

# Green Economy Indicators for Prioritizing Tourism Sites in a World Natural Heritage: An Integrated Fuzzy AHP - Fuzzy TOPSIS Assessment of the Cat Ba Archipelago (Vietnam)

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## Article

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# Green Economy Indicators for Prioritizing Tourism Sites in a World Natural Heritage: An Integrated Fuzzy AHP - Fuzzy TOPSIS Assessment of the Cat Ba Archipelago (Vietnam)

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**Abstract:** This study develops an integrated Fuzzy Analytic Hierarchy Process (Fuzzy AHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (Fuzzy TOPSIS) framework for prioritizing tourism sites according to green economy objectives in Vietnam's Cat Ba Archipelago, part of a world natural heritage site in Vietnam. A purposively selected panel of 10 decision-makers evaluates 10 tourism sites against 10 environmental, economic, social, and institutional criteria. Fuzzy AHP determines the relative importance of the criteria, while Fuzzy TOPSIS assesses the sites according to their proximity to the fuzzy positive ideal solution. The results identify natural capital management as the most important criterion, followed by policy guidelines and resource benefit distribution, highlighting a conservation-led pathway in which ecosystem protection, enforceable environmental limits, and equitable benefit sharing are central to green tourism development. Sensitivity analysis confirms that the overall ranking pattern remains stable across the tested weighting scenarios. The findings further show that higher priority does not imply faster tourism expansion; rather, interventions should be differentiated according to local ecological conditions, infrastructure, institutional capacity, and livelihood needs. The proposed framework advances community-level spatial prioritization by linking multidimensional green economy criteria with site-specific intervention strategies. It provides a transparent decision-support tool for allocating green tourism and environmental-management interventions and is adaptable to other ecologically sensitive island and coastal destinations.

**Keywords:** Green economy; sustainable tourism; Fuzzy AHP; Fuzzy TOPSIS; tourist site prioritization; World Natural Heritage; Cat Ba Archipelago; Vietnam.

## 1. Introduction

The adoption of the Millennium Development Goals (MDGs) strengthened internationally coordinated development commitments and increased demand for indicators capable of assessing progress across diverse economic and institutional contexts (Kenny & Sumner, 2011; Sachs, 2015). Within the subsequent sustainable development agenda, the green economy has emerged as an important paradigm for reconciling economic advancement with environmental protection and social inclusion. A green economy aims to improve human well-being and social equity while reducing environmental risks and ecological scarcities (Barbier, 2012; Bobylev et al., 2015). It promotes low carbon development, resource efficiency, biodiversity conservation, and inclusive economic opportunities while recognizing ecological limits and

the long term value of natural capital (Rockström et al., 2009; Foley et al., 2005). The concept therefore extends beyond environmental protection to integrate economic performance, social equity, institutional quality, and human well-being. Earlier environmental economic research similarly emphasizes the importance of ecosystem services and natural resource stocks in sustaining human welfare (Pearce et al., 1989; Costanza et al., 1997). Because tensions may arise among economic growth, social objectives, and ecological limits, appropriate indicators and decision-support mechanisms are required to distinguish genuine green transitions from conventional growth pathways (Victor, 2008).

In practice, the green economy encompasses renewable energy, sustainable transport, resource-efficient buildings, water and waste management, biodiversity conservation, and responsible production and consumption. It consequently links economic, ecological, social, and institutional dimensions (Barbier, 2010; UNEP, 2011; Victor & Jackson, 2012). Green economy indicators translate these broad objectives into measurable dimensions of resource use, economic activity, and social outcomes (Merino-Saum et al., 2018). However, approaches differ in their emphasis on green growth, low carbon development, resource efficiency, ecological modernization, and social transformation (Georgeson et al., 2017; Loiseau et al., 2016). This challenge is particularly relevant in developing countries, where economic growth, employment, infrastructure needs, inequality, and resource depletion must be addressed simultaneously (Bina, 2013; Raworth, 2017). As no universal measurement framework exists, green economy assessments typically employ multidimensional indicators adapted to specific geographical and sectoral contexts (OECD, 2017). The UNESCAP framework emphasizes equitable access, structural transformation, eco-efficiency, productivity, natural capital investment, ecological limits, and institutional support for managing economic, social, and environmental trade-offs (UNESCAP, 2014).

Tourism is particularly suitable for applying this approach because it depends heavily on environmental quality, natural landscapes, ecosystem services, cultural assets, and host communities. Tourism can generate employment, diversify livelihoods, improve infrastructure, and create incentives for conservation, but poorly managed growth can increase waste, resource consumption, habitat disturbance, land-use change, congestion, and unequal benefit distribution. Green tourism therefore requires indicators addressing environmental performance, resource efficiency, community benefits, institutional participation, green investment, and natural capital protection (Law et al., 2017). Rapid tourism development nevertheless creates environmental and social pressures, including littering, inadequate wastewater and solid-waste treatment, ecosystem disturbance, resource consumption, and infrastructure stress. These risks are particularly significant in the Cat Ba Archipelago (Hai Phong, Vietnam) because tourism occurs within protected forests, marine ecosystems, national-park zones, and rural communities. Systems-based planning is therefore required because tourism, livelihoods, conservation, infrastructure, and institutional management are closely interconnected (Thanh & Kambiz, 2010).

The transition towards green tourism consequently requires coordinated investment in environmental infrastructure, ecosystem restoration, clean energy, community participation, and resource management. However, Cat Ba's tourism sites differ substantially in natural assets, accessibility, infrastructure, livelihood structures, environmental pressures, and institutional support. Limited financial and technical resources therefore require decision-makers to determine both which green economy criteria are most important and which sites should be prioritized.

Despite the availability of green economy frameworks, relatively little research integrates multidimensional green economy indicators with community-level tourism prioritization in environmentally sensitive island destinations. Existing studies provide destination-level indicator systems (Law et al., 2017) and

demonstrate multicriteria methods for tourism-site selection and coastal planning (Zarei et al., 2016), but conventional approaches may inadequately represent uncertainty and qualitative expert judgments.

To address this gap, this study integrates Fuzzy Analytic Hierarchy Process (Fuzzy AHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (Fuzzy TOPSIS) to prioritize tourism sites in Cat Ba. Fuzzy AHP determines the relative weights of green economy criteria, while Fuzzy TOPSIS ranks the sites according to their proximity to an ideal green economy solution. Their integration accommodates linguistic judgments and uncertainty while producing a systematic ranking of alternatives (Pourjavad & Mayorga, 2016; Zyoud et al., 2016).

The remainder of the paper is structured as follows. Section 2 presents the study area, data collection, and methodology; Section 3 reports the criterion weights, site rankings, and sensitivity analysis; Section 4 deals with the discussion, policy implications, and limitations; and Section 5 concludes the paper.

## **2. Methodology**

### **2.1. Study area**

The Cat Ba Archipelago lies southeast of Hai Phong city (Vietnam). This predominantly limestone archipelago covers approximately 240 km<sup>2</sup> and comprises 366 islands and islets (Thuc et al., 2013). The wider Cat Ba Biosphere Reserve covers 26,419 ha, including 16,417 ha of terrestrial and 10,002 ha of marine area. Its landscapes include tropical limestone karst, forests, caves, marine lakes, mangroves, wetlands, and coral reefs (Thung et al., 2019). Local livelihoods have traditionally depended on fishing, aquaculture, agriculture, forest-related activities, and increasingly tourism, with substantial differences among communities in accessibility, infrastructure, natural resources, and proximity to tourism centres.

Cat Ba is internationally significant for biodiversity conservation. It includes Cat Ba National Park and has been a UNESCO World Biosphere Reserve since 2004. Its terrestrial and marine ecosystems support numerous rare and endemic species, including the critically endangered Cat Ba langur, while providing important services for fisheries, tourism, coastal protection, and local livelihoods (Pham et al., 2018). In September 2023, the UNESCO World Heritage Committee expanded the Ha Long Bay World Heritage property to include the Cat Ba Archipelago. The resulting Ha Long Bay-Cat Ba Archipelago World Natural Heritage Site is recognized under criteria (vii) and (viii) for its exceptional scenery and marine-invaded tropical karst landscapes (UNESCO World Heritage Centre, 2023). This designation strengthens requirements for protecting outstanding universal value, controlling development pressures, assessing environmental impacts, and managing tourism within ecological carrying capacity.

Cat Ba was selected because it illustrates the opportunities and trade-offs of tourism-led green economic development. Tourism can diversify livelihoods, create employment, improve infrastructure, and strengthen incentives for conservation, but may also increase resource consumption, habitat disturbance, pollution, waste, and unequal benefit distribution. The combination of high conservation value, tourism potential, resource-dependent livelihoods, and multiple protection regimes therefore makes Cat Ba suitable for a multidimensional green economy assessment.

The study assesses ten tourism sites (Figure 1). These sites were purposively selected to capture four dimensions: (i) Several sites lie within or adjacent to protected areas, national-park and biosphere-reserve zones, and areas associated with the World Heritage property, making conservation regulations and ecological carrying capacity important development constraints. Viet Hai is particularly relevant because of its location within the protected landscape of Cat Ba National Park; (ii) The sites vary substantially in

accessibility and infrastructure. Some are well connected to tourism centres and transport networks, whereas others remain relatively isolated, affecting access to markets, public services, investment, clean technologies, and tourism opportunities; (iii) Communities face differing environmental and climate-related pressures, including waste and wastewater, ecosystem degradation, unsustainable resource use, landscape change, and coastal hazards. Resource efficiency, natural capital protection, pollution control, institutional coordination, and risk reduction are therefore central assessment dimensions; and (iv) The sites represent different stages of livelihood and tourism transformation. Fishing, aquaculture, and small-scale agriculture remain important, while tourism increasingly creates opportunities in accommodation, food services, transport, guiding, local products, and community-based tourism. Including both relatively established sites such as Viet Hai and less-developed communities enables the identification of differentiated pathways towards a greener local economy.

The selected sites represent comparative alternatives rather than a statistically representative sample of all tourism destinations in Cat Ba. Their selection supports the decision-making objective of identifying sites with the greatest potential to advance green economy goals and determining where policy intervention, environmental investment, institutional support, and tourism infrastructure should be prioritized.



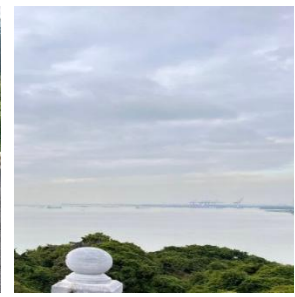
(a)



(b)



(c)



(d)



(e)



(f)



(g)



(h)



(i)



(k)

**Figure 1. Ten selected tourist sites in Cat Ba:** (a) Hamlet *Ngoai* (Phu Long Commune), (b) Hamlet *Ao Coi* (Phu Long Commune), (c) Hamlet 1 (Hien Hao Commune), (d) Hamlet 2 (Hien Hao Commune) (A4), (e) Hamlet *Hai Son* (Tran Chau), (f) Hamlet *Lien Minh* (Tran Chau), (g) Hamlet 1 (Viet Hai Commune), (h) Hamlet 2 (Viet Hai Commune), (i) Hamlet 1 (Xuan Dam Commune), (k) Hamlet 2 (Xuan Dam Commune) (Source: Photos by authors)

## 2.2. A Combination of Fuzzy AHP and Fuzzy TOPSIS

### 2.2.1. Fuzzy AHP

This study employs the Fuzzy AHP to rank criteria related to the green economy goals. This model facilitates the evaluation of the relative significance of various options through a pairwise comparison matrix (Saaty, 1980; Carnero, 2014) and incorporates multiple criteria into the weighting process (Chang, 1996). The Fuzzy AHP introduces linguistic variables to express the relative value of each pair of criteria, thereby mitigating imprecision and uncertainty (Pourjavad & Mayorga, 2016).

In the Fuzzy AHP, experts' ratings are expressed using triangular Fuzzy numbers (Chang, 1996). The Fuzzy matching matrix takes on the following structure:

$$\tilde{A} = (\tilde{a}_{ij})_{n \times n} = \begin{bmatrix} (1, 1, 1) & (l_{12}, m_{12}, u_{12}) & \dots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (1, 1, 1) & \dots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \dots & (1, 1, 1) \end{bmatrix}$$

Inside:

$$\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij}) \text{ and } \tilde{a}_{ij}^{-1} = (1/u_{ij}, 1/m_{ij}, 1/l_{ij}) \text{ with } i, j = 1, \dots, n \text{ and } i \neq j.$$

The steps involved in the Chang's extent analysis method can be succinctly summarized as follows (Chang, 1996):

Step 1: Compute the sum of each row in the matching matrix and subsequently standardize these row sums using Fuzzy arithmetic operations.

$$\tilde{S}_i = \sum_{j=1}^n \tilde{a}_{ij} \otimes \left[ \sum_{k=1}^n \sum_{j=1}^n \tilde{a}_{kj} \right]^{-1} = \left( \frac{\sum_{j=1}^n l_{ij}}{\sum_{k=1}^n \sum_{j=1}^n l_{kj}}, \frac{\sum_{j=1}^n m_{ij}}{\sum_{k=1}^n \sum_{j=1}^n m_{kj}}, \frac{\sum_{j=1}^n u_{ij}}{\sum_{k=1}^n \sum_{j=1}^n u_{kj}} \right)$$

with  $i = 1, \dots, n$

This expression  $\otimes$  represents an extended multiplication operation between two fuzzy numbers, specifically triangular fuzzy numbers. These triangular fuzzy numbers serve as the pertinent weights for each option within a given condition and are also utilized to express the weights associated with each condition. The cumulative weight is then calculated to evaluate each option.

Step 2: Calculate the degree of possibility  $\tilde{S}_i \geq \tilde{S}_j$  using the following formula:

$$V(\tilde{S}_i \geq \tilde{S}_j) = \sup_{y \geq x} \left[ \min \left( \tilde{S}_j(x), \tilde{S}_i(y) \right) \right]$$

The above formula can be represented equivalently as follows:

$$V(\tilde{S}_i \geq \tilde{S}_j) = \begin{cases} 1, & m_i \geq m_j \\ \frac{u_i - l_j}{(u_i - m_i) + (m_j - l_j)}, & l_j \leq u_i, i, j = 1, \dots, n; i \neq j \\ 0, & \text{else} \end{cases}$$

Inside

$$\tilde{S}_i = (l_i, m_i, u_i) \text{ and } \tilde{S}_j = (l_j, m_j, u_j)$$

Step 3: Estimate the priority vector

$$W = (w_1, \dots, w_n)^T$$

of the matching matrix  $\tilde{A}$  as follows:

$$W_i = \frac{V(\tilde{S}_i \geq \tilde{S}_j | j = 1, \dots, n; j \neq i)}{\sum_{k=1}^n V(\tilde{S}_i \geq \tilde{S}_k | j = 1, \dots, n; j \neq k)}, i = 1, \dots, n$$

$$\begin{aligned} \text{But } V(\tilde{S}_i \geq \tilde{S}_j | j = 1, \dots, n) &= V(\tilde{S}_i \geq \tilde{S}_1) \cap V(\tilde{S}_i \geq \tilde{S}_2) \cap \dots \cap V(\tilde{S}_i \geq \tilde{S}_n) \\ &= \min V(\tilde{S}_i \geq \tilde{S}_j), j = 1, \dots, n \end{aligned}$$

So

$$W_i = \frac{\min V(\tilde{S}_i \geq \tilde{S}_j), j = 1, \dots, n; j \neq i}{\sum_{k=1}^n \min V(\tilde{S}_i \geq \tilde{S}_j), j = 1, \dots, n; j \neq k}, i = 1, \dots, n$$

To compare fuzzy parameters in pairs, linguistic variables corresponding to fuzzy numbers are defined, as shown in Table 1.

Table 1: Corresponding linguistic variables and Fuzzy numbers

| Language variables          | Corresponding triangular Fuzzy numbers        | Inverse triangular Fuzzy numbers                            |
|-----------------------------|-----------------------------------------------|-------------------------------------------------------------|
| Extremely important (5)     | (9,9,9)                                       | (1/9,1/9,1/9)                                               |
| Very important (4)          | (6,7,8)                                       | (1/8,1/7,1/6)                                               |
| More important (3)          | (4,5,6)                                       | (1/6,1/5,1/4)                                               |
| More important moderate (2) | (2,3,4)                                       | (1/4,1/3,1/2)                                               |
| Equally important (1)       | (1,1,1)                                       | (1,1,1)                                                     |
| Intermediate                | (7, 8, 9), (5, 6, 7),<br>(3, 4, 5), (1, 2, 3) | (1/9,1/8,1/7), (1/7,1/6,1/5),<br>(1/5,1/4,1/3), (1/3,1/2,1) |

### 2.2.2. Fuzzy TOPSIS

TOPSIS assumes that the preferred alternative should be closest to the positive ideal solution and farthest from the negative ideal solution (Hwang & Yoon, 1981; Wang & Chang, 2007). The fuzzy extension represents linguistic evaluations and uncertainty using triangular fuzzy numbers, making it suitable for multidimensional decisions that cannot be expressed precisely with crisp values (Shanian & Savadogo,

2006; Kutlu & Ekmekçioğlu, 2012; Ajripour & Alamian, 2021). Each alternative is ultimately assigned a closeness coefficient reflecting its relative proximity to the positive ideal solution (Amiri-Aref et al., 2012).

In this study, Fuzzy TOPSIS is used to rank the ten tourism sites according to their performance against the weighted green economy criteria according to six steps.

Step 1: Aggregate the fuzzy ratings of the alternatives

Let

$$\tilde{x}_{ijt} = (e_{ijt}, f_{ijt}, g_{ijt})$$

denote the triangular fuzzy rating assigned to alternative  $A_i$  by decision-maker  $D_t$  with respect to criterion  $C_j$ , where:

$$i = 1, 2, \dots, n; j = 1, 2, \dots, m; t = 1, 2, \dots, l$$

Here,  $n$  is the number of alternatives,  $m$  is the number of criteria, and  $l$  is the number of decision-makers. The three components  $e_{ijt}$ ,  $f_{ijt}$ , and  $g_{ijt}$  represent the lower, modal, and upper values of the triangular fuzzy rating, respectively.

The individual fuzzy ratings are aggregated using the arithmetic mean:

$$\tilde{x}_{ij} = \frac{1}{l} \otimes (\tilde{x}_{ij1} \oplus \tilde{x}_{ij2} \oplus \dots \oplus \tilde{x}_{ijl}) = (e_{ij}, f_{ij}, g_{ij})$$

where:

$$e_{ij} = \frac{1}{l} \sum_{t=1}^l e_{ijt},$$

$$f_{ij} = \frac{1}{l} \sum_{t=1}^l f_{ijt},$$

and

$$g_{ij} = \frac{1}{l} \sum_{t=1}^l g_{ijt}.$$

The resulting fuzzy decision matrix is expressed as:

$$\tilde{X} = [\tilde{x}_{ij}]_{n \times m}.$$

Step 2: Construct the normalized fuzzy decision matrix

Because the evaluation criteria may be measured on different scales, the aggregated fuzzy ratings are normalized using a linear scale transformation. The normalized fuzzy decision matrix is denoted by:

$$\tilde{R} = [\tilde{r}_{ij}]_{n \times m}.$$

For a benefit criterion, for which a higher value indicates better performance, the normalized fuzzy rating is calculated as:

$$\tilde{r}_{ij} = \left( \frac{e_{ij}}{g_j^*}, \frac{f_{ij}}{g_j^*}, \frac{g_{ij}}{g_j^*} \right), j \in B,$$

where:

$$g_j^* = \max_i g_{ij},$$

and  $B$  denotes the set of benefit criteria.

For a cost criterion, for which a lower value indicates better performance, the normalized fuzzy rating is calculated as:

$$\tilde{r}_{ij} = \left( \frac{e_j^-}{g_{ij}}, \frac{e_j^-}{f_{ij}}, \frac{e_j^-}{e_{ij}} \right), j \in C,$$

where:

$$e_j^- = \min_i e_{ij},$$

and  $C$  denotes the set of cost criteria.

This transformation places all fuzzy ratings on a comparable scale while preserving the ordering of the alternatives.

Step 3: Construct the weighted normalized fuzzy decision matrix

The weighted normalized fuzzy decision matrix is obtained by multiplying each normalized fuzzy rating by the corresponding criterion weight derived from the Fuzzy AHP analysis:

$$\tilde{V} = [\tilde{v}_{ij}]_{n \times m},$$

where:

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes w_j, i = 1, 2, \dots, n; j = 1, 2, \dots, m.$$

Here,  $w_j$  denotes the normalized weight of criterion  $C_j$ , and:

$$\sum_{j=1}^m w_j = 1.$$

If

$$\tilde{r}_{ij} = (r_{ij}^L, r_{ij}^M, r_{ij}^U),$$

then:

$$\tilde{v}_{ij} = (w_j r_{ij}^L, w_j r_{ij}^M, w_j r_{ij}^U).$$

Step 4: Determine the fuzzy positive and negative ideal solutions

The fuzzy positive ideal solution, denoted by  $\tilde{A}^+$ , consists of the best weighted performance values observed for each criterion. The fuzzy negative ideal solution, denoted by  $\tilde{A}^-$ , consists of the least desirable weighted performance values.

They are defined as:

$$\tilde{A}^+ = (\tilde{v}_1^+, \tilde{v}_2^+, \dots, \tilde{v}_m^+),$$

and

$$\tilde{A}^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_m^-),$$

where:

$$\tilde{v}_j^+ = \max_i \tilde{v}_{ij},$$

and

$$\tilde{v}_j^- = \min_i \tilde{v}_{ij}.$$

For two triangular fuzzy numbers,

$$\tilde{p} = (p_1, p_2, p_3)$$

and

$$\tilde{q} = (q_1, q_2, q_3),$$

their distance can be calculated using the vertex method:

$$d(\tilde{p}, \tilde{q}) = \sqrt{\frac{1}{3}[(p_1 - q_1)^2 + (p_2 - q_2)^2 + (p_3 - q_3)^2]}.$$

The separation of alternative  $A_i$  from the fuzzy positive ideal solution is:

$$d_i^+ = \sum_{j=1}^m d(\tilde{v}_{ij}, \tilde{v}_j^+),$$

whereas its separation from the fuzzy negative ideal solution is:

$$d_i^- = \sum_{j=1}^m d(\tilde{v}_{ij}, \tilde{v}_j^-).$$

A desirable alternative therefore has a relatively small  $d_i^+$  and a relatively large  $d_i^-$ .

Step 5: Calculate the closeness coefficient

The closeness coefficient of alternative  $A_i$  is calculated as:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}, 0 \leq CC_i \leq 1.$$

The coefficient indicates the relative proximity of each alternative to the fuzzy positive ideal solution. Its boundary conditions are:

$$CC_i = 1 \text{ if } A_i = \tilde{A}^+,$$

and

$$CC_i = 0 \text{ if } A_i = \tilde{A}^-.$$

Therefore, a higher  $CC_i$  indicates stronger overall performance against the green economy criteria.

Step 6: Rank the alternatives

The tourist site alternatives are ranked in descending order of their closeness coefficients. The alternative with the highest  $CC_i$  is considered the closest to the fuzzy positive ideal solution and the farthest from the fuzzy negative ideal solution. It is consequently assigned the highest priority for advancing the green economy goals considered in this study.

### 2.2.3. Integration of Fuzzy AHP and Fuzzy TOPSIS

This study integrates Fuzzy AHP and Fuzzy TOPSIS prioritizing tourist sites in Cat Ba according to their potential to advance green economy goals. The two methods perform complementary functions. Fuzzy AHP determines the relative importance of the green economy criteria, whereas Fuzzy TOPSIS evaluates and ranks the tourist sites based on their overall performance against the weighted criteria. The analytical procedure begins with the identification of criteria and alternatives. Drawing on established green economy frameworks and previous studies, ten criteria are selected and organized into five broader themes: equitable distribution and access, structural transformation, eco-efficiency and productivity, investment in natural capital, and planetary limits. These criteria are subsequently contextualized to reflect the environmental, socio-economic, and institutional characteristics of tourism development in the Cat Ba Archipelago (Table 2).

Decision-makers then conduct pairwise comparisons to assess the relative importance of the ten criteria. Their linguistic judgments are converted into triangular fuzzy numbers and aggregated to construct the fuzzy pairwise-comparison matrix. The consistency of each comparison matrix is assessed using the consistency ratio, with  $CR < 0.10$  indicating an acceptable level of consistency. The resulting fuzzy weights are then defuzzified and normalized before being incorporated into the Fuzzy TOPSIS analysis.

In the Fuzzy TOPSIS stage, decision-makers evaluate the performance of each tourist site against the ten criteria. The individual fuzzy ratings are aggregated, normalized, and multiplied by the corresponding criterion weights obtained from Fuzzy AHP. The fuzzy positive ideal solution and fuzzy negative ideal solution are subsequently determined. For each alternative, the closeness coefficient is calculated based on its distance from the two ideal solutions. The tourist sites are then ranked in descending order of their closeness coefficients, with a higher coefficient indicating stronger overall alignment with the green economy goals.

Finally, a sensitivity analysis is performed by varying the criterion weights under alternative scenarios. This analysis examines whether the rankings remain stable when the relative importance assigned to the criteria changes. It therefore provides evidence of the robustness and reliability of the integrated decision-making framework and supports more defensible policy and investment decisions under conditions of uncertainty.

In the Fuzzy TOPSIS component, the alternatives comprise the ten selected tourist sites:

$$A = \{A_1, A_2, \dots, A_{10}\}.$$

These alternatives are Hamlet Ngoai, Phu Long ( $A_1$ ); Hamlet Ao Coi, Phu Long ( $A_2$ ); Hamlet 1, Hien Hao ( $A_3$ ); Hamlet 2, Hien Hao ( $A_4$ ); Hamlet Hai Son, Tran Chau ( $A_5$ ); Hamlet Lien Minh, Tran Chau ( $A_6$ ); Hamlet 1, Viet Hai ( $A_7$ ); Hamlet 2, Viet Hai ( $A_8$ ); Hamlet 1, Xuan Dam ( $A_9$ ); and Hamlet 2, Xuan Dam ( $A_{10}$ ).

Figure 2 presents the hierarchical structure of the integrated model. The overall objective at the highest level is to prioritize tourist sites according to their potential to advance green economy goals. The second level comprises the ten evaluation criteria, denoted by  $C_1 - C_{10}$ , which are conceptually grouped into the five themes presented in Table 2. These themes are used to organize and interpret the criteria but do not constitute an additional weighting level unless theme-level weights are separately calculated.

The third level contains the ten tourist site alternatives, denoted by  $A_1 - A_{10}$ . Fuzzy AHP determines the weight assigned to each criterion, while Fuzzy TOPSIS uses these weights together with the fuzzy performance ratings to calculate the closeness coefficient and final ranking of each alternative. The structure therefore establishes a direct analytical relationship between the overall green economy objective, the evaluation criteria, and the tourist sites being prioritized.

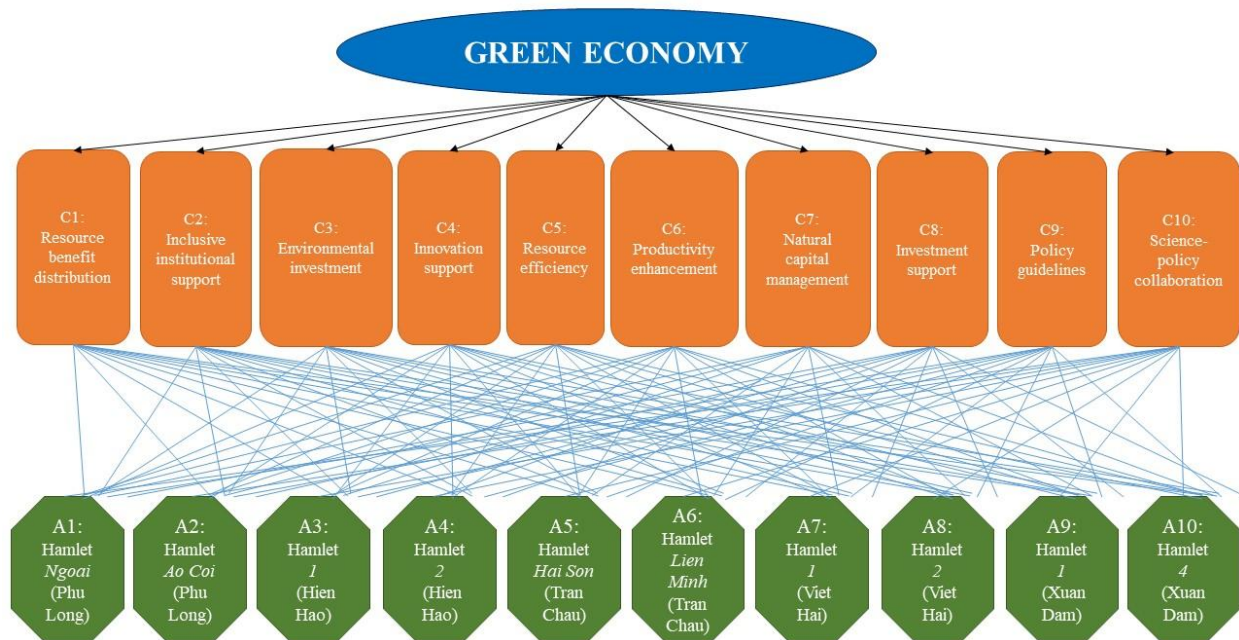


*Figure 2. Hierarchical structure of the integrated Fuzzy AHP-Fuzzy TOPSIS model*

Table 2. Green economy criteria used to prioritize tourist sites in the Cat Ba Archipelago

| <i>Themes</i>                     | <i>Criterion</i>                                  | <i>Operational dimensions</i>                                                                                                                     | <i>Site-level indicators and interpretation</i>                                                                                                                        | <i>Related SDGs and sources</i>                                                     |
|-----------------------------------|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Equitable distribution and access | Resource benefit distribution (C <sub>1</sub> )   | Distribution of benefits derived from resources, energy, ecosystem services, and tourism, together with the distribution of environmental burdens | Equitable access to tourism income, employment, ecosystem services, water, energy, food sources, and infrastructure; fair distribution of environmental burdens.       | [SDGs 8, 10, 11]<br>UNESCAP (2014);<br>Imanov (2021);<br>Stanković et al. (2024)    |
|                                   | Inclusive institutional support (C <sub>2</sub> ) | Institutional and policy support for inclusion and participation                                                                                  | Access to environmental information and meaningful participation of residents and businesses in tourism planning, environmental assessment, and community initiatives. | [SDGs 10, 16, 17]<br>UNESCAP (2014);<br>Ryszawska (2015)                            |
| Structural transformation         | Environmental investment (C <sub>3</sub> )        | Green investment and investment in environmental goods and services                                                                               | Investment in renewable energy, low carbon transport, green buildings, wastewater and solid-waste systems, ecosystem restoration, and payments for ecosystem services. | [SDGs 7, 9, 11, 13]<br>UNESCAP (2014);<br>Ryszawska (2015);<br>Eyraud et al. (2013) |
|                                   | Innovation support (C <sub>4</sub> )              | Institutional and policy support for technological, social, and organizational innovation                                                         | Support for green technologies, environmentally responsible tourism products, eco-design, research, training, and organizational innovation.                           | [SDGs 8, 9, 12]<br>UNESCAP (2014);<br>Nadezhin (2023)                               |
| Eco-efficiency and productivity   | Resource efficiency (C <sub>5</sub> )             | Efficiency in the use of energy, water, materials, and other resources and in the management of waste and emissions                               | Reduction of energy, water, material use, single-use plastics, waste, wastewater, greenhouse-gas emissions, and other tourism-related pollutants.                      | [SDGs 6, 7, 12, 13]<br>OECD (2017);<br>UNESCAP (2014);<br>Li (2024)                 |
|                                   | Productivity enhancement (C <sub>6</sub> )        | Institutional and policy support for resource productivity and operational efficiency                                                             | Resource-productivity gains, green employment, local value added, cost savings, polluter-pays mechanisms, and corporate responsibility incentives.                     | [SDGs 8, 9, 12]<br>UNESCAP (2014);<br>Mikhno et al. (2021); Nadezhin (2023)         |
| Investment in natural capital     | Natural capital management (C <sub>7</sub> )      | Stocks of natural capital and flows of natural resources and ecosystem services                                                                   | Condition, protection, restoration, and sustainable use of forests, mangroves, wetlands, coral and seagrass habitats,                                                  | [SDGs 13, 14, 15]                                                                   |

|                  |                                                 |                                                                                                                                  |                                                                                                                                                                                |                                                                    |
|------------------|-------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|
|                  |                                                 |                                                                                                                                  | marine resources, wildlife, agricultural land, and karst landscapes.                                                                                                           | UNESCAP (2014); Merino-Saum et al. (2018)                          |
|                  | Investment support (C <sub>8</sub> )            | Institutional and policy support for investment in natural capital                                                               | Legal and financial support for protected areas, biodiversity, restoration, landscape conservation, forest and marine management, and payments for ecosystem services.         | [SDGs 13, 14, 15] UNESCAP (2014); Acosta et al. (2020)             |
| Planetary limits | Policy guidelines (C <sub>9</sub> )             | Resource-use, pollution, and emissions limits and targets at regional and national levels                                        | Land- and marine-use zoning, carrying-capacity controls, biodiversity safeguards, traditional-resource protection, and enforceable waste, wastewater, and emissions standards. | [SDGs 11-15, 16] UNESCAP (2014); Law et al. (2017)                 |
|                  | Science-policy collaboration (C <sub>10</sub> ) | Institutional support for the science-policy interface and stakeholder participation in target setting, monitoring, and feedback | Environmental data collection and sharing, evidence-based target setting, monitoring, evaluation, feedback, and stakeholder participation.                                     | [SDGs 16, 17] UNESCAP (2014); OECD (2017); Khalfaoui et al. (2024) |

### 2.3. Data collection

Before the field survey, the research team conducts 4 structured group discussions (SDG) to adapt general green economy indicators to the environmental, socio-economic, and institutional conditions of the Cat Ba Archipelago. These discussions draw on the literature, international green economy frameworks, and the contextual knowledge of invited experts. They generate an initial pool of 11 indicators. After the research team reviews the indicators for relevance, clarity, and conceptual overlap, 10 criteria are retained for inclusion in the decision-maker questionnaire and subsequent Fuzzy AHP-Fuzzy TOPSIS analysis.

Primary data are collected through a structured questionnaire administered to a purposively selected panel of 10 decision-makers ( $D_1 - D_{10}$ ), who assess the 10 selected tourist site alternatives ( $A_1 - A_{10}$ ). The panel comprises seven village leaders ( $D_1 - D_7$ ), two local tourism business owners ( $D_8$  and  $D_9$ ), and one scholar with relevant environmental and tourism expertise ( $D_{10}$ ). The selection of these participants is based on their direct knowledge of the study area, practical experience with local tourism and livelihood activities, or familiarity with the environmental and green economy challenges affecting the coastal and island communities of Cat Ba.

The questionnaire contains four sections and requires approximately 30 minutes to complete. The first section asks respondents to assess the relevance of the proposed green economy indicators using yes-no questions and to explain their assessments based on their knowledge and experience. The second section records the respondent's place of residence, professional position, and relationship with the study area to confirm the contextual basis of the assessment. The third section asks respondents to evaluate the performance of the selected tourist sites against the 10 green economy criteria using linguistic rating scales. The fourth section asks respondents to make pairwise comparisons among the 10 criteria. These comparisons provide the input data for constructing the Fuzzy AHP comparison matrices and calculating the relative criterion weights.

The linguistic assessments are converted into triangular fuzzy numbers and aggregated across the decision-makers. The resulting dataset provides two complementary types of information: the relative weights of the green economy criteria derived through Fuzzy AHP and the performance ratings of the tourist sites used in Fuzzy TOPSIS. Together, these data support the calculation of the closeness coefficients and the final prioritization of the tourist sites.

## 3. Results

### 3.1. Criterion weighting using Fuzzy AHP

Table 3 presents the aggregated pairwise-comparison matrix and the corresponding final AHP weights for the ten green economy criteria. Natural capital management ( $C_7$ ) receives the highest priority, with a weight of 0.141. Policy guidelines ( $C_9$ ) rank second (0.125), followed by inclusive institutional support ( $C_2$ ) (0.102). By contrast, innovation support ( $C_4$ ) receives the lowest weight (0.058). These results indicate that the decision-makers place greater emphasis on protecting natural capital, establishing clear resource uses and environmental limits, and strengthening inclusive institutional arrangements than on the other dimensions of the green economy.

*Table 3. Aggregated pairwise-comparison matrix and final AHP weights of the green economy criteria*

|       | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | Weight | Rank |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------|--------|------|
| $C_1$ | 1.00  | 1.05  | 1.40  | 1.50  | 1.05  | 1.35  | 0.73  | 1.00  | 0.85  | 1.20     | 0.097  | 5    |
| $C_2$ | 1.20  | 1.00  | 1.45  | 1.90  | 1.25  | 1.30  | 0.80  | 1.05  | 0.78  | 1.05     | 0.102  | 3    |
| $C_3$ | 1.13  | 0.92  | 1.00  | 1.70  | 1.17  | 1.05  | 0.72  | 1.30  | 0.80  | 1.20     | 0.095  | 7    |
| $C_4$ | 0.75  | 0.55  | 0.68  | 1.00  | 0.68  | 0.60  | 0.43  | 0.63  | 0.50  | 0.88     | 0.058  | 10   |
| $C_5$ | 1.05  | 0.95  | 1.40  | 1.70  | 1.00  | 1.25  | 0.63  | 0.90  | 0.75  | 1.25     | 0.094  | 8    |
| $C_6$ | 1.05  | 0.85  | 1.20  | 1.80  | 1.10  | 1.00  | 0.58  | 1.25  | 0.75  | 1.45     | 0.096  | 6    |

|                 |      |      |      |      |      |      |      |      |      |      |       |   |
|-----------------|------|------|------|------|------|------|------|------|------|------|-------|---|
| C <sub>7</sub>  | 1.60 | 1.40 | 1.70 | 2.5  | 1.80 | 1.90 | 1.00 | 1.75 | 1.30 | 1.35 | 0.141 | 1 |
| C <sub>8</sub>  | 1.15 | 1.05 | 1.03 | 1.80 | 1.35 | 1.13 | 0.85 | 1.00 | 0.78 | 1.05 | 0.097 | 4 |
| C <sub>9</sub>  | 1.30 | 1.50 | 1.75 | 2.20 | 1.50 | 1.50 | 0.85 | 1.60 | 1.00 | 1.25 | 0.125 | 2 |
| C <sub>10</sub> | 1.05 | 1.20 | 1.08 | 1.48 | 1.10 | 0.85 | 0.97 | 1.05 | 0.95 | 1.00 | 0.093 | 9 |

The consistency of each decision-maker's pairwise-comparison matrix is assessed before the individual judgments are aggregated. Table 4 reports the maximum eigenvalue ( $\lambda_{\max}$ ), consistency index (CI), and consistency ratio (CR) for each decision-maker. The CR values range from 0.054 to 0.098, and all values remain below the acceptable threshold of 0.10. The pairwise comparisons therefore satisfy the consistency requirement and are retained for the subsequent Fuzzy AHP analysis.

**Table 4. Consistency assessment of the decision-makers' pairwise-comparison matrices**

| Decision-maker                   | $\lambda_{\max}$ | Consistency Index (CI) | Consistency Ratio (CR) |
|----------------------------------|------------------|------------------------|------------------------|
| Village leader (D <sub>1</sub> ) | 10.94            | 0.105                  | 0.071                  |
| Village leader (D <sub>2</sub> ) | 11.02            | 0.113                  | 0.076                  |
| Village leader (D <sub>3</sub> ) | 11.01            | 0.112                  | 0.075                  |
| Village leader (D <sub>4</sub> ) | 11.34            | 0.146                  | 0.098                  |
| Village leader (D <sub>5</sub> ) | 11.10            | 0.123                  | 0.082                  |
| Village leader (D <sub>6</sub> ) | 11.25            | 0.139                  | 0.093                  |
| Village leader (D <sub>7</sub> ) | 10.72            | 0.08                   | 0.054                  |
| Business owner (D <sub>8</sub> ) | 10.72            | 0.08                   | 0.054                  |
| Business owner (D <sub>9</sub> ) | 10.99            | 0.111                  | 0.074                  |
| Scholar (D <sub>10</sub> )       | 11.04            | 0.115                  | 0.077                  |

### 3.2. Tourist site prioritization using Fuzzy TOPSIS

The Fuzzy TOPSIS analysis evaluates the ten selected tourist sites against the weighted green economy criteria derived from the Fuzzy AHP stage. Table 5 presents separation measures, closeness coefficients, and final ranking of the tourist site alternatives. The results show that Hamlets 1, 2 in Viet Hai (A<sub>7</sub>, A<sub>8</sub>) rank first and second, with a closeness coefficient of 0.128. Hamlet 1, 2 in Xuan Dam (A<sub>9</sub>, A<sub>10</sub>) follow in third and fourth positions (0.127). Although the differences among the four highest-ranked alternatives are small, the results consistently identify the Viet Hai and Xuan Dam sites as the alternatives closest to the fuzzy positive ideal solution.

Hamlet Ao Coi in Phu Long (A<sub>2</sub>) ranks fifth, with a closeness coefficient of 0.122, followed by Hamlet Ngoai in Phu Long (A<sub>1</sub>), with a coefficient of 0.116. Hamlet Hai Son in Tran Chau (A<sub>5</sub>) and Hamlet Lien Minh in Tran Chau (A<sub>6</sub>) rank seventh and eighth, with coefficients of 0.115 and 0.114, respectively. Hamlet 2 in Hien Hao (A<sub>4</sub>) ranks ninth, with a coefficient of 0.081, whereas Hamlet 1 in Hien Hao (A<sub>3</sub>) ranks last, with the lowest coefficient of 0.078.

The ranking pattern is consistent with the calculated separation measures. The four highest-ranked alternatives are A<sub>7</sub>, A<sub>8</sub>, A<sub>9</sub>, and A<sub>10</sub> have the smallest distances from the fuzzy positive ideal solution ( $d_i^+$ ), ranging from 1.541 to 1.544, and the largest distances from the fuzzy negative ideal solution ( $d_i^-$ ), ranging from 0.224 to 0.226. By contrast, A<sub>3</sub> and A<sub>4</sub> have the greatest distances from the positive ideal solution and comparatively small distances from the negative ideal solution. A higher  $CC_i$  value indicates stronger overall performance across the weighted green economy criteria rather than superiority on any single criterion.

**Table 5. Separation measures, closeness coefficients, and final ranking of the tourist site alternatives**

| Alternatives   | Tourist sites            | $d_i^+$ | $d_i^-$ | $CC_i$ | Rank |
|----------------|--------------------------|---------|---------|--------|------|
| A <sub>1</sub> | Hamlet Ngoai (Phu Long)  | 1.566   | 0.206   | 0.116  | 6    |
| A <sub>2</sub> | Hamlet Ao Coi (Phu Long) | 1.553   | 0.216   | 0.122  | 5    |

|                 |                                     |       |       |       |    |
|-----------------|-------------------------------------|-------|-------|-------|----|
| A <sub>3</sub>  | Hamlet 1 (Hien Hao)                 | 1.627 | 0.137 | 0.078 | 10 |
| A <sub>4</sub>  | Hamlet 2 (Hien Hao)                 | 1.621 | 0.143 | 0.081 | 9  |
| A <sub>5</sub>  | Hamlet <i>Hai Son</i> (Tran Chau)   | 1.569 | 0.204 | 0.115 | 7  |
| A <sub>6</sub>  | Hamlet <i>Lien Minh</i> (Tran Chau) | 1.570 | 0.203 | 0.114 | 8  |
| A <sub>7</sub>  | Hamlet 1 (Viet Hai)                 | 1.541 | 0.226 | 0.128 | 1  |
| A <sub>8</sub>  | Hamlet 2 (Viet Hai)                 | 1.541 | 0.226 | 0.128 | 2  |
| A <sub>9</sub>  | Hamlet 1 (Xuan Dam)                 | 1.542 | 0.225 | 0.127 | 3  |
| A <sub>10</sub> | Hamlet 2 (Xuan Dam)                 | 1.544 | 0.224 | 0.127 | 4  |

### 3.3. Sensitivity analysis

A sensitivity analysis assesses the robustness of the Fuzzy TOPSIS results to changes in the criterion weights (Afshar et al., 2011). The analysis considers 10 scenarios ( $S_1 - S_{10}$ ), each of which is intended to represent a different configuration of weights assigned to the ten green economy criteria. For each scenario, the Fuzzy TOPSIS calculations are repeated to obtain new closeness coefficients and rankings for the ten tourist site alternatives (Table 6). The reported rankings remain unchanged across all ten scenarios:

$$A_7 > A_8 > A_9 > A_{10} > A_2 > A_1 > A_6 > A_5 > A_4 > A_3$$

Hamlet 1 in Viet Hai ( $A_7$ ) consistently occupies the highest position, followed by Hamlet 2 in Viet Hai ( $A_8$ ). Hamlet 1 and Hamlet 2 in Xuan Dam ( $A_9$  and  $A_{10}$ , respectively) remain in the third and fourth positions. The two Phu Long alternatives,  $A_2$  and  $A_1$ , retain intermediate rankings, while the Tran Chau alternatives,  $A_6$  and  $A_5$ , remain in the lower-middle group. Hamlet 2 and Hamlet 1 in Hien Hao ( $A_4$  and  $A_3$ , respectively) consistently occupy the two lowest positions.

The stability of the four highest-ranked alternatives reinforces the conclusion that the Viet Hai and Xuan Dam sites demonstrate the strongest overall alignment with the selected green economy criteria. Similarly, the consistently low rankings of  $A_3$  and  $A_4$  indicate that the relative position of the Hien Hao sites does not depend on a particular criterion-weight configuration. These sites therefore require more substantial improvements in environmental infrastructure, natural capital management, institutional support, and tourism-development conditions before they can compete with the higher-ranked alternatives.

Table 6. Sensitivity scenarios, criterion-weight configurations, closeness coefficients, and rankings of the tourist site alternatives

| Scenarios (S)   | Weight of criteria (w)                                     | Closeness Coefficient (CC) of alternatives (A) |                |                |                |                |                |                |                |                |                 | Ranking                                                                                                                                                             |
|-----------------|------------------------------------------------------------|------------------------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                 |                                                            | A <sub>1</sub>                                 | A <sub>2</sub> | A <sub>3</sub> | A <sub>4</sub> | A <sub>5</sub> | A <sub>6</sub> | A <sub>7</sub> | A <sub>8</sub> | A <sub>9</sub> | A <sub>10</sub> |                                                                                                                                                                     |
| S <sub>1</sub>  | $w_1 = w_2 = w_3 = \dots = w_{10} = [0.066; 0.135; 0.26]$  | 0.151                                          | 0.158          | 0.098          | 0.102          | 0.147          | 0.147          | 0.166          | 0.166          | 0.165          | 0.164           | A <sub>7</sub> >A <sub>8</sub> >A <sub>9</sub> >A <sub>10</sub> >A <sub>2</sub> ><br>A <sub>1</sub> >A <sub>6</sub> >A <sub>5</sub> >A <sub>4</sub> >A <sub>3</sub> |
| S <sub>2</sub>  | $w_1 = w_2 = w_3 = \dots = w_{10} = [0.042; 0.093; 0.194]$ | 0.111                                          | 0.116          | 0.073          | 0.076          | 0.109          | 0.109          | 0.122          | 0.122          | 0.121          | 0.121           | A <sub>7</sub> >A <sub>8</sub> >A <sub>9</sub> >A <sub>10</sub> >A <sub>2</sub> ><br>A <sub>1</sub> >A <sub>6</sub> >A <sub>5</sub> >A <sub>4</sub> >A <sub>3</sub> |
| S <sub>3</sub>  | $w_1 = w_2 = w_3 = \dots = w_{10} = [0.035; 0.081; 0.176]$ | 0.101                                          | 0.105          | 0.066          | 0.069          | 0.099          | 0.099          | 0.110          | 0.110          | 0.109          | 0.109           | A <sub>7</sub> >A <sub>8</sub> >A <sub>9</sub> >A <sub>10</sub> >A <sub>2</sub> ><br>A <sub>1</sub> >A <sub>6</sub> >A <sub>5</sub> >A <sub>4</sub> >A <sub>3</sub> |
| S <sub>4</sub>  | $w_1 = w_2 = w_3 = \dots = w_{10} = [0.02; 0.039; 0.098]$  | 0.056                                          | 0.058          | 0.036          | 0.038          | 0.054          | 0.055          | 0.060          | 0.060          | 0.060          | 0.060           | A <sub>7</sub> >A <sub>8</sub> >A <sub>9</sub> >A <sub>10</sub> >A <sub>2</sub> ><br>A <sub>1</sub> >A <sub>6</sub> >A <sub>5</sub> >A <sub>4</sub> >A <sub>3</sub> |
| S <sub>5</sub>  | $w_1 = w_2 = w_3 = \dots = w_{10} = [0.041; 0.087; 0.187]$ | 0.107                                          | 0.112          | 0.070          | 0.073          | 0.105          | 0.105          | 0.117          | 0.117          | 0.117          | 0.116           | A <sub>7</sub> >A <sub>8</sub> >A <sub>9</sub> >A <sub>10</sub> >A <sub>2</sub> ><br>A <sub>1</sub> >A <sub>6</sub> >A <sub>5</sub> >A <sub>4</sub> >A <sub>3</sub> |
| S <sub>6</sub>  | $w_1 = w_2 = w_3 = \dots = w_{10} = [0.036; 0.082; 0.178]$ | 0.102                                          | 0.106          | 0.066          | 0.070          | 0.100          | 0.100          | 0.111          | 0.111          | 0.111          | 0.110           | A <sub>7</sub> >A <sub>8</sub> >A <sub>9</sub> >A <sub>10</sub> >A <sub>2</sub> ><br>A <sub>1</sub> >A <sub>6</sub> >A <sub>5</sub> >A <sub>4</sub> >A <sub>3</sub> |
| S <sub>7</sub>  | $w_1 = w_2 = w_3 = \dots = w_{10} = [0.071; 0.158; 0.297]$ | 0.172                                          | 0.180          | 0.111          | 0.117          | 0.168          | 0.168          | 0.189          | 0.189          | 0.188          | 0.187           | A <sub>7</sub> >A <sub>8</sub> >A <sub>9</sub> >A <sub>10</sub> >A <sub>2</sub> ><br>A <sub>1</sub> >A <sub>6</sub> >A <sub>5</sub> >A <sub>4</sub> >A <sub>3</sub> |
| S <sub>8</sub>  | $w_1 = w_2 = w_3 = \dots = w_{10} = [0.044; 0.099; 0.203]$ | 0.117                                          | 0.122          | 0.076          | 0.077          | 0.114          | 0.115          | 0.128          | 0.128          | 0.127          | 0.127           | A <sub>7</sub> >A <sub>8</sub> >A <sub>9</sub> >A <sub>10</sub> >A <sub>2</sub> ><br>A <sub>1</sub> >A <sub>6</sub> >A <sub>5</sub> >A <sub>4</sub> >A <sub>3</sub> |
| S <sub>9</sub>  | $w_1 = w_2 = w_3 = \dots = w_{10} = [0.065; 0.145; 0.278]$ | 0.160                                          | 0.168          | 0.104          | 0.109          | 0.157          | 0.157          | 0.177          | 0.176          | 0.176          | 0.175           | A <sub>7</sub> >A <sub>8</sub> >A <sub>9</sub> >A <sub>10</sub> >A <sub>2</sub> ><br>A <sub>1</sub> >A <sub>6</sub> >A <sub>5</sub> >A <sub>4</sub> >A <sub>3</sub> |
| S <sub>10</sub> | $w_1 = w_2 = w_3 = \dots = w_{10} = [0.038; 0.081; 0.171]$ | 0.098                                          | 0.103          | 0.064          | 0.067          | 0.096          | 0.096          | 0.108          | 0.108          | 0.107          | 0.107           | A <sub>7</sub> >A <sub>8</sub> >A <sub>9</sub> >A <sub>10</sub> >A <sub>2</sub> ><br>A <sub>1</sub> >A <sub>6</sub> >A <sub>5</sub> >A <sub>4</sub> >A <sub>3</sub> |

### 3.4. Intervention groups

The small differences in closeness coefficients, particularly among the highest-ranked alternatives, make a grouped interpretation more appropriate than a strict site-by-site ranking. Accordingly, the ten sites are classified into four intervention groups based on their Fuzzy TOPSIS performance and site-specific development conditions (Table 7). These groups indicate differentiated intervention needs rather than a simple hierarchy of tourism investment priorities.

Group I comprises the Viet Hai and Xuan Dam sites ( $A_7, A_8, A_9, A_{10}$ ), which show the strongest current alignment with the selected green economy criteria. Their high priority does not imply accelerated tourism expansion. Instead, interventions should consolidate existing advantages while safeguarding natural capital through carrying-capacity controls, conservation zoning, limits on development intensity, low-impact infrastructure, and mechanisms to retain tourism benefits locally.

Group II comprises the two Phu Long sites ( $A_1, A_2$ ). Their intermediate performance indicates substantial potential for a controlled green-tourism transition, but further progress depends on improvements in environmental infrastructure, coastal and mangrove protection, transport management, tourism skills, enterprise capacity, and participatory spatial planning.

Group III includes the two Tran Chau sites ( $A_5, A_6$ ), whose closeness coefficients are nearly identical. These sites require stronger institutional and market capacity, particularly improved waste and wastewater management, resource-efficient tourism enterprises, local supply chains, landscape protection, and coordination among communities, businesses, and public agencies.

Group IV comprises the two Hien Hao sites ( $A_3, A_4$ ), which have the lowest closeness coefficients. Tourism promotion should therefore be preceded by baseline ecological and livelihood assessments, improvements in essential environmental services and infrastructure, capacity building, risk screening, and small-scale pilot initiatives. This sequencing can reduce the risk of premature tourism expansion before adequate environmental and institutional conditions are established.

*Table 7. Differentiated intervention strategies derived from the Fuzzy TOPSIS priority pattern*

| Intervention groups                                     | Tourist sites                                   | Priority actions                                                                                                                                                                                                                              |
|---------------------------------------------------------|-------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Group I: Consolidate and safeguard                      | $A_7, A_8, A_9, A_{10}$ : Viet Hai and Xuan Dam | Carrying-capacity controls; conservation zoning; limits on development intensity and land conversion; low-impact mobility; wastewater and solid-waste standards; local ownership and benefit retention; transparent environmental monitoring. |
| Group II: Enable a controlled transition                | $A_1, A_2$ : Phu Long                           | Environmental infrastructure; mangrove and coastal safeguards; tourism skills; green finance; enterprise environmental standards; participatory spatial planning; transport management.                                                       |
| Group III: Strengthen institutional and market capacity | $A_5, A_6$ : Tran Chau                          | Waste and wastewater management; resource-efficient tourism enterprises; local supply-chain development; landscape protection; stronger coordination among communities, businesses, and public agencies.                                      |
| Group IV: Prepare before promotion                      | $A_3, A_4$ : Hien Hao                           | Baseline ecological and livelihood assessments; essential environmental services and infrastructure; environmental education and capacity building; risk screening; small-scale pilot initiatives before major tourism development.           |

## 4. Discussion

This study integrates Fuzzy AHP and Fuzzy TOPSIS to weight green economy criteria and prioritize tourism sites in the Cat Ba Archipelago in the Ha Long Bay-Cat Ba Archipelago World Natural Heritage Site

(Vietnam). Fuzzy AHP derives criterion weights from uncertain expert judgments, whereas Fuzzy TOPSIS ranks sites according to their performance against these weighted criteria. This hybrid approach is consistent with previous applications combining criterion weighting with proximity to an ideal sustainability outcome (Patil & Kant, 2014; Pourjavad & Mayorga, 2016; Zyoud et al., 2016). It is particularly suitable for environmentally sensitive island destinations, where environmental, institutional, social, livelihood, and infrastructure conditions cannot always be measured precisely.

The result findings identify natural capital management (C<sub>7</sub>) as the most important criterion, indicating that Cat Ba's green transition is primarily conservation-led, emphasizing ecological protection, enforceable development limits, and equitable benefit sharing. The priority of natural capital management reflects Cat Ba's dependence on forests, karsts, mangroves, marine ecosystems, biodiversity, and scenic resources that support tourism and local livelihoods. Tourism sustainability therefore depends on maintaining these ecological assets. This finding is consistent with previous studies showing that tourism and conservation can reinforce each other within ecological limits (Collins, 1999; Kuo & Hsiao, 2008; Boley & Green, 2015) and with green economy research emphasizing natural capital conservation (Merino-Saum et al., 2018; Acosta et al., 2020). Evidence from Cat Ba also confirms the benefits of marine biodiversity and mangrove conservation (Pham et al., 2018; Thung et al., 2019). The high ranking of policy guidelines (C<sub>9</sub>) highlights the need for enforceable rules on zoning, carrying capacity, construction, waste, resource use, and biodiversity conservation, consistent with green growth frameworks emphasizing ecological limits, implementation, and monitoring (UNESCAP, 2014; OECD, 2017). Following the 2023 World Heritage designation, stronger development controls, impact assessments, monitoring, and institutional accountability are increasingly important (UNESCO World Heritage Centre, 2023). Inclusive institutional support (C<sub>2</sub>) similarly strengthens the legitimacy and implementation of environmental regulations and benefit-sharing arrangements (Thanh & Kambiz, 2010). Resource benefit distribution (C<sub>1</sub>) further shows that conservation must be accompanied by equitable access to tourism income, employment, infrastructure, and ecosystem services while limiting disproportionate social and environmental costs, consistent with inclusive green economy principles (Loiseau et al., 2016; Georgeson et al., 2017). Although innovation support (C<sub>4</sub>) receives the lowest weight, this likely reflects priority sequencing rather than limited relevance. Renewable energy, low-emission transport, environmental monitoring, circular waste systems, and green construction remain important for longer-term transformation (Eyraud et al., 2013; Mikhno et al., 2021; Nadezhin, 2023).

The study extends previous research on the green economy and tourism prioritization by linking multidimensional indicators with community-level spatial prioritization. Law et al. (2017) proposed a tourism green economy framework incorporating environmental performance, economic benefits, social inclusion, and governance. The present study applies comparable dimensions at the community level while adding a mechanism for weighting criteria and ranking sites, thereby identifying where green-tourism interventions should be prioritized.

The approach also resembles Zarei et al. (2016), who combined a network-based weighting method with Fuzzy TOPSIS for tourism-site selection on Qeshm Island. Both studies address island environments characterized by ecological sensitivity, infrastructure constraints, and competing resource uses. However, the present study explicitly structures its criteria around green economy dimensions and evaluates communities within an area that simultaneously functions as a national park, a UNESCO Biosphere Reserve, and part of a World Natural Heritage property. Other integrated Fuzzy AHP-Fuzzy TOPSIS applications confirm the method's suitability for decisions involving uncertain judgments and conflicting sustainability objectives (Pourjavad & Mayorga, 2016; Zyoud et al., 2016), while Forouzandeh et al. (2022) similarly demonstrate the usefulness of proximity-to-ideal methods for distinguishing among tourism alternatives.

The study contributes to this comparative literature in three respects. First, it applies an integrated fuzzy framework below the destination level to compare individual tourism communities. Second, it demonstrates that green economy criteria can distinguish sites with different conservation values, infrastructure, accessibility, livelihood transitions, environmental pressures, and institutional capacities. Third, the sensitivity

analysis indicates that the broad ranking pattern remains stable across the tested weighting scenarios, although several alternatives have identical or nearly identical closeness coefficients.

The Fuzzy TOPSIS results place the two Viet Hai sites (A7 and A8) and the two Xuan Dam sites (A9 and A10) in the highest-priority group. Viet Hai's strong performance reflects its natural landscapes, community-based tourism experience, and close links between livelihoods and protected-area management, consistent with the systems perspective of Thanh and Kambiz (2010), which emphasizes interactions among conservation, infrastructure, governance, and local livelihoods. Viet Hai's high ranking, however, indicates comparative green-tourism potential rather than a case for unrestricted expansion. Policy should emphasize visitor value, longer stays, locally retained income, environmental standards, controlled accommodation capacity, and visitor management to reduce congestion, waste, commercialization, and inappropriate construction. Xuan Dam also performs strongly due to its landscapes, accessibility, improving infrastructure, and livelihood-diversification potential. Unlike Viet Hai, which requires stronger controls on tourism intensity, Xuan Dam requires preventive spatial planning to avoid irreversible land-use change and landscape degradation. The results therefore support differentiated tourism strategies. Phu Long and Tran Chau occupy intermediate positions and require improvements in environmental infrastructure, local value chains, human resources, community participation, and institutional support. Hien Hao ranks lowest, suggesting that environmental remediation, waste and wastewater management, infrastructure, livelihood support, and local capacity development should precede major tourism promotion.

Because several closeness coefficients differ only marginally, the rankings should be interpreted with caution. A<sub>7</sub>, A<sub>8</sub>, A<sub>9</sub>, and A<sub>10</sub> have identical or near-identical values when rounded to three decimal places, indicating that the results are more robust for identifying broad priority groups than for establishing precise rankings within each group. Accordingly, the four groups correspond to differentiated policy regimes: consolidation and safeguarding for Group I, controlled transition for Group II, institutional and market strengthening for Group III, and preparation before promotion for Group IV. Importantly, a high closeness coefficient reflects stronger current alignment with green economy objectives rather than a need for faster tourism expansion. In ecologically sensitive areas, higher-ranked sites may instead require stricter controls on congestion, land conversion, infrastructure pressure, and benefit leakage.

Policy priorities also vary across sites. Viet Hai requires consolidation of its community-based tourism model and tighter management of visitor and accommodation intensity, whereas Xuan Dam requires anticipatory zoning and green infrastructure standards. Phu Long needs stronger environmental safeguards and enterprise support; Tran Chau requires improved institutional coordination and market integration; and Hien Hao needs ecological assessment, basic environmental services, capacity building, and small-scale pilot initiatives before major tourism promotion.

These groups should therefore be treated as adaptive rather than fixed. Reclassification should be based on measurable improvements in ecosystem condition, environmental compliance, local benefit retention, community participation, business environmental performance, and institutional monitoring capacity. Periodic reassessment, supported by field evidence, stakeholder consultation, and environmental and heritage impact assessments, can help redirect financial and technical support as local conditions evolve.

The findings suggest several policy implications. First, tourism planning should adopt a conservation-led and spatially differentiated approach. Given the high importance of natural capital management and policy guidelines, tourism strategies should be integrated with protected area zoning, world heritage management, land-use planning, marine spatial planning, and coastal-zone management. Strategic environmental assessment should address cumulative impacts, while major tourism and infrastructure projects should undergo environmental and heritage impact assessments. Ecological carrying capacities should also be established for visitor numbers, accommodation density, boat traffic, resource use, waste, wastewater, and access to sensitive habitats to protect the integrity and outstanding universal value of the World Natural Heritage property. Second, investment priorities should reflect site-specific conditions. Viet Hai should be developed as a

controlled, low-impact, community-based tourism area, emphasizing local ownership, low-emission transport, accommodation limits, compatible architecture, waste reduction, and local revenue retention. Xuan Dam requires stronger development controls before major investment, including regulations on building density, wastewater, renewable energy, and setbacks from sensitive areas. Phu Long and Tran Chau need improved environmental services, transport, workforce skills, market access, local-product development, and community participation, while Hien Hao should prioritize environmental restoration, basic infrastructure, livelihoods, and institutional capacity. The rankings should therefore guide the sequencing and type of interventions rather than simply investment volumes. Third, green-tourism policy should promote equitable benefit sharing through local procurement, community cooperatives, vocational training, household-business support, payments for ecosystem services, conservation-linked employment, and community funds. These mechanisms can strengthen links between conservation and local welfare while reducing benefit leakage to external investors. Fourth, participatory governance should be institutionalized through site-level management groups involving authorities, communities, conservation and heritage agencies, tourism enterprises, resource users, and researchers. These groups should help set environmental limits, review projects, monitor compliance, and oversee community funds, supported by transparent environmental reporting. Finally, green finance and innovation should reinforce, rather than replace, conservation and governance reforms. Preferential credit, incentives, technical assistance, and public-private investment can support renewable energy, resource-efficient accommodation, low-emission transport, monitoring, and circular waste systems, but public support should depend on measurable environmental and social performance. These priorities align with Vietnam's National Green Growth Strategy for 2021-2030 (Prime Minister of Vietnam, 2021).

Several limitations should be acknowledged. First, although fuzzy methods capture uncertainty, the results remain sensitive to criterion design, linguistic scales, fuzzy-number assignments, aggregation procedures, and defuzzification methods. Second, the model treats the criteria as independent despite likely interactions among institutional support, policy guidelines, investment, benefit distribution, and natural capital management. Network-based methods such as ANP or DEMATEL may better capture these relationships (Zarei et al., 2016). Finally, the rankings rely primarily on expert judgments and are not validated using comprehensive environmental and socio-economic data. Future studies should integrate field monitoring, household and business surveys, GIS, and remote sensing (Malczewski, 1999).

Despite these limitations, the study provides a structured framework for linking green economy objectives with community-level tourism prioritization. Its principal contribution lies not in producing a permanent or deterministic ranking but in making trade-offs explicit, identifying differentiated intervention needs, and supporting transparent decision-making. The integrated Fuzzy AHP-Fuzzy TOPSIS framework can therefore complement environmental assessments, feasibility studies, stakeholder consultation, and adaptive monitoring in the planning of green tourism in the Cat Ba Archipelago.

## 5. Conclusions

This study develops an integrated Fuzzy AHP-Fuzzy TOPSIS framework for prioritizing tourist sites in the Cat Ba Archipelago according to green economy goals. The results identify natural capital management as the most important criterion, followed by policy guidelines, and resource benefit distribution. This ranking underscores the central role of ecosystem protection, enforceable environmental limits, and equitable local benefits in tourism-led green development.

The Fuzzy TOPSIS results place the Viet Hai sites in the highest-priority group, followed closely by the Xuan Dam sites. The sensitivity analysis confirms that this broader ranking remains stable under the tested changes in criterion weights. These findings support a differentiated policy approach that combines natural capital conservation, ecological carrying capacity controls, inclusive community participation, green infrastructure, and equitable benefit-sharing mechanisms. The proposed framework provides a transparent decision-support tool for allocating tourism investment and environmental-management resources and may be adapted to other ecologically sensitive island and coastal destinations.

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## **Ethics approval and consent to participate**

The study protocol was reviewed by the Scientific Council of the Institute for Development Economics and Planning (IDEP) prior to data collection. As the study involved no medical or physical intervention, no vulnerable populations or minors, and no collection of sensitive personal data, IDEP determined that the study was exempt from full institutional ethics committee review under its internal procedures for social-science and survey-based research. The research was conducted in accordance with the principles established under Vietnam's Law on Science and Technology (Law No. 29/2013/QH13)<sup>1</sup> and internationally recognized ethical standards for social science research involving human participants, including respect for voluntary participation, informed consent, and confidentiality. Written confirmation of this review and exemption was issued by IDEP on 6 August 2026 (signed by the Director, Hoang Quoc Lam) and is available from the corresponding author upon request.

## **Consent to participate**

Informed consent was obtained from all participants before completion of the questionnaire. Participants were informed about the purpose of the study, the voluntary nature of participation, confidentiality safeguards, and their right to decline participation or withdraw at any time without disadvantage or penalty.

## **Author Contributions**

Xuan Sinh Le: Methodology, Formal analysis, Writing – original draft.

An Thinh Nguyen : Conceptualization, Methodology, Supervision, Funding acquisition, Writing – review & editing. Corresponding author.

Minh Anh Vi: Investigation, Data curation, Writing – original draft.

Mai Phuong Nguyen: Investigation, Data curation.

Hoai Thi Nguyen: Investigation, Formal analysis.

Ngoc Anh Le: Validation, Writing – review & editing.

Ngoc Trinh Phuong: Investigation, Data curation.

Thi Thao Do : Investigation, Resources.

Tuyen Thi Tran: Investigation, Resources.

Huyen Trang Le: Visualization, Writing – review & editing.

*All authors read and approved the final manuscript.*

## **Conflict of Interest**

The authors declare no conflicts of interest.

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<sup>1</sup> National Assembly of Vietnam (2013). Law on Science and Technology, Law No. 29/2013/QH13. Available at: <https://vanban.chinhphu.vn/?classid=1&docid=169383&pageid=27160&typegroupid=3>

## Data Availability Statement

The datasets generated and analyzed during the current study, comprising the structured questionnaire responses (pairwise comparisons for Fuzzy AHP and linguistic performance ratings for Fuzzy TOPSIS) obtained from the panel of decision-makers, are not publicly available due to confidentiality agreements with the participants but are available from the corresponding author (An Thinh Nguyen, [nguyenanhthinh183@gmail.com](mailto:nguyenanhthinh183@gmail.com)) upon reasonable request.

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