A Hybrid AHP-TOPIS-Based Marine Economic Activities Evaluation Model for Marine Geospatial Data Infrastructure

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ABSTRACT

Marine economic activities are related to the economics of marine resources and maritime sectors, particularly for Marine Geospatial Data Infrastructure (MGDI) and the blue economy. Malaysia has different resource-based economic activities within its maritime delineation zones (MDZs), characterized to be a multi-criteria decision-making (MCDM) problem. However, previous studies have not adequately examined these activities across the MDZs. This paper assesses Malaysia's marine economic activities in these zones through a novel and hybrid framework incorporating the Analytic Hierarchy Process (AHP) and the Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS) models. AHP was used to evaluate the economic criterion of MGDI, while, the priorities obtained serve as part of the input data for the TOPSIS model that examined the trends in economic activities across the MDZs and rank them in order of preference. The results suggest that naval administration, sovereignty, and defense are highly prioritized among the five marine economic activities considered, with a value of 42%. Meanwhile, the Contiguous Zone was the highest-ranked MDZ for economic activities in Malaysian waters, with a computed CC_j values of 27.7%. This approach provides stakeholders with an evaluation model to assess marine economic activities in different MDZs, providing a robust framework for effective evaluations of MCDM, and marine operations.

KEYWORDS: Marine Geospatial Data Infrastructure (MGDI); Ocean Delineation Zones; Blue Economy; Marine Activities; Multiple Criteria Decision-Making (MCDM) Problems; Analytic Hierarchy Process (AHP); Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS); Maritime clusters.

1. INTRODUCTION

Malaysia is a coastal nation that ratified the UN Convention on the Law of the Sea (UNCLOS) on 16th October 1996 (Hamzah, 2019; Saharuddin, 2001). . It is one of the fastest-growing economies in Southeast Asia, ranking third in the region. China is Malaysia's biggest trading partner, accounting for over 30% of its trade and being the world's second-largest economy (Permal and Jamal, 2020). Moreover, Malaysia's coasts and seas are rich in natural resources, with diverse marine life, ecosystems, and habitats that support the country's key maritime sectors. These sectors include offshore energy activities, oil and gas development, fisheries, shipping, freight logistics ports, shipbuilding, marine tourism, maritime transportation, palm oil, timber, other agricultural products,

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and maritime environmental management. These marine activities provide critical security, coastal protection systems, and economic and social benefits to the people, contributing to the country's Gross Domestic Product (GDPs) and revenue generation (Hamzah and Wong, 1997; MIMA, 2021). As a result, these industries offer market-based opportunities and resources for businesses (MIDA, 2021). Thus, Malaysia’s maritime economy is driven by these various marine activities across different sectors.

Between 2011and 2015, Malaysia’s fisheries sector sustained the livelihoods of over 64,000 local fishermen and makes substantial contribution to the national economy. The industry accounted for 1.3% of the country’s GDP, with an annual value of RM 12.7 billion. Additionally, the fish caught from the South China Sea amounted to USD 2.4 billion a year. Malaysia's marine parks offer a wealth of benefits to ecosystem services that include fisheries, the tourism industry, protection of the coast's climate change regulations, as well as nutrient assessments. For instance, an assessment of the six archipelagos of marine parks were valued to be RM 8.7 billion (Department of Marine Park Malaysia (DMPM) (NA). The values reported for other years still reflect the economics of the marine sector.

Marine delineation zones (MDZs) are based on national and international regulations that coastal states follow. The MDZs include Baseline, Internal Waters, Territorial Sea (12 nm), Contiguous Zones (24 nm), Archipelagic Water, Exclusive Economic Zones (EEZ) (200 nm), Continental Shelf, and High Seas Zones (>=350 nm), with their respective nautical miles’ distances from the shoreline (Mean Lowest Low Water (MLLW) mark) (UNCLOS, 2012). The boundaries of MDZs vary depending on the administrative and political jurisdictions and diverse marine economic activities such as fisheries, offshore minerals development, and transportation (Colgan, 2003). Moreover, within these zones are different marine natural resources that require careful evaluation to determine their economic contribution to the MDZs.

It has been suggested that considering different perspectives can lead to better decision-making for effective service delivery (Feeney, 2003; Scott, 2010). As such, Colgan (2016b) has highlighted the opportunities and challenges associated with the concept of a Blue Economy for a sustainable economy of ocean resources. Assessing marine economic activities within the Marine Development Zones (MDZs) involves evaluating their relevant contributions to the Marine Geospatial Data Infrastructure (MGDI) and Blue Economy initiatives. MGDI is a subset of Spatial Data Infrastructure (SDI) (MSDIWG, 2009; Pepper, 2009; Rajabifard *et al.*, 2005; Russell, 2008). MGDI and Blue Economy exhibit multiple criteria decision-making (MCDM) problems, which require criteria evaluations concerning marine activities for seamless marine geospatial solutions (Othman *et al.*, 2011; Saharuddin, 2001).

In other cases, off-shore oil activities and scientific policy directions of the stakeholders could be hindered due to oil spills and the attendant multi-year legal processes. This problem was the case with the 2010 Deepwater spill of BP exploration and production constituting damages to the coastal ecosystems (Nichols and Kildow, 2014). Previous studies have highlighted the economic impact of land loss due to natural environmental challenges, such as global sea-level rise and subsidence) and human activities (such as dredging, channelization, industrial development, agricultural drainage, and oil and gas extraction. Moreover, Colgan (2003) emphasized the various outcomes of the ocean economy from earlier studies. Therefore, it is expected that the contributions of the ocean and coastal economy are time-bound and vary across different regions of interest. These contributions are expressed in different forms, including gross domestic product or related measures, employment, wages, and overall socio-economic dimensions such as population and housing growth.

Table 1. Categorization of Ocean uses (Adapted from Saharuddin, 2001).

S/N	Traditional Marine-Based	Non-Traditional and New Marine-Based
i.	Marine Fishing	Marine Eco-tourism
ii.	Non-renewable resources - Crude Petroleum and Natural Gas Production	Marine Education
iii	Sea Transport Services	Sports and Recreation,
iv	Naval Administration, Sovereignty and Defense	Manufacture of Seafood
v.	Telecommunication	Marine engineering works and services; Manufacture of Marine Engines
vi.	Cable Laying	Fresh water resource management
vii.	Industrial Discharge of Waste	Integrated coastal zone management
viii.	Aquaculture	Renewable resources: e.g. fish stock management.
ix.	Conservation	Habitat management
x.	Marine heritage	Ocean Research and Development
xi.	Marine Biotechnology	Disaster management and emergency response

There are various categories of marine-based activities, such as traditional activities like marine fishing and aquacultures, and non-traditional activities like eco-tourism and ocean research and development.

Meanwhile, evaluating these activities in the MDZs requires the use of Multi-Criteria Decision Making (MCDM) methods, their outputs are expressed as weights or priorities, among others (Kahraman, 2008; Le Roux *et al.*, 2023; Liu *et al.*, 2019; Nyerges and Jankowski, 2010; Rane *et al.*, 2023; Yang and Chen, 2023; Zhao *et al.*, 2020). Some of them were highlighted in Hamid-Mosaku *et al.* (2020). The Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) are two popular MCDM methods used in this study for evaluating marine economic activities in MDZs. According to Zavadskas *et al.* (2016), MCDMs is a comprehensive operations research method, integrating computational and mathematical tools, while Nadkarni and Puthuvayi (2020) considered it to be effectively useful in the selection and raking, based on preferences of the best alternatives, as well as between alternatives in a multidimensional environment (Sierra *et al.*, 2018); and for detailed assessment of such dimensions in a chosen area of interest (Hamid-Mosaku *et al.*, 2024; Villalba *et al.*, 2024; Wei *et al.*, 2024).The AHP approach is computationally simple and widely used by researchers to evaluate the criteria, sub-criteria, and indicators, particularly concerning accuracy, popularity, and theoretical robustness (Chang *et al.*, 2012; Delgado-Galván *et al.*, 2014; Hamid-Mosaku *et al.*, 2024; Hanafiah *et al.*, 2020; Villalba *et al.*, 2024); they were identified and categorized using the AHP model based on MGDI initiatives. The economy criterion is one of the main criteria for evaluating marine-based activities, and it is broken down into sub-criteria like tourism, sport and recreation, fishing and seafood, sea transportation, oil and gas, and another ocean uses. These sub-criteria are then structured according to their contributions to MDZs (Hamid-Mosaku *et al.*, 2016). Therefore, this paper focuses on evaluating the contributions of marine economic activities to the MDZs. These MDZs are distances measured in nautical miles and serve as the alternatives in the TOPSIS method earlier highlighted. AHP is used to estimate the criteria weights, while Cheng *et al.* (2002) posited that TOPSIS is a practical tool and utility-based approach, and is used to compare each alternative with the criteria in the evaluation matrices and weights. Despite the abundance of literature on these methods and applications, there is paucity of reported researches on AHP and TOPSIS in evaluating the criteria and performance of MDZs for the ocean and coastal economy assessments.

It is also to be noted that several previous studies (Janßen *et al.*, 2013; Kildow *et al.*, 2009; Meiner, 2010; Morrissey and O'Donoghue, 2013; Stojanovic and Farmer, 2013; Surís-Regueiro *et al.*,

2013) did not take into account the need to evaluate the importance of criteria weights of marine economic activities and economic sectors. Fernandez-Macho (2016) conducted a new study using Data Envelopment Analysis (DEA), which is a multi-criteria evaluation method. In addition, Colgan (2016a) conducted studies on ocean-dependent marine activities under the current conditions of climate change vulnerability. However, the integrated approach of AHP and TOPSIS was not used in these studies. Furthermore, previous studies did not evaluate these activities separately using either AHP or TOPSIS. Some related studies included ocean-dependent activities and their vulnerability to climate change and risk mitigation studies (Colgan, 2016a; Cooper *et al.*, 2016), quantification of the benefits and costs of coastal infrastructure, and investments (McCreless and Beck, 2016). Additionally, this research presents a hybrid scientific approach that combines AHP and TOPSIS, which has not been considered before. From the foregoing background, the objectives of this study involve assessing Malaysia's main maritime sectors' economic activities, their contextual relevance, and priorities to different marine delineation zones (MDZs). The study achieves this through a literature review, appraisal of criteria and indicators, and emphasis on the importance weights of marine economic activities. The AHP model is used to structure these factors for prioritization. Moreover, the study aims to assess and rate alternatives' performance criteria for the MDZs for marine economic activities through TOPSIS.

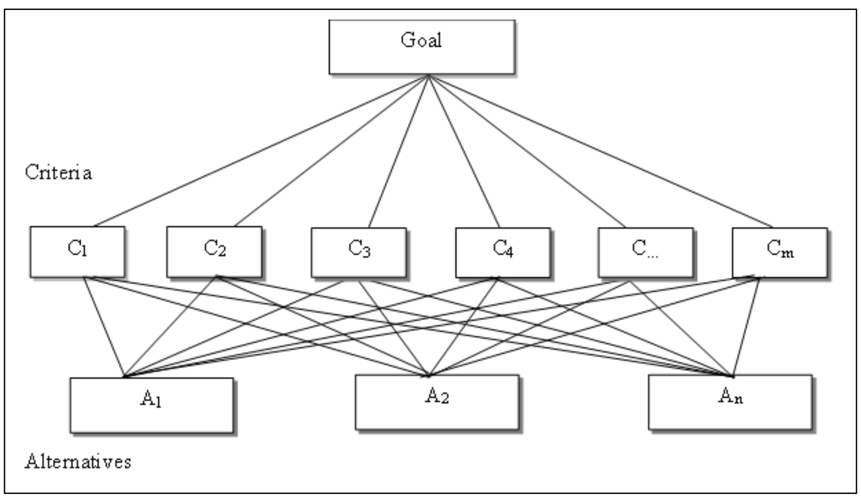

Figure 1. AHP three-level hierarchy structure Source: Saaty and Vargas (2006)

The manuscript is arranged as follows: Section 2 presents the frameworks of AHP and TOPSIS models. Section 3 introduces the methodological frameworks adopted. Section 4 covers the empirical applications of the proposed models, while results and discussion are offered in Sections 5 and 6, respectively. The conclusions are presented in Section 7.

2. FRAMEWORK FOR THE EVALUATION MODELS

The evaluation framework used for this research is based on AHP and TOPSIS models in the context of MGDI initiatives. The framework consists of three stages: i) decomposition of the complex problem into decision elements by carefully identifying the criteria sub-criteria, parameters, indicators, and alternatives for the study through AHP computation, ii) evaluating alternatives using TOPSIS algorithms, and iii) ranking the final computed values for further evaluation.

2.1 Decomposition of the Complex Problem into Decision Elements

The marine environment is complex, and to make viable decisions, there is a need to structure this complexity into a form that can be easily modeled. In this study, ocean activities are reviewed, structured, and evaluated. MDZs are classified into Traditional and Non-Traditional/New Marine-based (Saharuddin, 2001), as shown in Table 1. Furthermore, the identified sub-criteria for marine economic activities are tourism, sport and recreation, fishing and seafood, sea transportation, oil and gas, and other ocean uses. AHP is used to evaluate the importance of these criteria based on their weights. The six steps suggested in previous studies (Hosseinali and Alesheikh, 2008; Ribeiro *et al.*, 2014) was implemented in this study for AHP.

Step 1: The decision problem is broken down into a hierarchical tree-like structure, as shown in Figure 1. At the first level, objective of the study is specified. Other factors identified and reviewed are divided into categories such as criteria, sub-criteria, and alternatives.

Step 2: Next, Equation 1 is used to make pairwise comparisons judgment between the factors represented as matrix (D).

This involves creating a matrix (D) that compares the decision attributes of each criterion as elements $\{x_{ij}\}$ using Eqn. 1, and assigns a degree of preference of ith criterion over jth criterion. Thus, the size of the matrix D requires $n(n-1)/2$ comparisons, where n is the number of criteria or sub-criteria, requiring comparisons.

$$\textit{Comparison matrix}$$

$$D = \begin{matrix} & C_1 & C_2 & C_3 & \cdots & C_n \\ C_1 \\ C_2 \\ C_3 \\ \vdots \\ C_n \end{matrix} \begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \\ x_{31} & x_{32} & x_{33} & \cdots & x_{3n} \\ \vdots & \vdots & \cdots & \cdots & \vdots \\ x_{n1} & x_{n2} & x_{n3} & \cdots & x_{nn} \end{bmatrix} \quad (1)$$

This ensures the comparisons of each element in their respective levels, and those in the next higher level are subject to the following conditions:

$$x_{ii} = x_{jj} = 1 \quad (2)$$

$$x_{ij} = \frac{1}{x_{ji}} \quad (3)$$

In decision-making, experts' judgment is generally sourced from an individual and/or group of experts. The final outputs from the survey are called the priorities. As a result, group decision-makers judgments $(\widetilde{x_{ij}})$ need to be averaged using any of the two known methods (Ayhan, 2013): Arithmetic Mean (AM) (see Eqn .4) or Geometric Mean (see Eqn. 5).

$$\widetilde{x_{ij}} = \frac{\sum_{i=1}^{n} x_{ij}}{n} \quad (4)$$

$$\breve{x}_i = \left(\prod_j^n \widetilde{x_{ij}}\right)^{1/n}, \;\; i = 1, 2, \dots, n, \quad (5)$$

Therefore, the average pairwise comparison matric $(\breve{D})$ is given by Equation 6.

$$\breve{D} = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ \vdots \\ C_n \end{array} \overset{Comparison\ matrix}{\begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & \cdots & C_n \end{array} \\ \begin{bmatrix} \breve{x}_{11} & \breve{x}_{12} & \breve{x}_{13} & \cdots & \breve{x}_{1n} \\ \breve{x}_{21} & \breve{x}_{22} & \breve{x}_{23} & \cdots & \breve{x}_{2n} \\ \breve{x}_{31} & \breve{x}_{32} & \breve{x}_{33} & \cdots & \breve{x}_{3n} \\ \vdots & \vdots & \cdots & \cdots & \vdots \\ \breve{x}_{n1} & \breve{x}_{n2} & \breve{x}_{n3} & \cdots & \breve{x}_{nn} \end{bmatrix} \end{array}} \quad (6)$$

Step 3: Obtain the Normalized Comparison matrix (R) from Eqn. 7 through the normalization procedure from the comparison matrix ($\breve{D}$), as expressed by Eqn. 8.

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad \text{for } ith \text{ criterion over } jth \text{ criterion; } i = 1, 2, 3, \ldots \ldots, n; \;\; j = 1, 2, 3, \ldots \ldots, n. \quad (7)$$

and

$$R = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ \vdots \\ C_n \end{array} \overset{Comparison\ matrix}{\begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & \cdots & C_n \end{array} \\ \begin{bmatrix} r_{11} & r_{12} & r_{13} & \cdots & r_{1n} \\ r_{21} & r_{22} & r_{23} & \cdots & r_{2n} \\ r_{31} & r_{32} & r_{33} & \cdots & r_{3n} \\ \vdots & \vdots & \cdots & \cdots & \vdots \\ r_{n1} & r_{n2} & r_{n3} & \cdots & r_{nn} \end{bmatrix} \end{array}} \quad (8)$$

However, it should be noted that the priorities could be computed either from Eqn. 1 or Eqn. 8 (for an expert) or Eqn. 6 (for group of experts).

Step 4 and 5: Calculate an inconsistency index (μ), using Eqn. 9 based on Eqns. 1 to 3 to adjudge the reliability /consistency of the decision makers' judgment (Saaty and Vargas, 2006; Torfi *et al.*, 2010).

$$\mu = \frac{\lambda_{\max} - n}{n - 1} \quad (9)$$

where λmax and *n* respectively represent the matrix principal eigenvalue and its order. The closer the (μ) value to zero, the greater the consistency. The consistency of the assessment is ensured provided that the equality ($a_{ij}a_{jk} = a_{ik}, \forall i, j, k$) is true for the criteria. Thereafter, the result for the weights of the matrix is accepted if the value of the relevant index is less than 0.10 and thus considered to be consistent; otherwise, the survey must be done again (Forman and Peniwati, 1998; Saaty, 1980; Saaty, 1990).

Furthermore, from Eqn. 9, λ_{max} represents the highest eigenvalue of the matrix. Also, the consistency index of a randomly generated reciprocal matrix is called the random index (R.I.). Alonso and Lamata (2006) provide the generated average RI values (Table 2) for orders 1–15 matrices with a sample size of 100.

Next, the consistency ratio (C.R.) values are computed based on Equation 10. A C.R. <= 0.1 shows a consistent judgment, and the derived weights could be adopted for further analyses.

Table 2. RI (*n*) values (Alonso and Lamata, 2006)

n	**3**	**4**	**5**	**6**	**7**	**8**	**9**
R.I.	0.5799	0.8921	1.1159	1.2358	1.3322	1.3952	1.4537
n	10	11	12	13	14	15	-
R.I.	1.4882	1.5117	1.5356	1.5571	1.5714	1.5831	

$$\mathrm{C.R.} = \frac{\mathrm{C.I.}}{R.I.} \tag{10}$$

Therefore, the essence of these steps is to calculate the C.R. values is to ensure the reliability of the experts' judgment.

Step 6: Combine the weighted decision elements by using the hierarchical synthesis of the normalized eigenvectors and adding up all the weighted eigenvector entries from the lower hierarchies. This method helps to obtain priority vectors from a set of eigenvectors for each matrix, based on Eqn. 1 or Eqn. 8. However, computing the eigenvector can be time-consuming, so the geometric mean method provides an approximation approach to its calculation (Saaty and Kearns, 1985). In this method, the elements (n) in each row are multiplied and their nth root is calculated. Then, the elements in each column of the matrix are normalized. In this way, the average of each row represents the computed priorities.

2.1.1 Computational Platforms

There were two computational platforms used in this study for AHP computations. One is the existing SuperDecision decision support software for AHP and ANP implementation (SuperDecisions, 2024) and a developed ***MgdiEureka***.

2.2 Alternative Evaluation using TOPSIS-Based Models

Hwang and Yoon (1981) proposed the Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS) method, which is used for rating and evaluating problems related to alternatives in real-world decision-making challenges; Liu *et al.* (2019) affirms it to be an evaluation technique solving multi-criteria problems.

Behzadian *et al.* (2012); Pandey *et al.* (2023) performed a comprehensive review of TOPSIS applications in the literature. The TOPSIS method has been used in many other studies, either directly or in combination with other MCDM approaches (Chaube *et al.*, 2024; Dağdeviren and Yüksel, 2008; Le Roux *et al.*, 2023; Liu *et al.*, 2019; Önüt and Soner, 2008; Rane *et al.*, 2023; Singh and Benyoucef, 2011; Yang and Chen, 2023; Zhao *et al.*, 2020). However, there is a lack of studies and knowledge gaps for MGDI initiatives, decisions, and marine economic issues, except for these studies (Hamid-Mosaku, 2014; Hamid-Mosaku *et al.*, 2014; Hamid-Mosaku *et al.*, 2016; 2017; Hamid-Mosaku *et al.*, 2020) and the work of Stithou (2017) that highlighted the methods and tools for marine environmental issues; the GEOIDE project on Good Governance of Canada's Oceans (GGE, 2002), and that of indicators' evaluation for comparative maritime socioeconomic framework for the European Atlantic area (Fernandez-Macho, 2016; Foley *et al.*, 2015) as in the MARNET (Marine Atlantic Regions Network) project.

The study adopted the steps used in previous research (Önüt and Soner, 2008; Yildirim *et al.*, 2016) for the implementation of the TOPSIS model, as follows:

Step 1: Create a decision matrix that compares each alternative with each of the criteria involved, as shown in Eqn. 11.

The matrix A consists of elements $\{A_j\}$, denoting sets of alternatives j, $\mathrm{j} = 1,2,3\ldots,\mathrm{J}$; Fi represents the degree of preference of ith attributes or criterion $\mathrm{i} = 1,2,3\ldots,\mathrm{n}$; over ith alternatives; f_{ij} is a crisp value indicating the performance rating of each alternative A_i with respect to each criterion F_j, which can be a 'benefit' or 'cost' criterion; n is the number of criteria.

$$Comparison\ matrix$$

$$A = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_i \\ \vdots \\ A_j \end{array} \begin{array}{c} \begin{array}{cccccc} F_1 & F_2 & F_3 & F_j & \cdots & F_n \end{array} \\ \begin{bmatrix} f_{11} & f_{12} & f_{13} & \cdots & f_{1j} & \cdots & f_{1n} \\ f_{21} & f_{22} & f_{23} & \cdots & f_{2j} & \cdots & f_{2n} \\ f_{31} & f_{32} & f_{33} & \cdots & f_{3j} & \cdots & f_{3n} \\ \vdots & \vdots & \cdots & \cdots & \vdots & \cdots & \vdots \\ f_{i1} & f_{i2} & f_{i3} & \cdots & f_{ij} & \cdots & f_{in} \\ \vdots & \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ f_{j1} & f_{j1} & f_{j1} & \cdots & f_{jj} & \cdots & f_{jn} \end{bmatrix} \end{array} \tag{11}$$

Step 2: Compute the normalized decision matrix $\mathbb{R} = \left[(r_{ij})\right]$, based on Equation 12:

$$\acute{r}_{iJ} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{n} f_{ij}^2}} \qquad j = 1, 2, 3, \dots \dots, J; i = 1, 2, 3, \dots \dots, n; and \sqrt{\sum_{j=1}^{n} \acute{r}_{ij}} \geq 1 \tag{12}$$

However, it is worth noting that there are various normalization algorithms available in the literature that do not necessarily add up to unity. This has been exemplified in previous studies (Basu *et al.*, 2012; Deng *et al.*, 2000; Diakoulaki *et al.*, 1995; Nyerges and Jankowski, 2010; Shih *et al.*, 2007). Additionally, the authors have highlighted several algorithms (e.g., vector, linear, non-monotonic) for computing matrix normalizations, along with distance functions for computing TOPSIS ideal solutions. These distance functions include Minkowski's (L_p) metric for Manhattan distance, where p = 1, Euclidean distance where p = 2, and Tchebycheff distance p = ∝, as well as Weighted (L_p) metrics. In some cases, Deng *et al.* (2000) used four different algorithms (entropy measure (EM), Criteria Importance Through Intercriteria Correlation (CRITIC) – proposed by Diakoulaki *et al.* (1995), standard deviation (S.D.), and mean weight (MW)) to compute the objective weights for the case study considered, in order to examine the usefulness of the TOPSIS method.

Step 3: From Step 2, compute the weighted normalized decision matrix (v_{ij}), obtained as the product of the normalized decision matrix r_{ij} and its weights w_i, as shown by Eqn. 13:

$$v_{ij} = \left(w_i * \acute{r}_{iJ}\right) \qquad j = 1, 2, 3, \dots \dots, J;\ i = 1, 2, 3, \dots \dots, n \tag{13}$$

where w_i indicates the weight of ith attribute or criterion, and $\sqrt{\sum_{j=1}^{n} w_i} = 1$, as obtained from the decision matrix D based on Eqn. 7 and Eqn. 8, but v_{ij} will not necessarily be equal to unity. This is also the case in some previous studies (Basu *et al.*, 2012; Deng *et al.*, 2000; Diakoulaki *et al.*, 1995; Nyerges and Jankowski, 2010; Shih *et al.*, 2007).

Step 4: Compute the positive-ideal (A^*) (Eqn. 14) and negative-ideal (A^-), (i.e., PIS and NIS) solutions, using Eqn. 15:

$$A^* = \{v_1^*,\ \ v_2^*\ \ v_3^*, \dots \dots . v_i^*\} = \left\{\left(\max v_{ij} \,\middle|\, i \in I'\right),\ \left(\min v_{ij} \,\middle|\, i \in I''\right)\right\}, \tag{14}$$

$$A^- = \{v_1^-,\ \ v_2^-\ \ v_3^-, \dots \dots . v_i^-\} = \left\{\left(\min v_{ij} \,\middle|\, i \in I'\right),\ \left(\max v_{ij} \,\middle|\, i \in I''\right)\right\}, \tag{15}$$

where I' is linked with the benefit (or positive) criteria, and $I^{"}$ is related to the cost (negative) criteria. This can be achieved based on the type of criterion on each column, which could be a benefit criterion or cost criterion, as highlighted in Step 1. Subsequently, choose the highest value on a benefit criterion column for a positive ideal solution (PIS) and the least for a negative ideal solution (NIS). Otherwise, the highest value on a cost criterion column is chosen for a negative ideal solution (NIS) and the least is chosen for a positive ideal solution (PIS).

Step 5: Compute the separation measures, using n-dimensional Euclidean distance. The separation of each alternative from the positive-ideal solution D_j^* is given as (Eqn. 16):

$$D_j^* = \sqrt{\sum_{i=1}^{n}\left(v_{ij} - v_i^*\right)} \quad j = 1, 2, 3, \dots \dots, J. \qquad (16)$$

Similarly, separation of each alternative from the negative-ideal solution D_j^- (Eqn. 17) is:

$$D_j^- = \sqrt{\sum_{i=1}^{n}\left(v_{ij} - v_i^-\right)} \quad j = 1, 2, 3, \dots \dots, J. \qquad (17)$$

Step 6: Compute the relative closeness to the ideal solution. The alternative A_j can be expressed as (Equation 18):

$$CC_j^* = \frac{D_j^-}{D_j^* + D_j^-} \qquad (18)$$

where the CC_j^* index value lies between 0 and 1.

Step 7: Use the index values to rank the performance of the alternatives (Opricovic and Tzeng, 2004). The larger the index value, the better the performance.

2.3 Ranking the Final Computed Values and Further Evaluation

The final ranking is obtained from the computed CC_j^* values, as in Step 7 of sub-section 2.2. Further evaluation is followed in Sections 5 and 6 under Results and Discussion.

3 MATERIALS AND METHODS

The following section provides a description of the sources of materials used and the methodology adopted for this study. A hybrid methodology was used based on the three stages described in Section 2.

3.1 Study Area

This investigation focuses on the Malaysian maritime zone, including Malaysia Peninsular and the states of Sabah and Sarawak. The study area is separated by over 400 miles of the South China Sea and almost 2,000 nautical miles of ocean and airspace. The neighboring countries are Thailand to the north and Singapore to the south. Indonesia borders Sabah and Sarawak, while Sarawak shares a border with Brunei Darussalam (MICC, 2008).

Malaysia gained jurisdiction over a continental shelf of 373,500km^2 and an Exclusive Economic Zone (EEZ) of 475,600km^2 (Saharuddin, 2001) by ratifying with UNCLOS. The country has a total land area of 332,800 km^2, a total maritime extent of 623,907 km^2, and a coastline of 4490 km (Taib, 2009a). Figure 2 provides a map extent of the study area.

Figure 2. Map of Malaysia (Peninsular, Sabah and Sarawak).

3.2 The Analytical Hierarchy Process (AHP) Procedure

The criteria (factors) for the AHP procedure were reviewed from literature. Thereafter, a Delphi process was conducted to critically assessed them with marine stakeholders in three rounds until a consensus was reached in order to ascertain their correctness and suitability. Afterward, an AHP structured questionnaire was developed and administered among three sets of marine experts' groups from academia (tagged as 'Expert Group 1'), mapping agencies (tagged as 'Expert Group 2'), and producers and end-users (tagged as 'Expert Group 3'). Subsequently, the pairwise comparison matrices from the thirty experts' judgments were grouped, and the mean was used to formulate the AHP model (Hamid-Mosaku *et al.*, 2016). Based on this model, marine economic activities in Malaysia were designated as A11 (Tourism, sport, and recreation), A12 (Fishing and seafood), A13 (Sea transportation), A14 (Oil and gas), and A15 (Naval administration, sovereignty, and defence), as earlier depicted in Table 1.

3.2.1 Brief about *MgdiEureka*

In Hamid-Mosaku (2014), the ***MgdiEureka*** was fully described as a standalone Desktop Web-Based application developed using the Model, View and Control (MVC) Framework and system analyses, design and development (SADD) concepts. It was divided into two: Module I is a users' interactive interface; developed using JavaScripts/Apache/MySQL/PHP (JAMP) and Module II is a combination of ASP.Net and C# developed for the analytic computational algorithms of MCDM procedures for AHP, ANP, FAHP, TOPSIS, and FTOPSIS and their extensions in a fuzzy environment.

3.3 Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS) Procedure

The marine delineation zones (MDZs) were chosen as the alternatives $\{A_j\}$ for this study, and depicted as ALT1-ALT5. The TOPSIS approach measures the relative weights of these alternatives criteria: (ALT1 for Internal Waters, ALT2 for Territorial Sea (12 nm), ALT3 for Contiguous Zones (24 nm), ALT4 for Exclusive Economic Zones (200 nm), and ALT5 for Continental Shelf and High Seas (>=350 nm) in relation to the MDZs, whose influences are being investigated based on the identified marine activities. This is the TOPSIS Comparison Matrix (A) – Eqn 11, of marine economic activities with Alternatives. The relative weights are evaluated based on Eqns. 11 to 18. The first three criteria from Sub-section 3.2 were classified as 'benefit criteria' while the last two were 'cost criteria'.

4 EMPIRICAL APPLICATIONS OF THE MODELS

This section provides empirical and practical applications of the models presented thus far.

4.1 Empirical Applications for AHP Model

Table 3 shows the empirical data used for marine economic activities based on the mean AHP pairwise comparison matrix (D) obtained from the expert groups. The data was obtained from Step 2 and Eqns. 1 to 6 from Sub-section 2.1.

Table 3. Pairwise comparison matrix for the Analytic Hierarchy Process (AHP) model.

Criteria	**AHP_Decision Matrix**				
A1	A11	A12	A13	A14	A15
A11 Tourism, Sport and Recreation	1	0.167	0.200	0.143	0.125
A12 Fishing and Sea Food	6	1	2	0.500	0.333
A13 Sea Transportation	5	0.500	1	0.333	0.250
A14 Oil and Gas	7	2	3	1	0.500
A15 Naval administration, sovereignty and defence	8	3	4	2	1

4.1.1 *MgdiEureka* Computational Interface

A sample interface of *MgdiEureka* is shown in Figure 3. The results obtained from it were compared with those from the SuperDecision software as presented in Section 5.

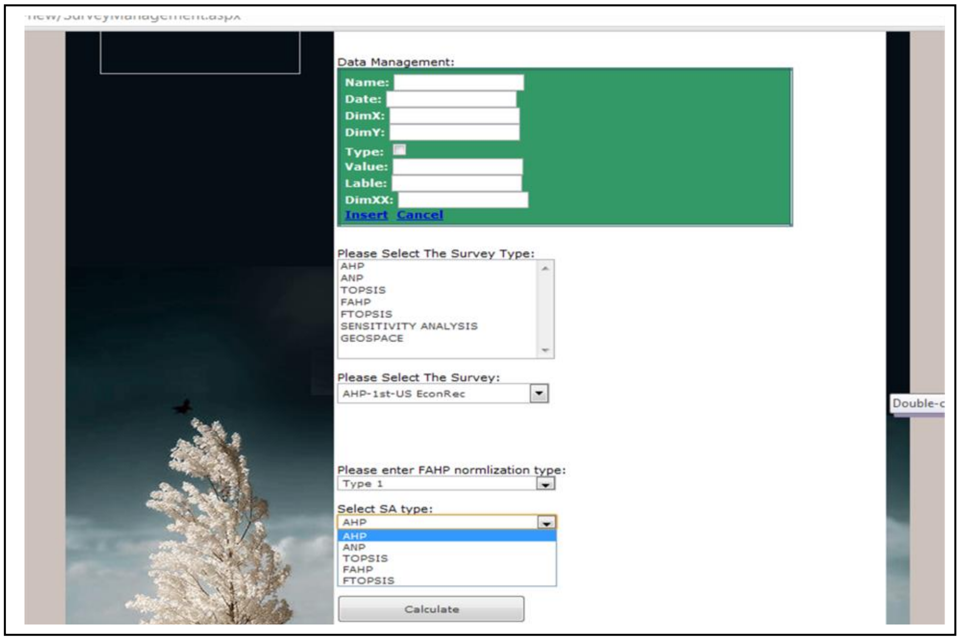

Figure 3 Module II Interface, with different survey options (Hamid-Mosaku

4.2 Empirical Applications for TOPSIS Procedure

4 compares various marine economic activities with different alternatives. The values in this Table 4 are the computed mean comparison matrix (A) for the performance rating of the alternatives A_i based on the marine economic activities' criteria F_j. The expert groups obtained these ratings through Step 1, Eqn. 11, and through Eqns. 12 to 18 from sub-section 2.2. Thus, from Table 3, criteria A11 to A13 have been selected as 'benefit criteria' while A14 and A15 were chosen as 'cost criteria'. The 'benefit criteria' includes criteria that are shared by government parastatals and other public or private users. On the other hand, 'cost criteria' include those directly from the government and parastatals.

Table 4. TOPSIS Comparison Matrix of marine economic activities with Alternatives

Alternative Decision Matrix for TOPSIS Method					
A1	A11	A12	A13	A14	A15
ALT1	0.429	0.393	0.076	0.039	0.188
ALT2	0.429	0.393	0.297	0.058	0.321
ALT3	0.048	0.120	0.297	0.058	0.116
ALT4	0.048	0.062	0.297	0.351	0.321
ALT5	0.048	0.033	0.033	0.494	0.053

5 RESULTS

The following section presents the results of the study based on the four stages outlined in Section 2. The ***'MgdiEureka'*** system developed and adopted for this study was used for the computations in parts while the SuperDecisions software was used for AHP/ANP. The validity of the AHP computations was confirmed by comparing them with the results obtained using the SuperDecision software.

5.1 Evaluation of AHP Results

The computed priorities (weights) and consistency ratio (C.R.) of the AHP model were evaluated based on Steps 4 and 5, and Eqns. 9 and 10. Table 5 shows the results of this evaluation using both ***MgdiEureka*** and SuperDecisions software. Their respective C.R. values are 0.0317 and 0.0311, both of which are within the acceptable C.R. value of 0.10 (i.e., 0.0317, 0.0311 < 0.1). This indicates that the weights are consistent. Additionally, the computed C.I. value was 0.0303 based on Eqn.9. Meanwhile, the comparison helps to validate the ***MgdiEureka*** values with those obtained by the SuperDecisions software. The percentage differences are not so significant to affect the overall decisions. These priorities serve as part of the input data for TOPSIS computations.

Table 5. Priority Results from AHP computation and Comparison of AHP Priority from **MgdiEureka** and SuperDecisions.

AHP_Decision Matrix						**Computed Priority Results**				
A11	A12	A13	A14	A15	A1	***MgdiEureka (by Geometric Mean)***	Super Decisions	Average Priority	Diff.	% Difference
1	0.167	0.2	0.143	0.125	A11	0.033	0.034	0.034	0.00073	0.073
6	1	2	0.5	0.333	A12	0.1688	0.168	0.168	-0.00083	-0.083
5	0.5	1	0.333	0.250	A13	0.107	0.108	0.1089	0.00102	0.102
7	2	3	1	0.500	A14	0.270	0.268	0.269	-0.00204	-0.204
8	3	4	2	1	A15	0.421	0.422	0.421	0.00114	0.114
Consistence Ratio (C.R.) Test results						0.0317	0.031	0.031	0.0006	0.06

5.2 Evaluation of TOPSIS Results

The TOPSIS algorithm has been evaluated using various procedures outlined in Sub-sections 2.2 and 3.3, and by Eqns. 11 to 18. Tables 6 to 9 are the computational outputs from the TOPSIS algorithms for the computation of the final CC_j values for ranking the alternatives. However, it should be noted that the column normalization in Table 6 based on Eqn. 12 represents a special case where the usual sum to unity for normalization does not seems to apply. In fact, it is always more than one. This has also been observed in previous studies (Deng *et al.*, 2000; Diakoulaki *et al.*, 1995; Shih *et al.*, 2007; Vahdani *et al.*, 2013). Therefore, the result for the computed CC_j values is shown in Table 8, with the normalized CC_j equivalents. The final ranked CC_j value is shown in Table 9. Figure 4 provides a comparison of computed CC_j values with different alternatives for TOPSIS algorithms.

6. DISCUSSION

The ocean activities and resources in Malaysia involve multiple stakeholders. Various ministries and agencies are involved in maritime clusters, including PETRONAS, Department of Environment (DOE), Marine Department Malaysia (MARDEP), National Hydrographic Center (NHC), Royal Malaysia Navy (RMN), Malaysian Investment Development Authority (MIDA), Department of Fisheries, Malaysia, Ministry of Transport Malaysia, Economic Planning Unit (EPU), Malaysia Petroleum Resources Corporation (MPRC), Ministry of Energy, Science, Technology, Environment & Climate Change (MESTECC), and Ministry of Science and Technology.

This study explores the significance of various marine activities and their prioritization for accurate evaluations along the marine delineation zones (MDZs) through a hybrid approach. This method has practical implications for implementing decision support capabilities that can be incorporated into the MGDI initiatives and MGDI decisions, particularly in relation to MDZs, marine economic activities, marine sectors, and Blue Economy concepts. The most highly ranked marine economic activity is A15 (Naval administration, sovereignty, and defense), with a priority value of over 42%, suggesting that expert opinions are being judged from both security and national concerns for coastal states against all forms of threats, rather than from the view of the marine economy in isolation. This also highlights the national investment in maritime security and surveillance for coastal states. Additionally, Ridzwan (2022) reported that the Royal Malaysian Navy (RMN) has allotted MYR2.4 billion (USD524.84 million) for the procurement of three improved Littoral Mission Ship (LMS) vessels in its 2023 defense budget, which underscores the importance and economic commitment of Malaysia to its territorial waters. External aggressions from neighboring countries at times might provoke such actions.

It's worth noting that the most important marine economic activities are those related to oil and gas (A14), which have a priority value of slightly above 26.9%. These activities are economically viable within the maritime delineation zone of any coastal state. Fishing and seafood, categorized as A12, come in third place with a priority value contribution slightly above 16.9%. A previous study by (Othman, 2004) identified three major roles played by the fisheries industry in Malaysia. These are: providing protein foods, creating employment opportunities for almost 86,000 rural fishermen, and contributing to the development of infrastructure in both local and urban areas, as well as international trade. However, there has been a shift towards industrialization in the country, resulting in a drop in the GDP of the Malaysian economy by 3.7% between 1983-2003 in agriculture. On the other hand, the fisheries sector contributed around 1.6% to the national gross domestic products (GDP) during that period.

According to this study, the ALT3-Contiguous Zones (24 nm) are the most significant maritime delineation zones for economic activities in Malaysian waters, with a contribution of slightly over 27.7%. The ALT1-Internal Waters follow closely behind with 25.8%, while the ALT2-Territorial Sea (12 nm) and ALT5-Continental Shelf and High Seas (>=350 nm) have values of over 19.7% and 18.5% respectively. The least significant zone, with a value of 8.8%, is the ALT4-Exclusive Economic Zones (200 nm). Figure 4 shows the distributions of the CC_j value. For this study, it is worth noting that the low value for the ALT4-Exclusive Economic Zones (200 nm) may be due to the constraints imposed by neighboring countries (Indonesia and Singapore) along the southern part of Peninsular Malaysia. This means that the full potential of this zone is not being fully harnessed, unlike what happens on the eastern part with Sabah and Sarawak.

Consequently, ALT5_Continental Shelf and High Seas (>=350 nm) has a higher value than ALT _4. This is because the marine activities of oil and gas that predominant in the eastern part of Malaysia, as well as Sabah and Sarawak within the South China Sea areas. The minimum values from ALT_4 and ALT_5 are not too surprising. They implied that Malaysia is yet to fully harness the abundant marine economic activities in these two zones. These findings are consistent with previous reports (DOFM, 2013; 2014; FAO, 2010). Thus, based on the results from Tables 8 and 9, the marine delineation zones can be ranked in descending order as follows: ALT3_Contiguous Zones (24 nm) > ALT1_Internal Waters > ALT2_Territorial Sea (12 nm) > ALT5_Continental Shelf and High Seas (>=350 nm) > ALT4_Exclusive Economic Zones (200 nm).

The computed results assigned the ranking significance described below, to the different economic activities in this cluster: Naval administration, sovereignty, and defense (A15), oil and gas (A14), fishing and seafood (A12), sea transportation (A13), and tourism, sport, and recreation (A11). These activities account for over 85% of the total priority values, while the rest make up just over 14%. Table 5 shows the ranking of these activities in descending order. It's important to note that each of these industries contributes significantly to the GDP, with tourism, sport, and recreation (A11) being particularly important in the Malaysian context.

Table 6. TOPSIS Normalized Matrix using **MgdiEureka**

A1	**A11**	**A12**	**A13**	**A14**	**A15**
ALT1	0.7006	0.686	0.1459	0.0637	0.3704
ALT2	0.7006	0.686	0.5700	0.0947	0.6324
ALT3	0.0784	0.2095	0.5700	0.0947	0.2285
ALT4	0.0784	0.1082	0.5700	0.5728	0.6324
ALT5	0.0784	0.0576	0.0633	0.8062	0.1044
Col-Sum	1.6364	1.7473	1.9192	1.6321	1.9681

Table 7. Weighted TOPSIS Normalized Decision Matrix using **MgdiEureka**

A1	**Benefits Criteria**			**Cost Criteria**	
	A11	A12	A13	A14	A15
ALT1	0.0233	0.1157	0.0157	0.0172	0.1557
ALT2	0.0233	0.1157	0.0612	0.0256	0.2659
ALT3	0.0026	0.0354	0.0612	0.0256	0.0961
ALT4	0.0026	0.0183	0.0612	0.1547	0.2659
ALT5	0.0026	0.0097	0.0068	0.2178	0.0439

Table 8. TOPSIS Results

Positive Ideal Solution	**Negative Ideal Solution**	**ALT**	**Separation Distance Measure**		**Relative Closeness (CC_j)**		
			D+	D-	Computed CC_j	Normalized (CC_j)	% Normalized (CC_j)
0.0233	0.0026	ALT1	0.1207	0.2532	0.6771	0.2577	25.77
0.1157	0.0097	ALT2	0.2222	0.2271	0.5055	0.1924	19.24
0.0612	0.0068	ALT3	0.0984	0.2634	0.7280	0.2771	27.71
0.0172	0.2178	ALT4	0.2795	0.0837	0.2304	0.0877	8.77
0.0439	0.2659	ALT5	0.2342	0.2220	0.4866	0.1852	18.52
		Total			2.6276	1	100.01

Table 9. Final Ranking of CC_j

ALT	Ranking
ALT3	1
ALT1	2
ALT2	3
ALT5	4
ALT4	5

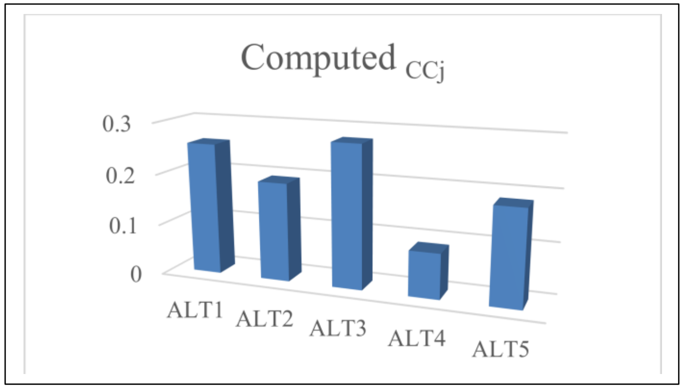

Figure 4 Comparison of CCj values with the different alternatives

The hybrid approach used in this study offers complementary advantages over either AHP or TOPSIS methods. Therefore, this approach will help stakeholders to make better and more efficient decisions when rating marine environmental activities and the MDZs. The decision support capabilities demonstrated in this study should be given adequate consideration in the quest for MGDI and Blue economy (BE) initiatives. Therefore, a new concept called the 'MDGI decision' is being introduced to capture the decisions made by stakeholders with complex and conflicting worldviews relating to both MGDI and BE initiatives. In this context, the BE concepts are considered similar to MGDI. Furthermore, this paper presents a computational and practical application in Section 4, demonstrating the qualitative and quantitative advantages for informed decision-making by marine stakeholders and practitioners.

7. CONCLUSIONS

This paper discusses marine economic activities in the context of Multiple Criteria Decision-Making (MCDM) problems. It focuses on the Marine Geospatial Data Infrastructure (MGDI) and MGDI decision initiatives within marine delineation zones. The Blue Economy initiative, which is concerned with sustainable use of ocean resources, is also examined as an MCDM problem that can be evaluated using an integrated AHP and TOPSIS approach. These zones represent alternatives for evaluating marine economic activities. The economic criterion cluster was used to evaluate various parameters and indicators, resulting in the identification of multiple economic activities. The Delphi approach was then used by selected marine stakeholders to rank the top five activities.

In this study, the importance criteria weights of various economic activities in the MDZs were evaluated and ranked using the AHP model, while the TOPSIS model was employed to evaluate their performance ratings. This study was motivated by the lack of similar considerations in previous research, applications, and publications. Therefore, the AHP and TOPSIS hybrid model is presented in this paper as a novel and scientific approach to enable efficient decision-making by stakeholders and judgment of various marine economic activities within the MDZs.

According to the distribution of the CC_j values, the ALT3-Contiguous Zones (24 nm) is the maritime zone that has the highest contribution of 27.71% towards marine economic activities. On the other hand, the lowest value of 8.8% is attributed to ALT4-Exclusive Economic Zone (200 nm) due to the uneven delineation of Malaysia's EEZ extent around the southern part of the Peninsular. The computed the CC_j values for ALT_4 and ALT_5 reflect Malaysia's prioritization of marine economic activities, as this area cannot extend to 200 nm due to the adjoining states. This does not apply to extensive oil and gas activities and fishing.

Despite the fact that the Exclusive Economic Zone (EEZ) around the southern part of Peninsular Malaysia is relatively small, Malaysia has not yet fully utilized its potential. However, the authors intend to conduct further evaluation of these outcomes. This involves investigating the impact of human subjectivities from various stakeholders with often-conflicting interests and worldviews by using fuzzy sets and fuzzy extensions of the current method, considering the dynamic nature of maritime zones.

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CRediT Authorship Contribution Statement
To be provided later.

Declaration of competing interests

None. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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