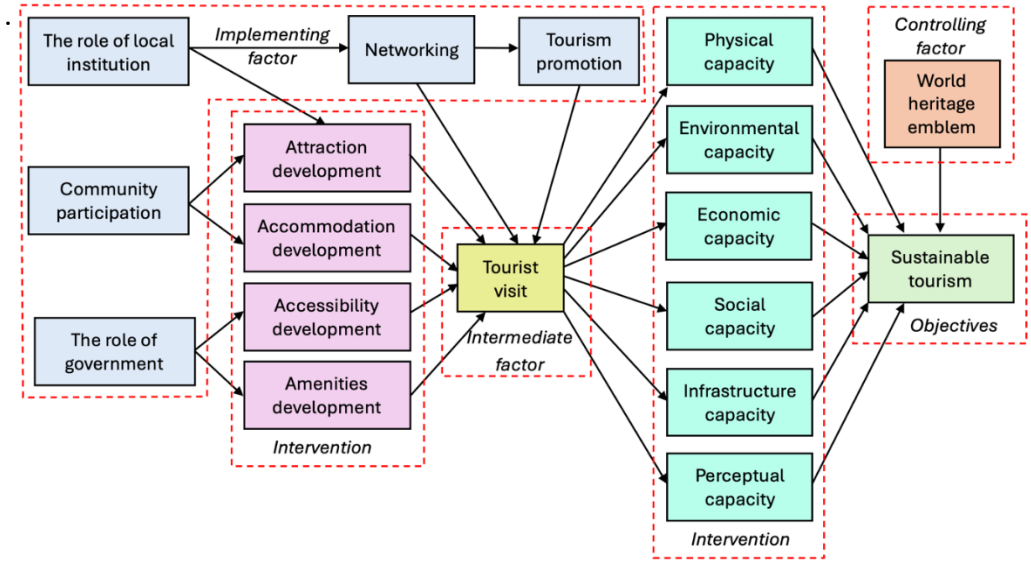

Figure 4. DAG of BN structure of sustainable tourism in Subak Pulagan

The quantitative component of the Bayesian Network analysis is derived from probabilistic data, where nodes are measured on categorical scales. Table 1 provides details of the variables and their respective node states.

Table 1. Variables (nodes) and node states of sustainable tourism in Subak Pulagan

Variable categories	Variable nodes	Dominant theme	Node states
Implementing factors	Role of local institutions	Institutional aspect	low, moderate, high
	Community participation		low, moderate, high
	Role of government		low, moderate, high
	Networking		yes, no
	Tourism promotion	Promotion aspect	yes, no
Interventions	Attraction development	Supporting factors for tourist destination success (4A)	optimal, moderate, not_yet
	Accommodation development		optimal, moderate, not_yet
	Accessibility development		optimal, moderate, not_yet
	Amenities development		optimal, moderate, not_yet
	Physical capacity	Tourism carrying capacity	low, moderate, high
	Environmental capacity		low, moderate, high
	Economic capacity		low, moderate, high
	Social capacity		low, moderate, high
	Infrastructure capacity		low, moderate, high
	Perceptual capacity		low, moderate, high
Controlling factor	World Heritage emblem	Predicate	blessing, burden
Intermediate factors	Tourist visit	Tourism aspect	low, moderate, high
Objectives	Sustainable tourism		yes, no

Model development and data collection

The Bayesian Network (BN) model was developed by constructing a Directed Acyclic Graph (DAG) to represent the causal relationships among institutional, environmental, and tourism-related variables. The identification of nodes and links was grounded in institutional economics theory and refined through expert consultation.

Data collection for probability inputs was conducted after the DAG structure was finalized. The probability values were obtained through Focus Group Discussions (FGDs) conducted in two sessions with 12 participants, including subak representatives, village tourism officials, academics, and regional tourism authorities. Participants were selected based on their direct involvement in subak or tourism management.

Data validation was performed through expert triangulation and follow-up discussions to verify both the BN structure and probability inputs. The final BN model was validated using expert triangulation and probabilistic consistency checks in GeNIe Academic software (Version 4) (Fauzi & Ariyani, 2024). The probability scores were subsequently entered into the Conditional Probability Tables (CPTs) and analyzed using GeNIe Academic.

Model validation and analysis

Expert triangulation was used both to validate the network structure and to assess the reliability of conditional probability estimates. The elicited probability values were incorporated into the CPTs, and the complete BN model was analyzed using GeNIe Academic (Version 4), which supports both structural validation and probabilistic simulation.

Conditional Probability Tables were developed by combining expert judgment with available empirical references to ensure plausibility. This approach aligns with the recommendations of Marcot et al. (2006), who established best practices for constructing Bayesian Networks in ecological and policy contexts. The model structure was iteratively refined through expert feedback to enhance face validity and ensure alignment with observed field realities.

RESULTS AND DISCUSSION

Strength analysis of BN structure

The Bayesian Network (BN) structure for sustainable tourism in Subak Pulagan (Figure 4) positions variables (nodes) according to their respective functions within the system. Figure 5 illustrates the BN structure, showing prior probabilities for sustainable tourism in Subak Pulagan.

Based on Figure 5, local institutions demonstrate satisfactory performance within the sustainable tourism system of the Subak Pulagan landscape. However, other aspects of institutional economics—particularly the role of government and networking—remain suboptimal. Likewise, the supporting factors for destination success have not yet developed sufficiently, especially in attractions, accommodations, and amenities. In contrast, accessibility is relatively well developed. The Subak Pulagan landscape benefits from well-maintained roads that facilitate access to the site. In addition, farm roads and irrigation channels are in good condition, as subak institutions have prioritized their improvement. These roads are not only crucial for tourists but also essential for supporting farmers' mobility and access to rice fields.

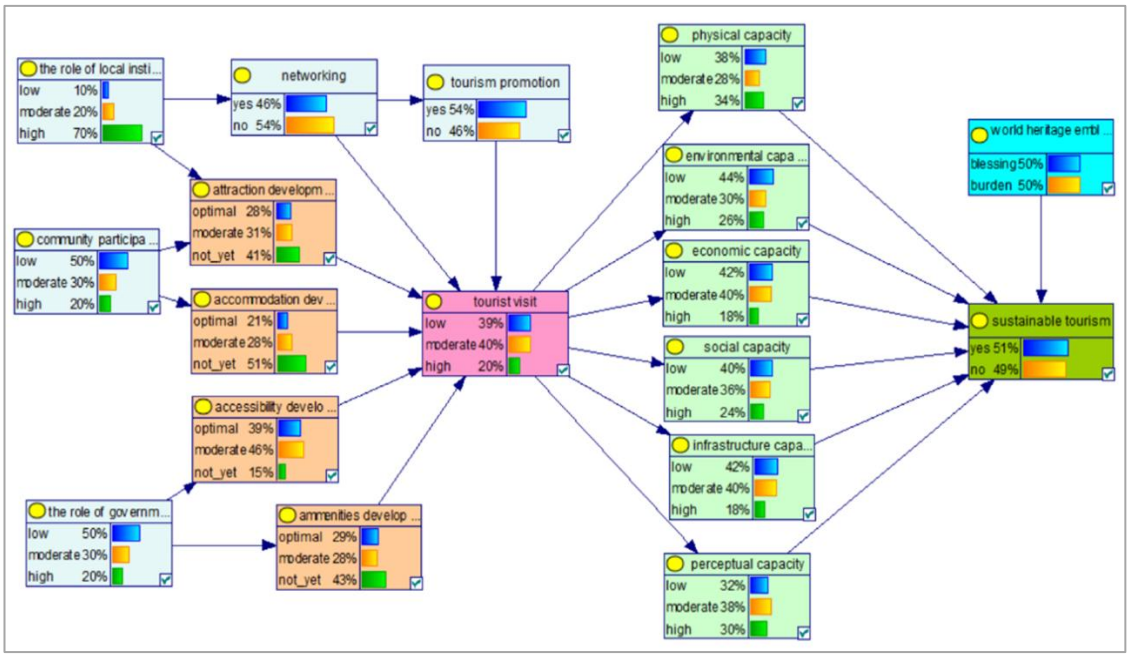

Figure 5. Structure of BN of sustainable tourism with prior probabilities

The analysis further indicates that tourist visits currently have a low probability of significantly affecting the carrying capacity of tourism in the Subak Pulagan landscape. The designation of the area as a World Cultural Heritage site is expected to promote the preservation of the subak landscape and its surrounding environment. Nonetheless, given the prohibition on farmland conversion, the government must take measures to strengthen the local economy. The establishment of Tampaksiring Tourism Village—the administrative area encompassing Subak Pulagan—presents opportunities to enhance local livelihoods through tourism development. The BN results also suggest that the World Cultural Heritage emblem exerts a neutral influence, indicating that heritage recognition alone does not directly enhance tourism sustainability.

The Bayesian Network analysis highlights the BN's ability to explain potential cause-and-effect relationships within the sustainable tourism system (Suasih et al., 2024). Table 2 presents the strength scores between nodes in the BN structure.

Table 2. Score of strength between nodes in the BN structure of sustainable tourism

Parent	Child	Average	Maximum
Accessibility development	Tourist visit	0.019	0.300
Accommodation development	Tourist visit	0.015	0.264
Amenities development	Tourist visit	0.014	0.264
Attraction development	Tourist visit	0.026	0.200
Community participation	Attraction development	0.313	0.458
Community participation	Accommodation development	0.329	0.458
Economic capacity	Sustainable tourism	0.006	0.300
Environmental capacity	Sustainable tourism	0.016	0.300
Infrastructure capacity	Sustainable tourism	0.016	0.300
Networking	Tourism promotion	0.300	0.300
Networking	Tourist visit	0.006	0.200
Perceptual capacity	Sustainable tourism	0.015	0.500
Physical capacity	Sustainable tourism	0.131	0.500

Parent	Child	Average	Maximum
Social capacity	Sustainable tourism	0.013	0.300
The role of government	Accessibility development	0.307	0.458
The role of government	Amenities development	0.266	0.360
The role of local institutions	Attraction development	0.228	0.346
The role of local institutions	Networking	0.133	0.200
Tourism promotion	Tourist visit	0.026	0.200
Tourist visit	Physical capacity	0.433	0.600
Tourist visit	Environmental capacity	0.266	0.400
Tourist visit	Economic capacity	0.291	0.435
Tourist visit	Social capacity	0.241	0.360
Tourist visit	Infrastructure capacity	0.133	0.200
Tourist visit	Perceptual capacity	0.179	0.264
World heritage emblem	Sustainable tourism	0.016	0.300

Based on Table 2, the most significant relationship occurs between tourist visits and physical capacity, with an average strength of 0.433 and a maximum value of 0.600. This is followed by the strong influence of community participation on amenities development (average 0.329; maximum 0.458) and community participation on accommodation development (average 0.313; maximum 0.458). These findings indicate that the probability of exceeding tourism carrying capacity—particularly physical capacity—will increase as the number of tourist visits grows.

Furthermore, the results suggest that the development of accommodation facilities can be optimized through community participation. Encouraging community-based accommodations, such as homestays, aligns with sustainable tourism principles and can enhance the local economy while preserving cultural integrity.

In Bayesian Network analysis, the strength of relationships between nodes is commonly interpreted using threshold values to assess their relative importance. Scutari (2010) notes that strength values exceeding 0.5 are typically considered *strong* and *policy-relevant*, particularly when derived using resampling techniques such as bootstrapping. This threshold helps distinguish structural dependencies that are likely to remain consistent across datasets.

In this study, the 0.5 threshold is used to identify significant relationships within the model. For example, the influence of tourist visits on physical capacity (maximum strength 0.600) exceeds this threshold, highlighting a critical area for policy intervention to prevent overcapacity and environmental degradation.

These findings are consistent with Astawa et al. (2018), who emphasized that the active involvement of local institutions and traditional knowledge systems strongly influences the success of community-based tourism in Bali. Similarly, Suasih et al. (2024) found that institutional support and participatory governance play essential roles in enhancing local tourism sustainability within subak-based villages.

Analysis of the impact of optimizing tourist visits

Tourism development in Bali has gradually shifted toward promoting quality tourism; however, mass tourism continues to dominate as the primary target. Therefore, this study evaluates the probability of sustainable tourism under optimal conditions for tourist visits. The analysis was conducted by setting the tourist visit node as the target, assigning it a probability of 100%, and designating it as “evidence” (Figure 6).

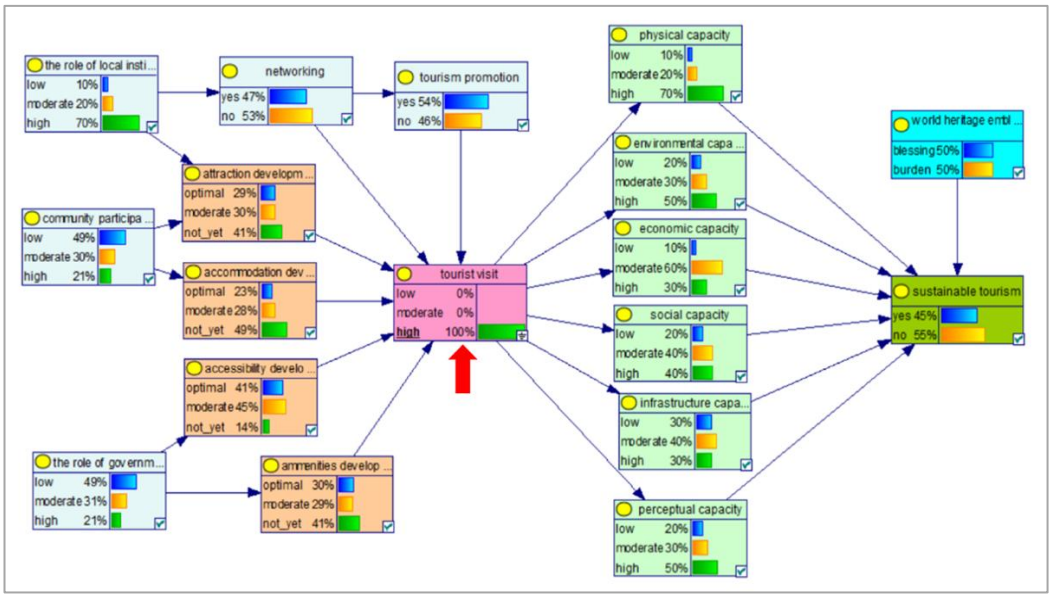

Figure 6. Structure of BN of sustainable tourism with tourism visit as evidence

As illustrated in Figure 6, when tourist visits are maximized, the predicted probability of sustainable tourism decreases to 45%, compared to 51% in the baseline scenario presented in Figure 5. This finding underscores the need to carefully manage tourist numbers to prevent exceeding the tourism carrying capacity. The result is consistent with the strength analysis presented in Table 2, which shows that a high volume of tourist visits increases the likelihood of exceeding carrying capacity—particularly in the physical, environmental, and perceptual dimensions.

This outcome suggests that an unrestrained increase in tourist numbers can place pressure on infrastructure, natural resources, and the overall visitor experience. Consequently, sustainable tourism management in Subak Pulagan should focus on quality-based tourism strategies, such as limiting visitor numbers, promoting eco-friendly tourism activities, and enhancing community-based management practices to balance economic benefits with environmental preservation.

Analysis of the impact of the World Cultural Heritage (WCH)

As previously discussed, Subak Pulagan is part of the subak landscape designated as a UNESCO World Cultural Heritage (WCH) site. This international recognition is expected to enhance the area's visibility and attract a broader range of visitors. Therefore, this study also examines the predicted impact of the WCH designation on sustainable tourism in Subak Pulagan. The analysis was carried out by setting the WCH designation variable as "evidence" with a probability value of 100% (Figure 7).

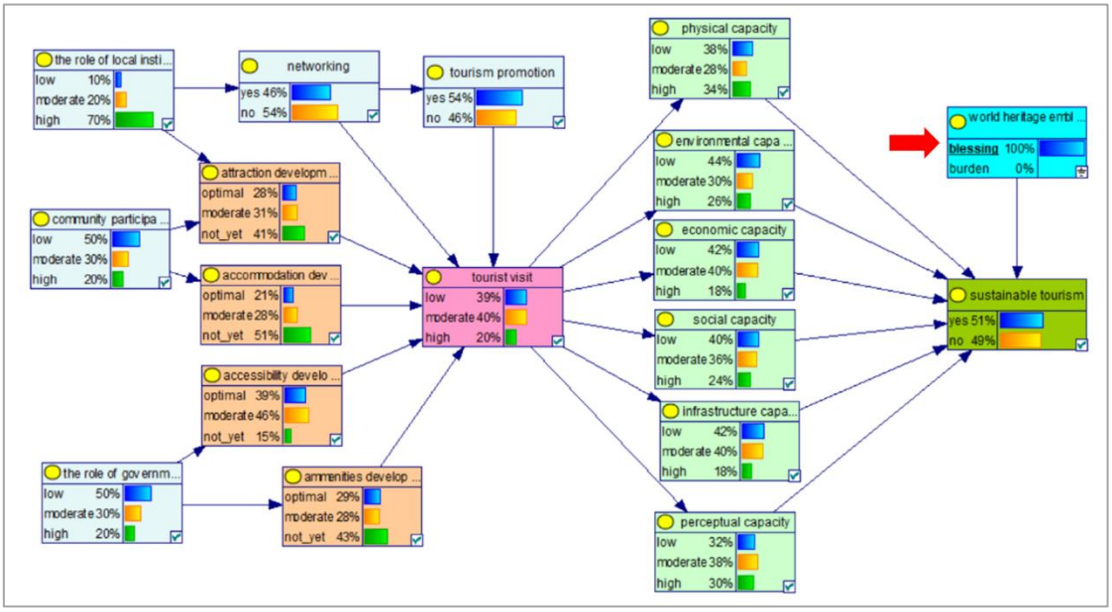

Figure 7. Structure of the BN of sustainable tourism with the World Cultural Heritage emblem as evidence

The results in Figure 7 indicate that the WCH designation and its associated impacts have no significant effect on sustainable tourism in Subak Pulagan. The probability value for sustainable tourism remains constant at 51%, identical to the baseline scenario.

This finding aligns with Taylor's (2016) observations that, in Jatiluwih—another subak area recognized as a WCH site—the symbolic status did not automatically yield economic benefits for local farmers due to the absence of effective operational policies and equitable benefit-sharing mechanisms. Similarly, Fauzi and Ariyani (2024) argue that WCH status often lacks downstream institutionalization, rendering it ineffective unless accompanied by concrete governance structures that ensure tangible local benefits.

These results reinforce the argument that institutional and governance factors play a more critical role in achieving sustainable tourism outcomes than heritage recognition alone. Without mechanisms to translate global acknowledgment into local economic and social benefits, the WCH title may remain primarily symbolic, offering prestige without practical impact on community welfare or sustainability.

Policy and theoretical implications

The findings of this study present important implications for both policy development and theoretical advancement in the field of sustainable tourism, particularly within cultural heritage sites.

From a policy perspective, the result indicating that community participation significantly influences the development of amenities and infrastructure underscores the need for governance frameworks that empower subak institutions with greater authority, financial support, and technical capacity. Strengthening these community-based institutions would enable more effective management of tourism activities and infrastructure within the subak landscape. This approach is consistent with the findings of Huang et al. (2025), who employed a DPSIR–Bayesian Network early-warning model to assess tourism ecological risk in Sichuan, China. Their study demonstrated that locally led and data-informed governance mechanisms effectively balance tourism development with environmental conservation.

Another practical insight arises from applying the 0.5 strength threshold to identify

policy-relevant relationships within the Bayesian Network. This threshold provides a clear decision-making criterion for prioritizing interventions to alleviate tourism pressure. Comparable probabilistic thresholding methods have been effectively applied in tourism risk assessment and infrastructure monitoring, providing a concrete, evidence-based strategy for regulatory action. By adopting such a threshold, policymakers can focus on relationships with the most significant causal weight, thereby optimizing governance and resource allocation.

From a theoretical standpoint, this research contributes to integrating institutional economics and probabilistic modeling into sustainable tourism studies. While prior research has often explored governance and community participation qualitatively, this study advances the field by *operationalizing* these concepts within a Bayesian Network framework. This enables the formal simulation of interactions among social, governance, environmental, and visitor-related factors. Such an approach facilitates the quantification of complex interdependencies and enhances predictive understanding of sustainability outcomes.

This methodological contribution aligns with Qazi et al. (2025), who employed a Bayesian Belief Network (BBN) to explore multidimensional sustainability pathways, highlighting the potential of Bayesian models to reveal synergies and trade-offs among economic, social, and environmental dimensions. Extending this framework to the context of *heritage tourism*, the present study demonstrates that the probability of achieving sustainable outcomes can be dynamically modeled and quantitatively assessed.

In summary, the evidence suggests that empowering subak governance and strengthening monitoring infrastructure through probabilistic early-warning systems can substantially enhance the sustainability of cultural heritage tourism. Methodologically, integrating institutional variables into a Bayesian framework offers a novel, quantitative, and adaptive tool that enriches theoretical understanding of tourism sustainability in complex socio-ecological systems.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Tourism in Subak Pulagan has significant development potential through a village- or rural-tourism approach. However, it is essential to prevent the overcapacity of tourist numbers, as this could undermine the sustainability of tourism in the area. A substantial increase in tourist visits is anticipated to exert considerable pressure on both physical and environmental capacities. Furthermore, the designation of Subak Pulagan as a World Cultural Heritage site and its associated impacts have not yet made a notable contribution to sustainable tourism in the region.

Recommendations

Based on the analysis, it is recommended to strengthen preventive measures to address tourism carrying capacity, particularly in the physical and environmental dimensions. Regarding the World Cultural Heritage designation, effective synergy among local governments, the central government, and UNESCO is needed to implement measurable, community-centered programs. Although this designation entails responsibilities for farmers and local communities to preserve the subak landscape, its economic benefits have not yet been fully realized. Developing tourism in Subak Pulagan remains a strategic opportunity to strengthen the local economy, especially if supported by inclusive, governance-based planning.

This study has certain limitations due to its reliance on a static, probability-based model that depends on expert judgment obtained through FGDs. The model has not been validated using longitudinal or empirical data, which constrains its predictive accuracy. Therefore, future research is encouraged to employ dynamic Bayesian Network models or integrate longitudinal datasets to assess the temporal evolution of tourism impacts and enhance the robustness of simulations.

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Data Curation: Ni Nyoman Reni Suasih
Writing – Original Draft: I Made Putra Yasa, Ni Nyoman Reni Suasih
Writing – Review & Editing: Putu Yudy Wijaya

CONFLICT OF INTEREST
The authors declare no conflict of interest.

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