A Fuzzy Decision Making Method in Developing Environmental Performance Index

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Abstract: - Environmental Performance Index (EPI) is used to rank the performance in environment protection for most of the countries in the world. EPI is a score which gives a gauge at a national government scale using the method of proximity-to-target value. The current method fails to consider incomplete and vague environment data in its computations. This paper proposes a new score of EPI using a decision making method of interval-valued intuitionistic fuzzy TOPSIS. Differently from the typical arithmetic operations of the proximity-to-target value, which directly used subtraction and division, this method introduces the concept of distance to ideal solution based on the decision makers' assessments. A case of eleven countries in Southeast Asia region was considered to illustrate the computations. Three decision makers were invited to rate the extent of a country performs against the specific environmental criteria using the defined linguistic variables. An interval-valued intuitionistic fuzzy decision matrix was constructed based on dual degree of membership elicited from decision makers' assessment. The closeness coefficient that represents a score for each country was finally established after executing the five-step computation. With the closeness coefficient of 0.8028, Malaysia was the best EPI among the selected countries. The method successfully offers a new score of EPI and subsequently managed to identify the countries' environmental performance.

Key-Words: - Environmental assessment, intuitionistic fuzzy sets, environmental criteria, decision making, linguistic assessment

1 Introduction

Environmental sustainability is becoming an integral part of sustainable development. It is used for preservation of environment and creating friendly environmental awareness. More attention is now paid to various assessment methods associated with environmental sustainability. The widely used methods to assess the environmental sustainability are Ecological Footprint Analysis (EFA) and Emergy evaluation. The EFA compares human demand on nature with the biosphere's ability to regenerate resources and provide services. It is done by assessing the biologically productive land and marine area required to produce the resources a population consumes and absorb the corresponding waste using prevailing technology [1]. Per capita ecological footprint is comparing consumption and lifestyles and checking this against nature's ability to provide for this consumption [2]. The outcomes of these assessments are more on resources depletion, consumption patterns, waste production and absorption [3]. Another form of assessment in environmental sustainability is environmental impact where its measurement is established by the emergy investment ratio defined as the ratio of the emergy purchased from the economy divided by the emergy from the local environment [4]. The Emergy evaluation takes into account every contribution from nature and human economy in order to determine the important value of any resource [5], [6].

Performance in handling environmental policy categories is another perspective in the environmental sustainability assessment. The Yale and Columbia Universities [7] have collaborated with the World Economic Forum and the Joint Research Centre to develop Environmental Sustainability Index (ESI) between 1999 and 2005, and three Environmental Performance Indices (EPI) between 2006 and 2010. The EPI is more result-oriented and more accessible for public compared to ESI. An EPI is a score value derived from specific economic and environmental indicators, which synthesizes the complex scientific information in a simpler ways to understand and can be easily communicated. It provides a benchmark for environmental performance of a country's policies. In China, EPI for 30 provincial administrative regions based on data that acquired from China's Statistical Bureau was developed [8]. Generally, EPI provides a decision making tool for the governments in the design, implementation and control of environmental policies toward environmental sustainability [9]. According to Esty, the Director of the Yale University [7], the 2010 EPI shows the potential for a much more analytical rigorous approach to environmental decision making, but substantial investment in indicators that are systematically tracked and transparently displayed will be needed. The overall EPI rankings show, which countries are doing the best opposed the array of environmental pressures that every country confronts. EPI's indicators are more on results-oriented such as emissions or deforestation rates rather than policy inputs, such as program budget expenditures. The EPI provides a device to sail the individual countries and the world toward environmental sustainability. The index is a score value derived from specific economic and environmental indicators, which synthesizes the complex scientific information in a more simple ways to comprehend and can be easily communicated. The EPI provides a ranking of 163 countries on ten policy categories covering both environmental public health and ecosystem vitality. These indexes provide a gauge at a national government scale on how countries establishing environmental policy goals.

The EPI is calculated using the method of proximity-to-target. The data in establishing EPI were obtained from official statistics reported by governments, spatial data, observing from monitoring stations and from modelled data [10]. The method is intimately linked with typical arithmetic operations of subtractions and division. From arithmetic point of view, one of the weaknesses in this computation is the process of averaging the policy category data where some extreme values in the data may raise unnecessary noises. Moreover, the main concept in the proximity-to- target method is the transformation of raw data of indicators to a chosen set of policy targets in a score ranging from zero (worst performance) to 100 (at target). The transformation to the target values of the indicators is made using the operation of natural logarithm. Natural logarithm is usually used to normalize linearity of data to become an exponential function. The lack of linear property of raw data would undermine the very foundation of first hand data collection. Further, the score of each policy category is aggregated from a set of environmental indicators with a pre-determined weight of policy categories. Moreover, the raw data used to compute EPI are subjected to inaccuracy and vague due to mass data collection methods. In contrast to this method, this paper intends to embark on a fuzzy multi-criteria decision making method. The issues of arithmetic operations, linear transformation, vague data and weights of policy categories in proposing the score of EPI are dealt with the knowledge of distance from ideal solutions in TOPSIS method and interval-valued intuitionistic fuzzy set (IVIFS). The fuzzy set theory that inherently linked with human judgment could be employed to express and measure sustainability indicator.

Assessments of environmental indicators based on fuzzy set theory are not something unexplored. There are a handful of researches that have been conducted using this approach. Marius, et al., [11] assessed corporate environmental performance based on fuzzy approach. Recently, Tsai et al., [12] employed a fuzzy decision making to determine environmental performance. Cornelissen et al., [13] ,for example, proposed a method to assess the contribution of sustainability indicators to sustainable development by the approach using fuzzy set theory. As a consequence of the impact of sustainability on agricultural production systems, a standardized framework to monitor sustainable development would have great practical utility. Very recently, Gumus et al., [14] applied fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method to access a set of environmental and socio-economic indicators. Pipatrapa et al., [15] evaluate the environmental performance of Thailand's food industry using a combination of structural equation modeling and a fuzzy analytic hierarchy process. Fuzzy set theory that was introduced by Zadeh[16] and the developed fuzzy mathematical models were introduced to assess sustainable development based on context-dependent economic, ecological, and societal sustainability indicators. The fuzzy set theory that inherently linked with human judgments could be expressed and measured sustainability indicators. In another related research, Nasiri and Huang [8] developed a fuzzy decision aid model for environmental performance assessment in waste recycling. A methodological framework for this performance assessment was introduced. Two categories of indicators were developed: the efficiency indicators that compare the environmental achievements of a program with the required expenditures and the effectiveness indicators that compare the environmental benefits of a program with the amount of generated wastes. The aggregation of these indicators gives a number of environmental performance indices to represent the status of the environmental performance. The important values (criticalities) are often expert based uncertain judgments according to the objective of performance assessment in this aggregation. A fuzzy multiple attribute analysis was employed to express these judgments by fuzzy sets and to formulate the weighted aggregation process. Therefore, in this paper, fuzzy multi-criteria decision making approach that specifically used the concept of interval judgment and distance to ideal solution is proposed to assess the environmental performance. Decision makers (DMs) or experts assess the importance of the criteria or policy categories and evaluate alternatives with respect to each criterion using the linguistic rating variables. The role of experts' opinion in environmental modelling has been explored by many. In fact an extensive review about the inevitable role of experts in environmental modelling was made by Kruger et al., [17]. Based on these premises, this paper aims to propose a new score of EPI using the IVIFS TOPSIS. A case of Southeast Asia countries is considered to implement the feasibility of the method in computing the EPI.

2 Problem Formulation

Some basic definitions are required for the IVIF TOPSIS method. There are given as follows.

Definition 1 [18]. Let X be a fixed set (an universe of discourse), an intuitionistic fuzzy set $\tilde{A}$ in X is defined as,

$$\tilde{A} = \{x, \ \tilde{\mu}_{\tilde{A}}(x), \tilde{v}_{\tilde{A}}(x) \mid x \in X\}, \tag{1}$$

where $\tilde{\mu}_{\tilde{A}} : X \to [0,1]$ and $\tilde{v}_{\tilde{A}} : X \to [0,1]$ represent the intervals of the degrees of membership and non-membership of an element $x \in X$ to the set $\tilde{A}$, respectively, satisfying $0 \le \tilde{\mu}_{\tilde{A}}(x) + \tilde{v}_{\tilde{A}}(x) \le 1, \forall x \in X$.

For each IFS $\tilde{A}$ in X, the intuitionistic fuzzy index of $x \in \tilde{A}$ is defined as,

$$\pi_{\tilde{A}}(x) = 1 - \tilde{\mu}_{\tilde{A}}(x) - \tilde{v}_{\tilde{A}}(x) \tag{2}$$

It represents the degree of indeterminacy or hesitation of $x \in \tilde{A}$. For each $x \in X$, $0 \le \pi_{\tilde{A}}(x) \le 1$.

The pair $(\tilde{\mu}_{\tilde{A}}(x), \tilde{v}_{\tilde{A}}(x))$ is known as an intuitionistic fuzzy number (IFN). For notational convenience, an IFN is denoted as $a = (\mu, v)$ in the following, where

$$\mu \in [0,1], v \in [0,1], \mu + v = 1. \tag{3}$$

Definition 2. [19]. Let X be a non-empty set of the universe, and $\text{Int}[0,1]$ be the set of all closed subintervals of $[0,1]$, an interval-valued intuitionistic fuzzy set (IVIFS) $\tilde{A}$ in X is defined by

$$\tilde{A} = \{x, \ \tilde{\mu}_{\tilde{A}}(x), \tilde{v}_{\tilde{A}}(x) \mid x \in X\} \tag{4}$$

where functions $\tilde{\mu}_{\tilde{A}} : X \to \text{Int}[0,1]$ and $\tilde{v}_{\tilde{A}} : X \to \text{Int}[0,1]$ are the degree of membership and the degree of non-membership respectively. For every $x \in X$, $0 \le \sup\tilde{\mu}_{\tilde{A}}(x) + \sup\tilde{v}_{\tilde{A}}(x) \le 1$.

The lower and upper bounds are denoted as $\tilde{\mu}^L_{\tilde{A}}(x)$, $\tilde{\mu}^U_{\tilde{A}}(x)$, $\tilde{v}^L_{\tilde{A}}(x)$ and $\tilde{v}^U_{\tilde{A}}(x)$, respectively. The pair $(\tilde{\mu}_{\tilde{A}}(x), \tilde{v}_{\tilde{A}}(x))$ is called interval-valued intuitionistic fuzzy number (IVIFN). The IVIFS $\tilde{A}$ can be expressed as,

$$\tilde{A} = \{\langle x, [\tilde{\mu}^L_{\tilde{A}}(x), \tilde{\mu}^U_{\tilde{A}}(x)], [\tilde{v}^L_{\tilde{A}}(x), \tilde{v}^U_{\tilde{A}}(x)]\rangle \mid x \in X\} \tag{5}$$

For every $x \in X$, the degree of hesitation relative to $\tilde{A}$ is computed as:

$$\pi_{\tilde{A}}(x) = 1 - \tilde{\mu}_{\tilde{A}}(x) - \tilde{v}_{\tilde{A}}(x) = [1 - \tilde{\mu}^U_{\tilde{A}}(x) - \tilde{v}^U_{\tilde{A}}(x), 1 - \tilde{\mu}^L_{\tilde{A}}(x) - \tilde{v}^L_{\tilde{A}}(x)] \tag{6}$$

It is called the intuitionistic index of the element x in the set $\tilde{A}$.

2.1 Interval-Valued Intuitionistic Fuzzy TOPSIS Method

The TOPSIS method is one of the best grading methods of multi-criteria decision making. The method was first developed by Hwang and Yoon [20], and it has been used to solve many multi-criteria decision-making problems. Izadikhah [21] has extended TOPSIS method for group decision making with IVIFNs to solve the supplier selection problem under incomplete and uncertain information.

The basic principle of TOPSIS method is the chosen alternative should have the shortest distance from the positive-ideal solution (PIS) and the farthest distance from the negative-ideal solution (NIS). Based on normalized Hamming distance, the distance between two IVIFNs can be calculated.

The decision procedure for the IVIF TOPSIS method is presented as follows.

Step 1: Determine the weights of criteria.

The weights of criteria are expressed as IVIFNs. Let $W=\{W_1,W_2,\ldots,W_n\}$ be the vector of criteria's weights, where w_j indicates the importance of criterion c_j. The opinions of decision makers are gathered to get the aggregated IVIF weight of criteria.

Let the weight of j-th criterion with respect to t-th decision maker be $w_j^t=\left(\left[a_{jL}^t,a_{jU}^t\right],\left[\beta_{jL}^t,\beta_{jU}^t\right]\right)$. The weights of criteria are calculated using the equation (7) as follows:

$$
\begin{aligned}
w_j &= \lambda_1 w_j^1 + \ldots + \lambda_k w_j^k \\
&= \left(\left[1-\prod_{t=1}^{k}\left(1-a_{jL}^t\right)^{\lambda_t}, 1 \prod_{t=1}^{k}\left(1-a_{jU}^t\right)^{\lambda_t}\right], \left[\prod_{t=1}^{k}\left(\beta_{jL}^t\right)^{\lambda_t}, \prod_{t=1}^{k}\left(\beta_{jU}^t\right)^{\lambda_t}\right]\right), j=1,2,\ldots,n
\end{aligned}
\tag{7}
$$

Step 2: Determine the weighted decision matrix.

Construct the weighted decision matrix using equation (8). Let R be the weighted decision matrix such that $R=\left(r_{ij}\right)$ then

$$r_{ij} = w_j \bullet x_{ij} = \left(\left[a_{ij},b_{ij}\right],\left[c_{ij},d_{ij}\right]\right) \tag{8}$$

Step 3: Determine the IVIF PIS and NIS.

The PIS has the best measures over all attributes while the NIS has the worst measures over all attributes. The optimal alternative is the one with shortest distance from the PIS and the farthest distance from the NIS.

Assume that the set of benefit criteria as B and the set of cost criteria as C. Then determine the IVIF PIS as $A^+=\left(r_1^+,\ldots,r_n^+\right)$, where

$$r_j^+ = \begin{cases} \left(\left[\max_i a_{ij}, \max_i b_{ij}\right],\left[\min_i c_{ij}, \min_i d_{ij}\right]\right), j\in B \\ \left(\left[\min_i a_{ij}, \min_i b_{ij}\right],\left[\max_i c_{ij}, \max_i d_{ij}\right]\right), j\in C \end{cases}$$

(9)

and determine the IVIF NIS as $A^-=\left(r_1^-,\ldots,r_n^-\right)$, where

$$r_j^- = \begin{cases} \left(\left[\min_i a_{ij}, \min_i b_{ij}\right],\left[\max_i c_{ij}, \max_i d_{ij}\right]\right), j\in B \\ \left(\left[\max_i a_{ij}, \max_i b_{ij}\right],\left[\min_i c_{ij}, \min_i d_{ij}\right]\right), j\in C \end{cases}$$

(10)

Without loss of generality, assume that for $j=1,\ldots,n$, $r_j^+=\left(\left[a_j^+,b_j^+\right],\left[c_j^+,d_j^+\right]\right)$ and $r_j^-=\left(\left[a_j^-,b_j^-\right],\left[c_j^-,d_j^-\right]\right)$.

Step 4: Construct the separation measures.

The separation measure degree between alternative A_i and the IVIF PIS is defined using normalized Hamming distance as follows:

$$d_i^+ = \frac{1}{4m}\sum_{j=1}^{n}\left\{\left|a_{ij} - a_j^+\right| + \left|b_{ij} - b_j^+\right| + \left|c_{ij} - c_j^+\right| + \left|d_{ij} - d_j^+\right|\right\}, i = 1,..., m \quad (11)$$

The separation measure degree between candidate A_i and the IVIF NIS is defined using normalized Hamming distance as follows:

$$d_i^- = \frac{1}{4m}\sum_{j=1}^{n}\left\{\left|a_{ij} - a_j^-\right| + \left|b_{ij} - b_j^-\right| + \left|c_{ij} - c_j^-\right| + \left|d_{ij} - d_j^-\right|\right\}, i = 1,..., m \quad (12)$$

Step 5: Calculate the closeness coefficient.

The closeness coefficient (relative closeness) of the alternative A_i with respect to the ideal IVIF PIS A^* is defined as follows:

$$C_i = \frac{d_i^-}{d_i^- + d_i^+} \quad (13)$$

where $0 \leq C_i \leq 1$.

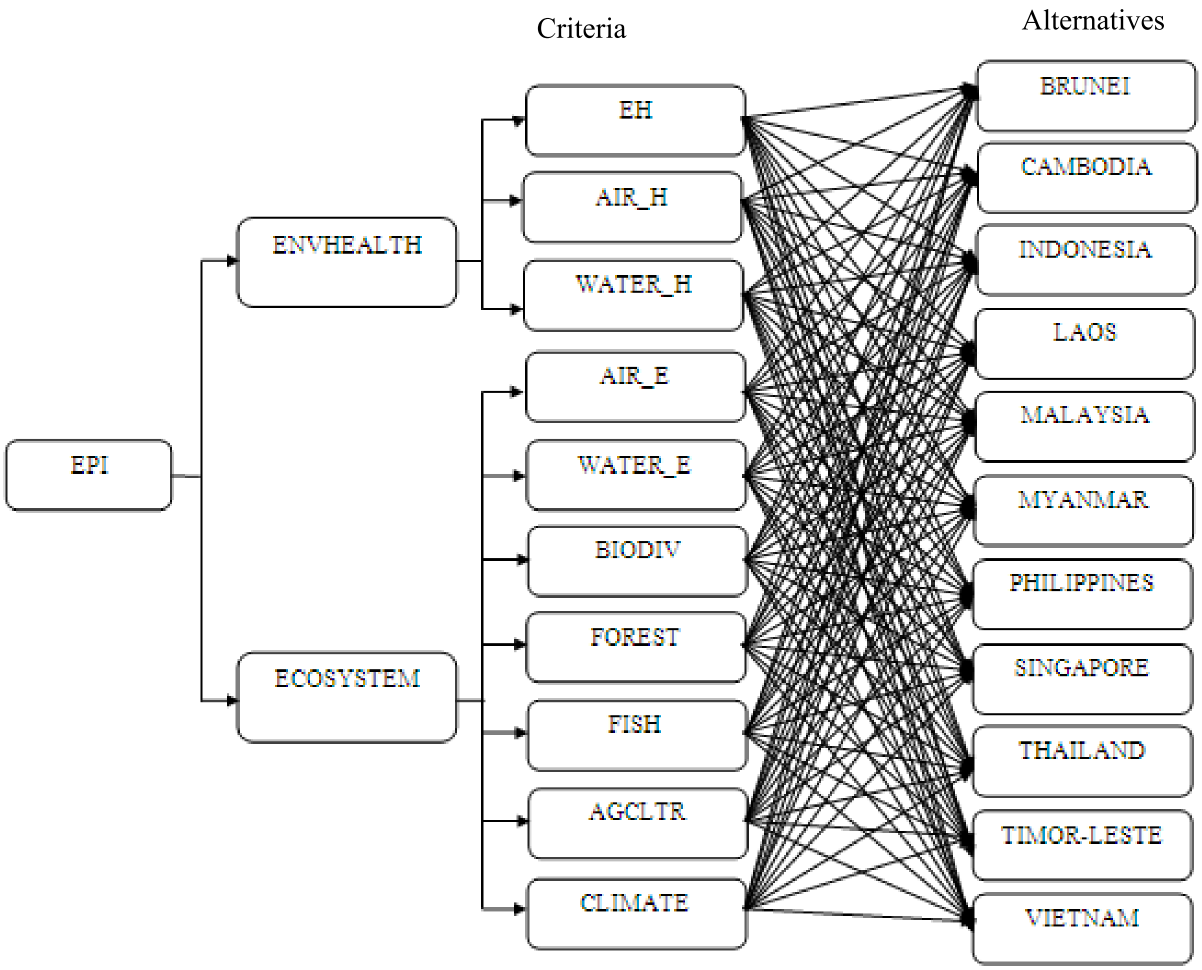
The score is given by closeness coefficient. The higher the closeness coefficient is, the better the alternative is.

3 Problem Solution

The EPI for Southeast Asia countries are ranked using the IVIF TOPSIS. Southeast Asia countries $A_i, (i = 1,...,11)$ are taken as the feasible alternatives in this study. The alternatives (countries) are A_1 Brunei, A_2 Cambodia, A_3 Indonesia, A_4 Laos, A_5 Malaysia, A_6 Myanmar, A_7 Philippines, A_8 Singapore, A_9 Thailand, A_{10} Timor-Leste, and A_{11} Vietnam. The ten main criteria, $C_i, (i = 1,...,10)$ are C_1 DALY, C_2 AIR_H, C_3 WATER_H, C_4 AIR-E, C_5 WATER_H, C_6 BIODID, C_7 FOREST, C_8 FISH, C_9 AGCLTR, and C_{10} CLIMATE. A committee of three decision makers D_1, D_2 and D_3 was created and requested to rate the alternatives against the criteria using a linguistic judgment. The three decision makers (DMs) comprise two environmental officers attached to Department of Environment Malaysia, and a Municipal Council respectively, and an academician attached to a public university in Malaysia.

Decision hierarchical structure is constructed based on the interconnected relationship between the selected countries (alternatives) and the evaluation criteria. The structure is presented in Figure 1.

Figure 1 Decision hierarchical structure



The three DMs were invited to assess the importance of the criteria and also to rate the alternatives with respect to each criterion. Linguistic weighting variables and linguistic rating variables are shown in Table 1 and Table 2 respectively.

Table 1. Linguistic weighting variables

Linguistic terms	IVIFNs
Extremely important (EI)	$([1.00,1.00],[0.00,0.00])$
Very important (VI)	$([0.80,0.90],[0.05,0.10])$
Important (I)	$([0.65,0.75],[0.10,0.20])$
Medium (M)	$([0.45,0.55],[0.35,0.45])$
Unimportant (U)	$([0.25,0.35],[0.55,0.65])$
Very Unimportant	$([0.00,0.10],[0.80,0.90])$

Source: Izadikhah [21]

Table 2. Linguistic rating variables.

Linguistic terms	IVIFNs
Extremely good (EG)/ Extremely high (EH)	$([1.00,1.00],[0.00,0.00])$
Very very good (VVG)/ Very very high (VVH)	$([0.80,0.90],[0.05,0.10])$
Very good (VG)/ Very high (VH)	$([0.70,0.80],[0.05,0.10])$
Good (G)/ High (H)	$([0.60,0.70],[0.15,0.20])$
Medium good (MG)/ Medium high (MH)	$([0.50,0.60],[0.25,0.30])$
Fair (F)/ Medium (M)	$([0.40,0.50],[0.35,0.40])$
Medium bad (MB)/ Medium low (ML)	$([0.30,0.40],[0.45,0.50])$
Bad (B)/ Low (L)	$([0.15,0.25],[0.55,0.60])$
Very bad (VB)/ Very low (VL)	$([0.00,0.10],[0.70,0.75])$
Very very bad (VVB)/ Very very low (VVL)	$([0.00,0.10],[0.85,0.90])$

Source: Izadikhah [21]

Linguistic data were used as input data to the method. After executing a five-step computation (Section 2.1), the final scores of EPI are obtained. Table 3 shows the final values of EPI for alternatives.

Table 3 Distance of alternative from IVIF PIS, IVIF NIS and EPI

Alternatives	Distance IVIIF PIS	Distance IVIFS PIS	EPI
A_1	0.0739	0.2141	0.7434
A_2	0.1928	0.0953	0.3308
A_3	0. 1529	0.1351	0.4691
A_4	0.1400	0.1481	0.5141
A_5	0.0568	0.2313	0.8028
A_6	0.1427	0.1454	0.5047
A_7	0.1238	0.1642	0.5701
A_8	0.1057	0.1824	0.6331
A_9	0.1178	0.1702	0.5910
A_{10}	0.2438	0.0449	0.1555
A_{11}	0.1349	0.1531	0.5316

Higher EPI values reflect the better alternative. The result shows that A_5 Malaysia is the best EPI among Southeast Asia countries followed by A_1 Brunei. A_8 Singapore is the next best performer after Malaysia and Brunei. The worst performer out of eleven countries is A_{10} Timor-Leste.

4 Discussion

The IVIF TOPSIS method for developing environmental performance index has several distinctive characteristics. The IVIFS TOPSIS method encompasses at least three characteristics in which all characteristics are meant to deal with incomplete and vague data. The method was supported by previous theories where interval-valued intuitionistic fuzzy set was purposely invented to handle vagueness, imprecision and uncertainty [22]. Therefore, the first characteristic in terms of the method is the use of linguistic terms, where the assessment was made in interval values. The three memberships of the IFS are the second characteristic entails in the method used. Membership degree, non-membership degree and hesitation degree of IVIFS are completely taken care of all linguistic data during the assessment process. The third characteristic in terms of the method used in this paper is the TOPSIS. The TOPSIS is known as the fundamental method in decision making approach where decisions are made through the proportion of distance measures. The performance assessment process has five steps where the first step begins with a linguistic assessment by decision makers and the final step ends with the values of closeness of coefficients. These values represent the single measure of environmental performance index. In the case of Southeast Asia countries, the assessment method successfully identified Malaysia, Brunei and Singapore as the three best performers in the environmental performance index. The performances of Malaysia and Brunei are consistent with the list issued by Emerson et al., [12]. However, In comparison with an entropy weighted based decision method, the result showed Singapore as the best performer followed by Brunei and Malaysia [23]. Despite a minor inconsistency in the final results, the chosen method would be used as an alternative method in determining the score of environmental performances. The inconsistency might occur due to the fact that information gathered from decision makers was based on their beliefs and opinions, where different decision makers may develop different results.

5 Conclusion

An important element in environmental assessment is a method which can take into account multiple variables with vague, imprecise and incomplete data. The method should establish a single score which reflects the contribution of each accounted criteria toward environmental performance index. This paper has employed the IVIF TOPSIS to compute environmental performance score based on decision makers assessments on the criteria and alternatives. The IVIF TOPSIS method provides a systematic structure to process the information required to develop the environmental performance index. It is suggested that a scientific mechanism could be implemented in the future as to test and verify during the process of data gathering. Apart from the distinctive characteristics of the method used in this study, the findings of the case of Southeast Asia countries could be used as a basis for managing an effective environmental criteria toward a better environmental performance. It is also suggested that several other methods could be considered to validate the environmental performance index not only in a specific region, but can also be extended to all countries in the world.

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