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An integrated neutrosophic ANP and VIKOR method for achieving sustainable supplier selection: A case study in importing field

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ABSTRACT

Sustainable supplier selections have been improved by an increased number of multi criteria group decision making (MCGDM) methods and techniques. This paper provides a multi criteria group decision making (MCGDM) proposed technique of the ANP (analytical network process) method and the VIKOR (ViseKriterijumska Optimizacija I Kompromisno Resenje) method under neutrosophic environment for dealing with incomplete information and high order imprecision. This is done by using of the triangular neutrosophic numbers (TriNs) to present the linguistic variables based on opinions of experts and decision makers. The aim is to solve the problem of supplier selection in sustainable supplier chain management (SSCM). The suggested technique consists of two phases. First, we use the ANP method to calculate the weights of criteria and sub criteria. Second, with the aid of VIKOR method and with obtained weights of the criteria and sub criteria from step one, we can find the solution. A case study is used to present the decision process in detail. Our proposed method is compared directly with the entropy method to justify our approach. We also use genetic algorithm to compute predicted values for five selected cities while varying economic, environmental and social criteria. Explanations of forecasted outputs and limitation for research have been presented. Our objective is to demonstrate that our proposal can calculate key measurement for major import and export cities, as well as to provide fair and reliable forecasted outcomes.

1. Introduction

Due to the competitions for economic growth, many countries and cities have exploited more natural resources. In the process of doing so, it has caused environmental issues and hazards, such as air pollution and water contamination. Therefore, companies, corporations and any members in the community of manufacturing have the growing social responsibilities, due to the depletion of natural resources, climate change and environmental hazards. To make a balance, the recommendation is to have green suppliers who are able to contribute to economic development and maintain good business ethics. The type of work and the systems green suppliers do, are known as sustainable supplier chain management (SSCM). There are three factors determining the extents of success of SSCM, namely social, economic and environment factors, which can be used to evaluate sustainable suppliers systematically [1,2].

The majority of businesses and investors takes risk all the times. This is particularly true if foreign investors have no much knowledge about a city or a country, and they tend to rely on information given to them by their networks and local governments. To help businesses and investors avoid medium and high risk cases, the multi criteria group decision making (MCGDM) methods and techniques can be used to evaluate sustainable suppliers as follows. First, researchers could use mathematical operations and fuzzy predilection relations. One specific example is the fuzzy multiple criteria hierarchical group decision-making problems presented by Chen and Lee [3,4]. Second, an integrated methodology based on analytic network process (ANP) and VIKOR (ViseKriterijumska Optimizacija I Kompromisno Resenje) can be used to evaluate supplier selection [5,6]. Third, TODIM (an acronym in Portuguese of interactive and multi criteria decision making) approach is developed for supplier evaluation based on interval type 2 fuzzy sets by Qin [7].

It has become a trend for researchers and scientists to perform a multiplicity of studies, particularly in the relative area of

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evaluation and supplier selection, together with the fuzzy research [8]. The following methods can be used to analyze supplier selection, such as Decision-making Trial and Evaluation Laboratory (DEMATEL), TOPSIS, TODIM, analytic hierarchy process (AHP), analytic network process (ANP), DEA and their subsets. There are three ways in the mainstream research as follows. First, the process of selecting the suppliers can be adopted by combining different methods, such Fuzzy Delphi and AHP-DEMATEL method [9], and combining AHP and TOPSIS under the fuzzy environment for evaluation suppliers [10]. Second, another alternative can be relied on one method, such as structured MCGDM under the intuitionistic fuzzy environment. Researchers in this area focus on mathematical operations and intuitionistic fuzzy predilection relations. Third, VIKOR method can be used under the intuitionistic fuzzy to find suitable suppliers with their locations [11]. Among these three mainstream, one thing in common is that the intuitionistic fuzzy environment for the evaluation of suppliers [12,13]. The majority of researchers used traditional fuzzy and intuitionistic fuzzy set to handle the incomplete information, vague data and the ambiguity of expert's judgment in order to solve MCGDM problems.

For the common approaches, we can locate the weights of criteria for resolving MCGDM problems which have unknown weights. To gain the weights in many MCDM problems, the AHP method is often excessively used. The reason is that AHP method assumes that the criteria are mutually independent, since there are no interactions between sub-criteria. Additionally, a usual problem is that much decision information is unclear and vague within the operation of decision making. It is commonly known that fuzzy and IFs can model these uncertainty and vague information well. Meanwhile the results of decision making should be more rigorous to be useful for the sustainable expansion of the company. Obviously, fuzzy and IFs cannot illustrate the linguistic imprecision and ambiguity of experts' opinions.

Due to intense market competition, increased consumer demand, and faster replication of the product, there are more factors which cannot be revealed easily in the sustainable supplier valuation process. Therefore, we plan to prepare to develop a method which can be more effective in sustainable supplier evaluation. The aim is to include a fair, step-by-step and logical measurement on important factors. This is our motivation for this research. To fulfill our motivation, we can adopt neutrosophic research in our proposed method to integrate ANP and VIKOR methods together. Neutrosophic is very effective in dealing with incomplete information, as well as unclear and vague data. Hence, experts and decision makers use neutrosophic to denote information in an uncertain environment [14]. The notion of neutrosophic set was suggested by Smarandache [15–17] to make the concept of IFs general. Many researchers head for solving MCGDM problems under the neutrosophic environment because the accuracy of the results [18–20].

The main achievements of this research are:

- Considering the significance of integrating of ANP method and VIKOR method under the environment of neutrosophic.
- Recognizing the most effective and detailed criteria for supplier's selection.
- Demonstrating the case study of analyzing social, economic and environmental factors to select the best suppliers for importing, and its predictive analysis.

The model can be closer to the actual decision making problems because being different from AHP method, the ANP depicts relations among elements and interdependencies and feedback. The ANP produces more accurate weights and more reasonable outputs. Additionally, the solution offered by VIKOR method is a feasible solution closest to the ideal solution. Besides, we should take the accessibility of the proposed method into consideration, so that we can use (TriNs) to depict the uncertain information instead of real numbers. Thus, to overcome these disadvantages, this paper seeks to develop an integrated ANP (Saaty 1980) and VIKOR (Opricovic 1998) method under neutrosophic environment to transact with sustainable supplier selections problems. The structure of this paper is as follows: Section 2 reviews the ANP method and the difference between ANP and AHP methods. Section 3 presents the VIKOR method. Section 4 clarifies the

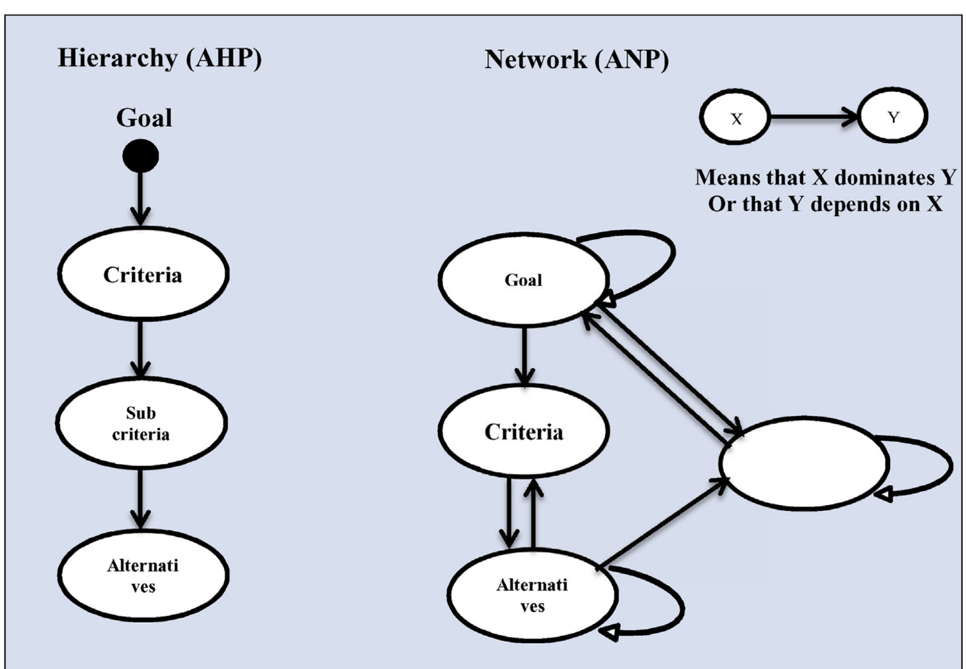

Fig. 1. Model structure for AHP and ANP.

preliminaries of neutrosophic. Section 5 clarifies the procedure for the proposed ANP-VIKOR method for the evaluation of the suppliers. Section 6 describe a case study to certify the practicality of the ANP-VIKOR method. Section 7 shows our evaluation based on predicted outcomes and Section 8 present discussion about research contributions and limitations. Section 9 concludes this paper with our contributions and future work.

2. The ANP method

There are a lot of multi-criteria decision making (MCDM) techniques such as the analytic network process (ANP) [21] that is modified based on the (AHP) method [22]. The (ANP) consider the dependency and feedback between elements of the problem that it sophisticated by Saaty in 1996. The (ANP) makes models of the decision making problems as networks not as hierarchies. From disadvantages of the analytic hierarchy it's not assumed the effect of criteria on the alternatives. But the feedback and dependencies are considered in the (ANP) method. In Fig. 1, we present the difference between AHP and ANP.

The Fig. 1 shows how the hierarchy of the AHP is presented and the higher element depends on the lower element but in the network there exist dependencies between elements of the problem that can be inner or outer dependencies. So, the analytic network process is appropriate for complex problem. We present in Fig. 2 the main process in ANP method.

3. The VIKOR method

Opricovic has developed the VIKOR method [23] and later sophisticated it for multi criteria optimization of difficult systems and complex problems [24–26]. When solving MADM problems to get compromise solutions, we use the VIKOR method which is considered an effective tool for solving problems that contain a set of clashing criteria. The next form M_P metric is considered the original formula for developing the VIKOR technique.

$$M_{Pj} = \left\{ \sum_{i=1}^{n} \left[\frac{w_i(A^* - A_{ij})}{(A^*_i - A^-_i)} \right] \right\}^{\frac{1}{p}}, 1 \le M \le \infty, j = 1, 2 \ldots J \quad (1)$$

In the previous M_P metric, A^-_i = min A_{ij}, A^*_i = max A_{ij}, respectively, clarify the best and worst values w_i = (i = 1, 2, . . . ,I) are the conformable weights of the attributes. The dimension between alternative A_i to the perfect solution are noted by M_{Pj}. The

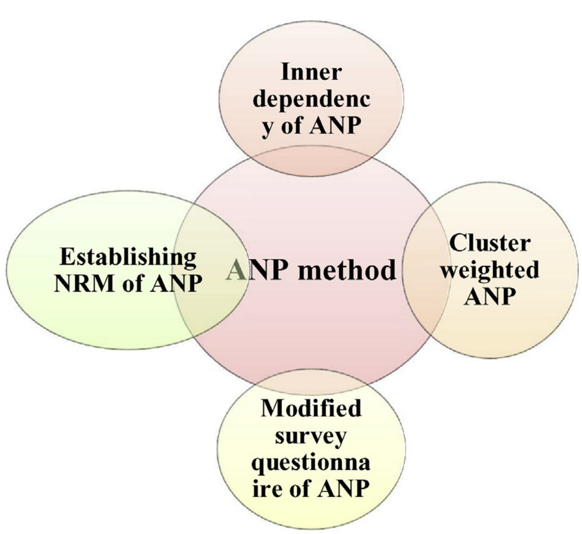

Fig. 2. Main process in ANP.

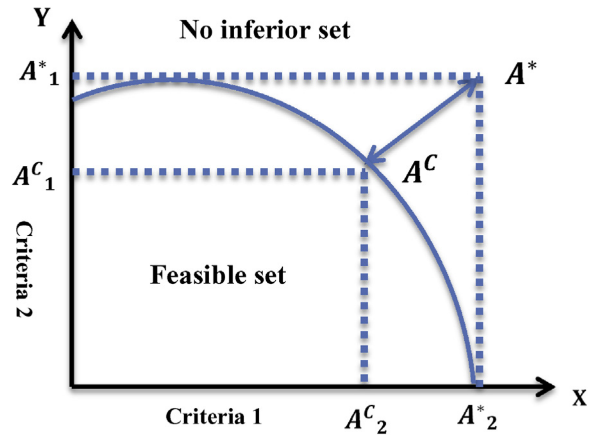

Fig. 3. Ideal and compromise solutions.

VIKOR method is interested in finding a compromise solution satisfying the maximized utility of the entire group and Fig. 3 shows that compromise solution.

4. Basic and fundamental concepts of neutrosophic

This section shows the basic definitions of neutrosophic set.

Definition 1. [27,28] Any neutrosophic set N in X, has a truth-membership function $T_N(x)$, an indeterminacy-membership function $I_N(x)$ and a falsity-membership function $F_N(x)$. Where X is a space of points and $x\in$. $T_N(x)$, $I_N(x)$ and $F_N(x)$ are real subsets of$]^-0, 1^+[$. The sum of $T_N(x)$, $I_N(x)$ and $F_N(x)$ has no constraints so $0^- \le$ sup $T_N(x)$ + sup $I_N(x)$ + sup $F_N(x)$ $\le 3^+$.

Definition 2. [27,29] A single valued neutrosophic set N over X taking the form N={⟨x, $T_N(x)$, $I_N(x)$, $F_N(x)$ ⟩:$x\in X$}, where X be a universe of discourse, $T_N(x)$:$X\to[0,1]$, $I_N(x)$:$X\to[0,1]$ and $F_N(x)$: $X\to[0,1]$ with $0\le T_N(x)+ I_N(x) + F_N(x) \le 3$ for all $x\in X$. For convenience, a single valued neutrosophic number is represented by N= (n_1, n_2, n_3), where $n_1, n_2, n_3 \in [0,1]$ and $n_1 + n_2 + n_3 \le 3$.

Definition 3. [30,31] Suppose that $\alpha_{\tilde{n}}$, $\theta_{\tilde{n}}$, $\beta_{\tilde{n}}\,\varepsilon\,[0,1]$ and $n_1, n_2, n_3 \varepsilon R$ where $n_1 \le n_2 \le n_3$.Then a single valued triangular neutrosophic number, $\tilde{n} = \langle\langle(n_1, n_2, n_3); \alpha_{\tilde{n}}, \theta_{\tilde{n}}, \beta_{\tilde{n}}\rangle\rangle$ is a special neutrosophic set on the real line set R, whose truth-membership, indeterminacy-membership and falsity-membership functions are defined as:

$$T_{\tilde{n}}(x) = \begin{cases} \alpha_{\tilde{n}}\left(\dfrac{x - n_1}{n_2 - n_1}\right) (n_1 \le x \le n_2) \\ \alpha_{\tilde{n}}\ (x = n_2) \\ \alpha_{\tilde{n}}\left(\dfrac{n_3 - x}{n_3 - n_2}\right) (n_2 < x \le n_3) \\ 0\ otherwise, \end{cases} \quad (2)$$

$$I_{\tilde{n}}(x) = \begin{cases} \dfrac{(n_2 - x + \theta_{\tilde{n}}(x - n_1))}{(n_2 - n_1)} (n_1 \le x \le n_2) \\ \theta_{\tilde{n}}\ (x = n_2) \\ \dfrac{(x - n_2 + \theta_{\tilde{n}}(n_3 - x))}{(n_3 - n_2)} (n_2 < x \le n_3) \\ 1\ otherwise \end{cases} \quad (3)$$

$$F_{\tilde{n}}(x) = \begin{cases} \dfrac{(n_2 - x + \beta_{\tilde{n}}(x - n_1))}{(n_2 - n_1)} (n_1 \le x \le n_2) \\ \beta_{\tilde{n}}\ (x = n_2) \\ \dfrac{(x - n_2 + \beta_{\tilde{n}}(n_3 - x))}{(n_3 - n_2)} (n_2 < x \le n_3) \\ 1\ otherwise. \end{cases} \quad (4)$$

$\alpha_{\tilde{n}}$, $\theta_{\tilde{n}}$ And $\beta_{\tilde{n}}$ exemplify the superior degree of truth-membership, lower indeterminacy and falsity membership degree. A single valued triangular neutrosophic number $\tilde{n} = \langle\langle(n_1, n_2, n_3); \alpha_{\tilde{n}}, \theta_{\tilde{n}}, \beta_{\tilde{n}}\rangle\rangle$ may express an ill-defined quantity about n, which is approximately equal to n.

Definition 4. [28,30] Let $\tilde{a} = \langle\langle(a_1, a_2, a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\rangle\rangle$ and $\tilde{b} = \langle\langle(b_1, b_2, b_3); \alpha_{\tilde{b}}, \theta_{\tilde{b}}, \beta_{\tilde{b}}\rangle\rangle$ be two single valued triangular neutrosophic numbers and $\gamma \neq 0$ be any real number. Then,

1 The addition of two numbers is as follows:

$$a\tilde{+}\tilde{b} = \langle\langle(a_1 + b_1, a_2 + b_2, a_3 + b_3); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}\rangle\rangle$$

2 The subtraction of two numbers is as follows:

$$\tilde{a} - \tilde{b} = \langle\langle(a_1 - b_3, a_2 - b_2, a_3 - b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}\rangle\rangle$$

3 Inverse of a neutrosophic number is as follows:

$$\tilde{a}{-1} = \left\langle\left\langle\left(\frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\rangle\rangle, \text{Where } (\tilde{a} \neq 0)\right.\right.$$

4 The multiplication of a neutrosophic number by a fixed value is as follows:

$$\gamma\tilde{a} = \begin{cases} \left\langle\left\langle\left(\frac{a_3}{\gamma}, \frac{a_2}{\gamma}, \frac{a_1}{\gamma}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\right\rangle\right\rangle \text{ if } (\gamma < 0) \\ \left\langle\left\langle\left(\frac{a_3}{\gamma}, \frac{a_2}{\gamma}, \frac{a_1}{\gamma}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\right\rangle\right\rangle \text{ if } (\gamma < 0) \end{cases}$$

5 The division of a triangular neutrosophic number by fixed value

$$\frac{\tilde{a}}{\gamma} = \begin{cases} \left\langle\left\langle\left(\frac{a_1}{\gamma}, \frac{a_2}{\gamma}, \frac{a_3}{\gamma}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\right\rangle\right\rangle \text{ if} (\gamma > 0) \\ \left\langle\left\langle\left(\frac{a_3}{\gamma}, \frac{a_2}{\gamma}, \frac{a_1}{\gamma}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\rangle\rangle \text{ if } (\gamma < 0)\right.\right. \end{cases}$$

6 Division of two numbers is as follows:

$$\frac{\tilde{a}}{\tilde{b}} = \begin{cases} \left\langle\left\langle\left(\frac{a_3}{\gamma}, \frac{a_2}{\gamma}, \frac{a_1}{\gamma}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\right\rangle\right\rangle \text{ if } (\gamma < 0) \\ \left\langle\left\langle\left(\frac{a_3}{\gamma}, \frac{a_2}{\gamma}, \frac{a_1}{\gamma}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\right\rangle\right\rangle \text{ if } (\gamma < 0) \\ \left\langle\left\langle\left(\frac{a_3}{\gamma}, \frac{a_2}{\gamma}, \frac{a_1}{\gamma}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\right\rangle\right\rangle \text{ if } (\gamma < 0) \end{cases}$$

7 Multiplication of two numbers is as follows:

$$\tilde{a}\tilde{b} = \begin{cases} \langle\langle(a_1b_1, a_2b_2, a_3b_3); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}\rangle\rangle & \text{if } (a_3 > 0, b_3 > 0) \\ \langle\langle(a_1b_3, a_2b_2, a_3b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}\rangle\rangle & \text{if } (a_3 < 0, b_3 > 0) \\ \langle\langle(a_3b_3, a_2b_2, a_1b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \theta_{\tilde{a}} \vee \theta_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}\rangle\rangle & \text{if } (a_3 < 0, b_3 < 0) \end{cases}$$

5. The ANP and VIKOIR methods

5.1. The functionality of linguistic variables

Words have more extent to describe the semantic and sentimental expressions compared with numbers. This research chooses triangular neutrosophic numbers which includes nine parameters to model linguistic variables. The (TriN) scales that are used in this proposed research are exhibited in Table 1.

5.2. The suggested method

In this section, the steps of the suggested triangular neutrosophic ANP-VIKOR framework are presented with detail. The suggested framework consists of five phases which contain many stages as follows:

Phase 1: Build a representative structure of ANP model to define the goal.

Before the process of decision making starts establish a panel of experts, e = [e_1, e_2, ..., e_n] for any MCGDM problem. It should reach a convention on what the goal is before the process starts. In any evaluation of a sustainable supplier, the goal is to find out the best suppliers for the corporation. So, determine the criteria of the problem from experts' opinions, target group survey and literature reviews and surveys to confirm these criteria. Then, determine the alternatives of the problem by introducing the best suppliers and choosing the best alternative. Before that, all the problems were presented by AHP which assumes that these criteria affect goal and alternatives and depend on criteria but in the real problem may be interdependency between elements of the problem criteria, sub criteria and alternatives. Concisely to overcome this drawback of AHP we used the Analytical network process that presents the problem in the network model to show the interdependency between elements such as feedback, interaction and circular relationships as exhibited in Fig. 4.

Table 1
The triangular neutrosophic scale for comprise matrix.

Linguistic term	Triangular Neutrosophic Scale
Low influence (LF)	$\langle\langle(0.1, 0.2, 0.3); 0.5, 0.1, 0.3\rangle\rangle$
	$\langle\langle(0.2, 0.3, 0.4); 0.8, 0.2, 0.3\rangle\rangle$
Fairly low influence (FLF)	$\langle\langle(0.3, 0.4, 0.5); 1.0, 0.1, 0.1\rangle\rangle$
Medium influence (MF)	$\langle\langle(0.4, 0.5, 0.6); 0.7, 0.3, 0.2\rangle\rangle$
Fairly high influence (FHF)	$\langle\langle(0.5, 0.6, 0.7); 0.9, 0.2, 0.1\rangle\rangle$
High influence (HF)	$\langle\langle(0.6, 0.7, 0.8); 0.8, 0.3, 0.5\rangle\rangle$
Strong influence (SF)	$\langle\langle(0.7, 0.8, 0.9); 0.8, 0.3, 0.5\rangle\rangle$
	$\langle\langle(0.8, 0.9, 1.0); 0.9, 0.2, 0.3\rangle\rangle$
	$\langle\langle(0.9, 1.0, 1.0); 0.1, 0.2, 0.2\rangle\rangle$

Phase 2: Compute the weights of the criteria and sub criteria of the problem.

This phase is considered the main phase in the solution of the problem and weighting the criteria.

Step 1. Each expert structure comparisons matrices on the same problem and aggregate matrices which are on the same problem element.

Step 2. In this step, experts compare all overall objectives criteria with sub criteria. Also criteria with alternatives and the interdependencies are considered in the comparison matrices between all elements.

$$\begin{array}{c} \\ C_1 \\ C_2 \\ \cdots \\ \cdots \\ \cdots \\ Cn \end{array} \begin{array}{c} C_1 \quad C_2 \ \ldots . C_n \quad \text{weights} \\ \begin{bmatrix} C_1 & C_{12} & \ldots & C_{1m} & w_1 \\ C_{21} & C_{22} & \ldots & C_{2m} & w_2 \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ C_{n1} & C_{n2} & \ldots & C_{nm} & w_n \end{bmatrix} \end{array} \quad (5)$$

The previous matrix shows the relationships between the criteria and calculating of weights and the following shows how present weights of sub criteria relevant to each criteria and calculating the local weight by Eq. (8). We obtain the global weight by multiplying Eq. (5) by the weights in Eq. (8).

In the suggested method, the triangular neutrosophic numbers are used to present the pairwise comparisons matrices as exhibited in Table 1. On the contrary, the ANP in traditional using of Saaty [32] scale of a nine point to represent the comparisons of matrices.

Step 3. Transform the comparisons matrices of the triangular neutrosophic numbers into crisp values by using the following Eqs. (5) and (6). Then, check the (CR) for each matrix which should be less than 0.1 [33].

Score function:

$$S\left(\tilde{a}_{ij}\right) = \frac{1}{8}[a_1 + b_1 + c_1] \times (2 + \alpha_{\tilde{a}} - \theta_{\tilde{a}} - \beta_{\tilde{a}}) \quad (6)$$

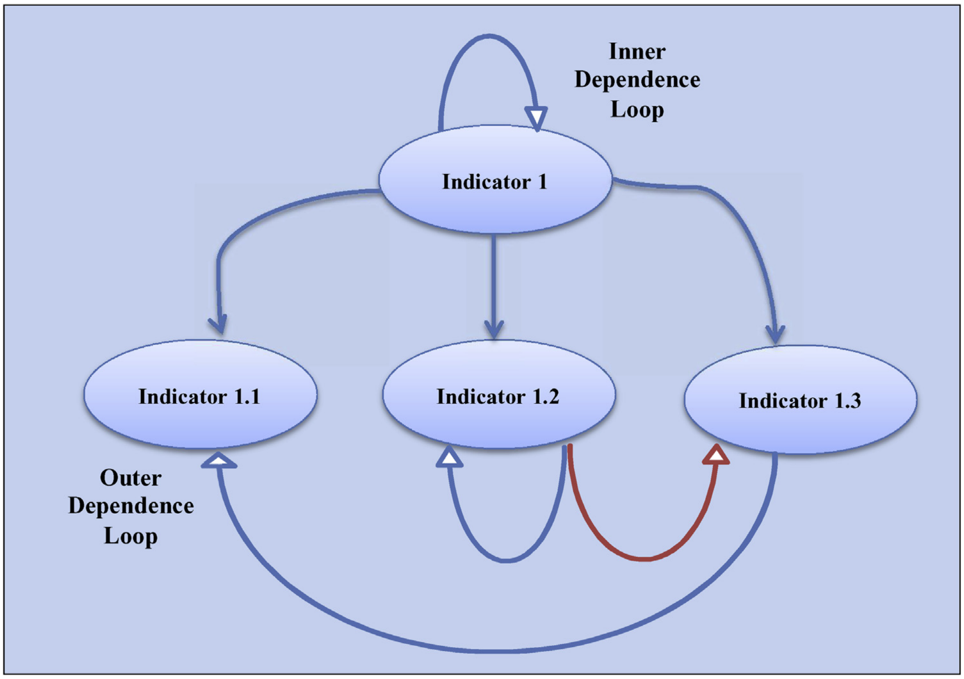

Fig. 4. Interdependencies in ANP.

Accuracy function:

$$A\left(\tilde{a}_{ij}\right) = \frac{1}{8}[a_1 + b_1 + c_1] \times (2 + \alpha_{\tilde{a}} - \theta_{\tilde{a}} + \beta_{\tilde{a}}) \tag{7}$$

Step 4. Determine weight by calculating the eigenvector of matrices which will be used in the constructing of the super matrix of interdependencies.

$$\begin{array}{c} \\ C_{11} \\ C_{21} \\ \cdots \\ \cdots \\ \cdots \\ C_{n1} \end{array} \begin{array}{l} C_1 \quad C_2 \ \ldots\ldots \quad C_n \\ \begin{bmatrix} w_{11} & w_{12} & \ldots & w_{1m} & w_{11} & w_{12} & \ldots & w_{1m} & w_{11} & w_{12} & \ldots & w_{1m} \\ w_{21} & w_{22} & \ldots & w_{2m} & w_{21} & w_{22} & \ldots & w_{2m} & w_{21} & w_{22} & \ldots & w_{2m} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ w_{n1} & w_{n2} & \ldots & w_{nm} & w_{n1} & w_{n2} & \ldots & w_{nm} & w_{n1} & w_{n2} & \ldots & w_{nm} \end{bmatrix} \end{array} \tag{8}$$

$$W_{local} = [W_{C_{11}}, W_{C_{12}} \ldots W_{C_{1n}}, W_{C_{21}}, W_{C_{22}} \ldots W_{C_{2n}}, W_{C_{31}}, W_{C_{32}} \ldots W_{C_{3n}}]^T \tag{9}$$

Step 5. In this step, we calculate the weights for the criteria. Firstly, to obtain the local weight for the sub criteria multiplying the weight of interdependence of criteria by the local weight obtained from experts' comparison matrices of criteria relevant to objective. Secondly, the global weight is calculated by multiplying the inner interdependent weight of the criterion to which it belongs by the local weight.

Phase 3: Rank the alternatives of the problem by using the VIKOR technique

Step 1. Every expert from three experts makes the separated evaluation matrix which consists of alternatives compared to criteria. Then, aggregate the three separated evaluation matrices by each expert into one matrix by using Eq. (10).

$$\tilde{X}_{ij} = \tilde{X}_{ij}^{\ 1} + \ldots\ldots\ldots\ldots\ldots + \frac{\tilde{X}_{ij}^{\ n}}{n} \tag{10}$$

Step 2. Determine the cost attributes and the benefits attributes of the sub criteria in the problem.

Step 3. Make indexes value being dimensionless, set decision-making matrix by using Eqs. (11) and (12).

The cost type indicators are calculated as follow:

$$Z_{ij} = \left(\frac{\mathrm{Min}\,X_{ij}}{X_{ij}}\right) \tag{11}$$

The benefit type indicators are calculated as follow:

$$Z_{ij} = \left(\frac{X_{ij}}{\mathrm{Max}\,X_{ij}}\right) \tag{12}$$

Step 5. Calculating the positive and negative ideal solutions using the Eqs. (13) and
(14).

Calculate the best and worst values which are:

For all cost criteria, i.e. $i \ \varepsilon \ c_c$

$$A^*_i = \min X_{ij} \text{ and } A^-_i = \max X_{ij} \tag{13}$$

For all benefit criteria, i.e. $i \ \varepsilon \ c_b$

$$A^*_i = X_{ij} \text{ and } A^-_i = \min X_{ij} \tag{14}$$

The adjustment solution A^c is the practical solution that is the "relative" to the ideal A^* and adjustment means a convention determined by mutual renunciations by $\Delta\ A_1 = A^*_1 - A^c_1$ and $\Delta\ A_2 = A^*_2 - A^c_2$.

Step 6. From here, we start using the weighted which are obtained from the ANP method.

$$W_{Global} = [W_{C_{11}}, W_{C_{12}} \ldots W_{C_{1n}}, W_{C_{21}}, W_{C_{22}} \ldots W_{C_{2n}}, W_{C_{31}}, W_{C_{32}} \ldots W_{C_{3n}}]^T \tag{15}$$

And the evaluation matrix for alternatives relevant to sub criteria after applies the two equations (13, 14) for cost criteria and benefit criteria as follows:

$C_1 \quad C_2 \ \ldots\ldots \quad C_n$

$$\begin{array}{c} A_1 \\ A_2 \\ \cdots \\ \cdots \\ \cdots \\ An \end{array}\begin{bmatrix} C_{11} & C_{12} & \ldots & C_{1m} & C_{11} & C_{12} & \ldots & C_{1m} & C_{11} & C_{12} & \ldots & C_{1m} \\ C_{21} & C_{22} & \ldots & C_{2m} & C_{21} & C_{22} & \ldots & C_{2m} & C_{21} & C_{22} & \ldots & C_{2m} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ C_{n1} & C_{n2} & \ldots & C_{nm} & C_{n1} & C_{n2} & \ldots & C_{nm} & C_{n1} & C_{n2} & \ldots & C_{nm} \end{bmatrix} \quad (16)$$

Step 7. Calculate the value of S_i, R_i and Q_i

From the previous two Eqs. (11) and (12), we can obtain the following S_i and R_i which are segregation of i^{th} with the better value and the segregation of i^{th} with the worst value by two equations exhibited as the following:

$$S_i = \sum_{x=1}^{N} \sum_{y=1}^{n_N} \left(w_{c_{xy}} \frac{d(A^*{}_{xy}, X_{ij})}{d(A^*{}_{xy}, A^-{}_{xy})} \right) \quad (17)$$

$$R_i = \max_{xy} \left\{ w_{c_{xy}} \frac{d(A^*{}_{xy}, X_{ij})}{d(A^*{}_{xy}, A^-{}_{xy})} \right\} \quad (18)$$

$$Q_i = \mu \frac{S_i - S_i^-}{S_i^* - S_i^-} + (1-\mu) \frac{R_i - R_i^-}{R_i^* - R_i^-} \quad (19)$$

In Eq. (19) μ mean the weight of the strategy of the maximum group utility that equal 0.5 where S^*, S^-, R^*, R^- calculating as follows:

$$S^*{}_q = \max_q\{S_q\} \text{ and } S^-{}_q = \min_q\{S_q\} \quad (20)$$

$$R^*{}_q = \max_q\{R_q\} \text{ and } R^-{}_q = \min_q\{R_q\} \quad (21)$$

Step 8. Contemplate the suppliers

Respectively, rank the S_i, R_i and Q_i and there are two conditions to satisfy before the alternative in the first position in Q_i ranking suggested as the adjustment's solutions. There are two conditions that should be satisfied:

Case 1

$$Q(S^2) - Q(S^1) \geq \frac{1}{M-1} \quad (22)$$

In which, M is the number of alternative suppliers in the problem and S^2 in the Q ranking list means the alternative with the second position.

Case 2: agreeable persistence

In the ranking list of Q the alternative S^1 should be the superior in the S or R. Go to the extra phase to get the compromises solution, if either condition is not satisfied. When case 1 is not satisfied, the maximum values of M need to be searched with the following relationship:

$$Q(S^N) - Q(S^1) < \frac{1}{M-1} \quad (23)$$

And when case 2 is not satisfied, then both S^1 and S^2 are adjustment solutions.

Phase 4: Sorting the alternatives again using of VIKOR method combined with entropy Method.

Numerical illustration for the previous supplier selection problem:

Step 1. Calculate the T_{ij} for the matrix

$$T_{ij} = \frac{v_{ij}}{\sum_{j=1}^{m} v_{ij}} \quad (24)$$

Step 2. Calculate the entropy value t_{ij} for the matrix

$$t_{ij} = -k \sum_{i=1}^{m} t_{ij} \ln(t_{ij}) \quad (25)$$

$$K = \frac{1}{\ln(m)}, \; m = \text{number of alternatives} \quad (26)$$

Step 3. Calculate the weights

Calculate the weights as the following:

$$W_j = \frac{(1-t_{ij})}{\sum_{j=1}^{n} (1-t_{ij})} \quad (27)$$

Step 4. Calculate the value of S_i, R_i and Q_i

In this step, follow step 3 to step 8 as in the previous illustrations. Then, start to sort the alternatives again after entropy method.

Step 5. Ending

Finally, the diagrammatic clarification of the offered framework is exhibited in Fig. 5.

6. The case study: results and analysis

In this section, the results are analyzed and presented as follows. The suggested structure has been applied to a real sustainable supplier selection problem of an import company.

This study has been conducted on a large importing company in Egypt. The United corporation for importing and exporting was founded in 2005 and is based in Port Said, Egypt. The corporation imports a lot of products such as hardware, electrical devices, toys, housewares et cetera from different countries. The corporation is seeking to increase the import rate and sales. The corporation is seeking to import from one of the largest countries in East Asia that is called the Asian Tigers and choose the best supplier. It must be considered the values of the society and citizenship and religious values in the products they import and be satisfaction of all citizens in terms of the social factor and be environmentally friendly products and a low financial cost affordable to citizens. Therefore, the corporation must evaluate available suppliers and their sustainability to select the best supplier to import from it. So, for this study the corporation collected information about the factors (economic, environment and social) that are considered by three experts. The experts are: strategic expert, marketing expert and Manufacturing expert with more than seven years of experience in this field. The suppliers are five and denoted by five cities respectively: A_1 Qingdao City (mainland China's base for green suppliers), A_2 Singapore, A_3 Johor Bahru (Malaysia), A_4 Taipei City and A_5 Hong Kong City. These five are considered as part of "Active Asian Economic Cities" (AAECs) due to its developed economy and active import and export businesses, particularly the establishment of green suppliers and recycling businesses.

Phase 1: Understanding of the problem.

Identify the criteria, the sub criteria and the alternatives of the available suppliers of the problem as exhibited in Fig. 6. In addition, we can determine how to apply the ANP and how criteria and sub criteria influence each other.

Phase 2: Compute the weights of the elements of the problem.

In this phase, opinions of experts presented in the comparisons matrices between criteria relevant to sub criteria and alternatives relevant to sub criteria and present the comparison matrices using of the (TRiNs) to deal with vague and incomplete information using of scales exhibited in Table 1. All the following tables from 1 to 21 presented how to calculate the weight between elements of the case study we studied (Table 2).

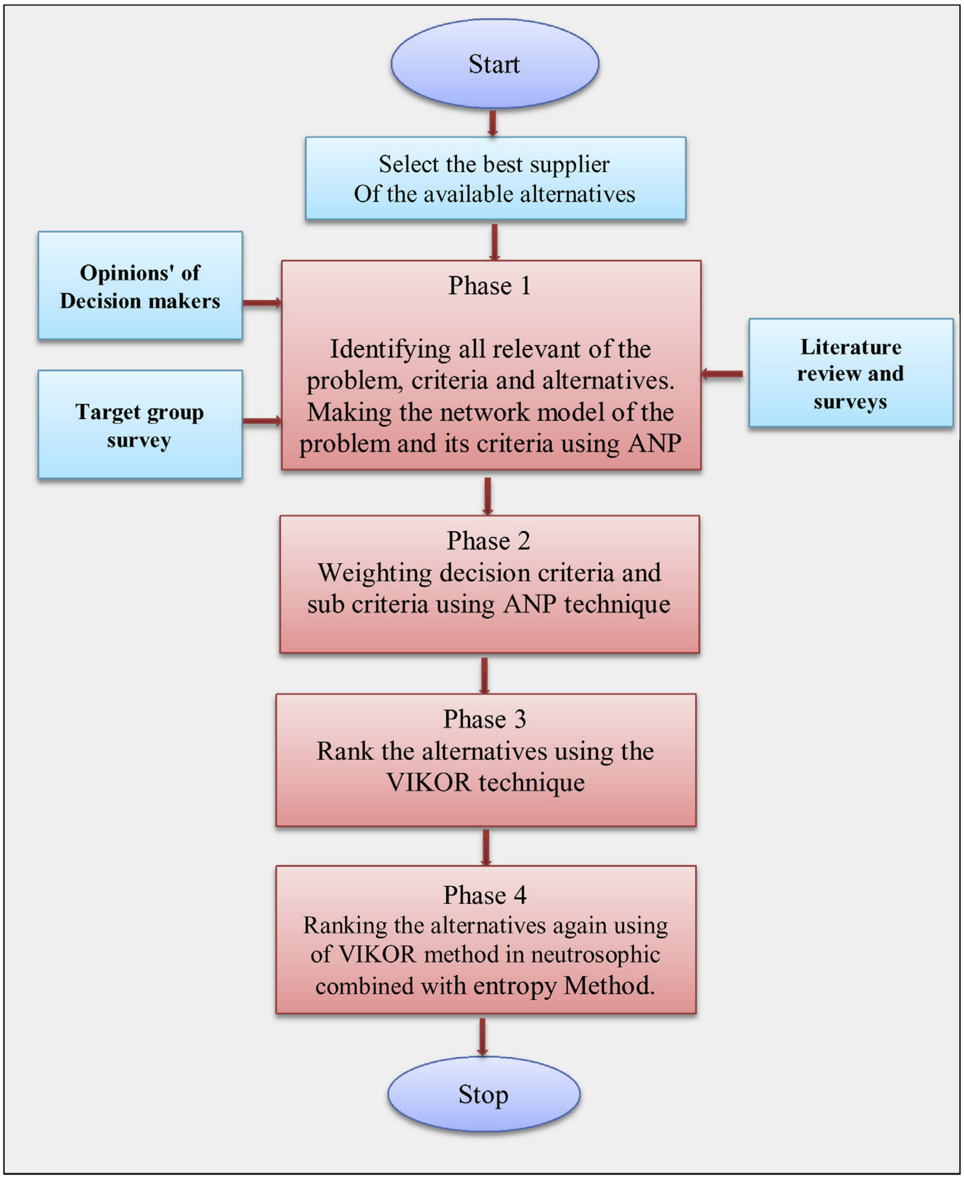

Fig. 5. The proposed framework of the model phases.

Adding the membership to values (truthiness, falsity, indeterminacy) to values that is presented in Table 3.

The next step is to convert the neutrosophic values to the crisp values in the matrix. Results are presented in Table 3 by Eq. (6). This is called the deneutrosophication function (Tables 4–10).

All the following matrices from 2 to 22 are consistent by checking the consistency ratio and the consistency ratio (CR) less than 0.1 in all matrices.

Hence, we calculated the comparative importance of the criteria on the base of their interdependence, which was calculated by using the matrix in Table 11 and the preferences of Table 4 as follows:

$$w_{\text{factor}} = \begin{bmatrix} economic\,(EC) \\ social\,(SO) \\ environment\,(EN) \end{bmatrix}$$

$$= \begin{bmatrix} 0.37 & 0.35 & 0.34 \\ 0.31 & 0.34 & 0.30 \\ 0.32 & 0.31 & 0.36 \end{bmatrix} \times \begin{bmatrix} 0.26 \\ 0.36 \\ 0.38 \end{bmatrix} = \begin{bmatrix} 0.36 \\ 0.31 \\ 0.33 \end{bmatrix}$$

From the previous matrix, it is clear that the inner interdependencies of criteria effect on its weights. It's obvious that, the weights of main criteria changed from (0.26, 0.36, and 0.38) to (0.36, 0.31, and 0.33). Therefore, when evaluating and selecting the suppliers the most significant factor is the economic (EC) criteria followed by social (SO) criteria and environmental (EN) criteria according to decision makers and experts.

Let's start the comparison matrices to calculate the local weights of sub criteria relevant to their clusters (criteria), showed in Tables 12–14 (Tables 15–20).

Economic factors (EC):

- $\mathbf{c}_{11}$ (cost of product "CP")
- $\mathbf{c}_{12}$ (Revenue on product "RP")
- $\mathbf{c}_{13}$ (Transportation cost "CO")

Social factors (SO):

- $\mathbf{c}_{21}$ (Vocational health and safety systems "VS")
- $\mathbf{c}_{22}$ (Information revelation "IR")

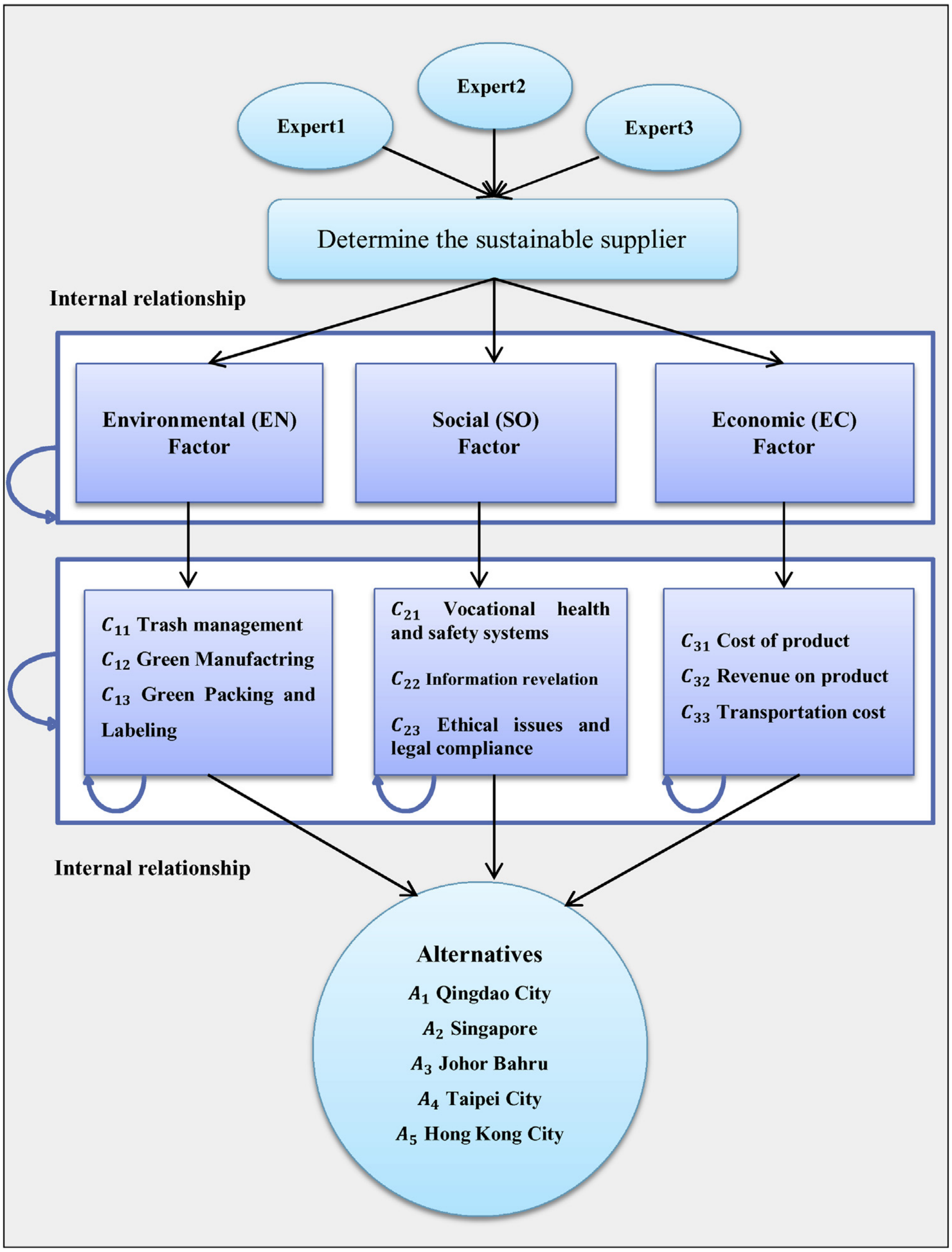

Fig. 6. Typical structure for determining the weights of sub criteria and selecting the best alternatives.

- $\mathbf{c}_{23}$ (Ethical issues and legal compliance "EL")

Environmental factors (EN):

- $\mathbf{c}_{31}$ (Trash management "TM")
- $\mathbf{c}_{32}$ (Green manufacturing "GM")
- $\mathbf{c}_{33}$ (Green packing and labeling "GL")

Concisely, the previous matrices showed the local weight of sub-criteria by inner interdependency to each criterion. So, we obtain the global weight of sub-criteria by multiplying local weight by the inner interdependent weight of the criterion showed in Table 21.

We obtain the global weight of sub criteria as follow $\boldsymbol{W}_{Global} = [0.13, 0.09, 0.14, 0.06, 0.15, 0.10, 0.16, 0.07, 0.11]^{\mathbf{T}}$. Fig. 7 shows the local and global weights of sub criteria (Tables 22 and 23).

Phase 3: Sorting alternatives of problems.

Every expert from the set of experts makes the evaluation matrix via the comparison between the five alternatives relative to each sub criteria by using the (TriNs) scale in Table 1. We can then convert every matrix into crisp value then aggregate the matrices into one matrix using Eq. (10) then obtain the matrix as exhibited in Table 24.

Establishing decision- making matrix by making indicators value being dimensionless where the following are benefits attributes the greater value being better.

- $\mathbf{c}_{11}$ (cost of product "CP")
- $\mathbf{c}_{13}$ (Transportation cost "CO")

Table 2
Pairwise comparison of factors and local weight.

Factors	Economic (EC)	Social (SC)	Environmental (EN)
Economic (EC)	⟨⟨0.5, 0.5, 0.5⟩⟩	⟨⟨0.4, 0.5, 0.6⟩⟩	⟨⟨0.9, 1.0, 1.0⟩⟩
Social (SC)	⟨⟨0.6, 0.7, 0.8⟩⟩	⟨⟨0.5, 0.5, 0.5⟩⟩	⟨⟨(0.7, 0.8, 0.9⟩⟩
Environmental (EN)	⟨⟨(0.8, 0.9, 1.0⟩⟩	⟨⟨(0.3, 0.4, 0.5⟩⟩	⟨⟨0.5, 0.5, 0.5⟩⟩

Table 3
Pairwise comparison matrix with the memberships.

Factors	Economic (EC)	Social (SC)	Environmental (EN)
Economic (EC)	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$	$\langle\langle\langle 0.4, 0.5, 0.6\rangle; 0.7, 0.3, 0.2\rangle\rangle$	$\langle\langle\langle 0.9, 1.0, 1.0\rangle; 0.1, 0.2, 0.2\rangle\rangle$
Social (SC)	$\langle\langle\langle 0.6, 0.7, 0.8\rangle; 0.8, 0.3, 0.5\rangle\rangle$	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$	$\langle\langle\langle 0.7, 0.8, 0.9\rangle; 0.8, 0.3, 0.5\rangle\rangle$
Environmental (EN)	$\langle\langle\langle 0.8, 0.9, 1.0\rangle; 0.9, 0.2, 0.3\rangle\rangle$	$\langle\langle\langle 0.3, 0.4, 0.5\rangle; 1.0, 0.1, 0.1\rangle\rangle$	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$

Table 4
Pairwise comparison of factors and local weight.

Factors	Economic (EC)	Social (SC)	Environmental (EN)	Weights
Economic (EC)	0.5	0.41	0.62	0.26
Social (SC)	0.58	0.5	0.61	0.36
Environmental (EN)	0.81	0.42	0.5	0.38

Table 5
Calculating the membership and crisp value of economic (EC) factor matrix relative to other factors.

Economic (EC) factor	Economic (EC)	Social (SC)	Environmental (EN)
Economic (EC)	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$	$\langle\langle\langle 0.3, 0.4, 0.5\rangle; 1.0, 0.1, 0.1\rangle\rangle$	$\langle\langle\langle 0.6, 0.7, 0.8\rangle; 0.8, 0.3, 0.5\rangle\rangle$
Social (SC)	$\langle\langle\langle 0.2, 0.3, 0.4\rangle; 0.8, 0.2, 0.3\rangle\rangle$	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$	$\langle\langle\langle 0.7, 0.8, 0.9\rangle; 0.8, 0.3, 0.5\rangle\rangle$
Environmental (EN)	$\langle\langle\langle 0.1, 0.2, 0.3\rangle; 0.5, 0.1, 0.3\rangle\rangle$	$\langle\langle\langle 0.8, 0.9, 1.0\rangle; 0.9, 0.2, 0.3\rangle\rangle$	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$

Table 6
Interdependency matrix of the main factors relative to economic (EC) factor.

Economic Factor	Economic (EC)	Social (SC)	Environmental (EN)	Weights
Economic (EC)	0.5	0.42	0.55	0.37
Social (SC)	0.26	0.5	0.60	0.31
Environmental (EN)	0.16	0.81	0.5	0.32

Table 7
Calculating the memberships and crisp value of Social (SC) factor matrix relative to other factors.

Social (SC) Factor	Economic (EC)	Social (SC)	Environmental (EN)
Economic (EC)	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$	$\langle\langle\langle 0.3, 0.4, 0.5\rangle; 1.0, 0.1, 0.1\rangle\rangle$	$\langle\langle\langle 0.8, 0.9, 1.0\rangle; 09, 0.2, 0.3\rangle\rangle$
Social (SC)	$\langle\langle\langle 0.6, 0.7, 0.8\rangle; 0.8, 0.3, 0.5\rangle\rangle$	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$	$\langle\langle\langle 0.7, 0.8, 0.9\rangle; 0.8, 0.3, 0.5\rangle\rangle$
Environmental (EN)	$\langle\langle\langle 0.4, 0.5, 0.6\rangle; 0.7, 0.3, 0.2\rangle\rangle$	$\langle\langle\langle 0.9, 1.0, 1.0\rangle; 0.1, 0.2, 0.2\rangle\rangle$	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$

Table 8
Interdependency matrix of the main factors relative to social (SC) factor.

Social (SC) Factor	Economic (EC)	Social (SC)	Environmental (EN)	Weights
Economic (EC)	0.5	0.42	0.81	0.35
Social (SC)	0.55	0.5	0.60	0.34
Environmental (EN)	0.41	0.61	0.5	0.30

Table 9
Calculating the memberships and crisp value of Environmental (EN) factor matrix relative to other factors.

Environmental (EN)Factor	Economic (EC)	Social (SC)	Environmental (EN)
Economic (EC)	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$	$\langle\langle\langle 0.4, 0.5, 0.6\rangle; 0.7, 0.3, 0.2\rangle\rangle$	$\langle\langle\langle 0.8, 0.9, 1.0\rangle; 09, 0.2, 0.3\rangle\rangle$
Social (SC)	$\langle\langle\langle 0.2, 0.3, 0.4\rangle; 0.8, 0.2, 0.3\rangle\rangle$	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$	$\langle\langle\langle 0.8, 0.9, 1.0\rangle; 0.9, 0.2, 0.3\rangle\rangle$
Environmental (EN)	$\langle\langle\langle 0.7, 0.8, 0.9\rangle; 0.8, 0.3, 0.5\rangle\rangle$	$\langle\langle\langle 0.5, 0.6, 0.7\rangle; 0.9, 0.2, 0.1\rangle\rangle$	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$

Table 10
Interdependency matrix of the main factors relative to Environmental (EN) factor.

Environmental (EN)	Economic (EC)	Social (SC)	Environmental (EN)	Weights
Economic (EC)	0.5	0.41	0.81	0.34
Social (SC)	0.26	0.5	0.81	0.30
Environmental (EN)	0.60	0.59	0.5	0.36

Table 11
The comparative influence of decision criteria, EC, SC, EN.

criteria	Economic (EC)	Social (SC)	Environmental (EN)
Economic (EC)	0.37	0.35	0.34
Social (SC)	0.31	0.34	0.30
Environmental (EN)	0.32	0.30	0.36

Table 12
The comparison matrix between sub criteria of environmental (EN) criteria.

Economic (EC)Factor	C_{11}/ **CP**	C_{12} / RP	C_{13} / CO
C_{11}/ **CP**	⟨⟨0.5, 0.5, 0.5⟩⟩	⟨⟨0.6, 0.7, 0.8⟩⟩	⟨⟨0.9, 1.0, 1.0⟩⟩
C_{12} / RP	⟨⟨0.4, 0.5, 0.6⟩⟩	⟨⟨0.5, 0.5, 0.5⟩⟩	⟨⟨0.8, 0.9, 1.0⟩⟩
C_{13} / CO	⟨⟨0.7, 0.8, 0.9⟩⟩	⟨⟨0.1, 0.2, 0.3⟩⟩	⟨⟨0.5, 0.5, 0.5⟩⟩

- c_{31} (Trash management “TM”)
- c_{32} (Green manufacturing “GM”)
- c_{33} (Green packing and labeling “GL”)

The following are cost attributes the smaller value being better.

- c_{21} (Vocational health and safety systems “VS”)
- c_{22} (Information revelation “IR”)
- c_{23} (Ethical issues and legal compliance “EL”)
- c_{12} (Revenue on product “RP”)

Calculating the positive and negative ideal solutions

The next step is to calculate the positive and negative ideal solutions (A^*, A^-) from the previous matrix using Eqs. (13) and (14) as follows: The positive ideal solutions are A^* = (1, 1, 1, 1, 1, 1, 1, 1, and 1) and the negative ideal solutions are A^- = (0.63, 0.73, 0.57, 0.51, 0.60, 0.62, 0.62, 0.40, and 0.60) (Tables 25 and 26).

Step 6: calculating the S, R, Q for each alternative

Calculating the S, R, and Q for each alternative using Eqs. (17)–(21) as shown in the following Table 27.

In the previous Table 27 it is showed a list of alternatives Q after using the equations. From the results showed follows that the two conditions are satisfied. The first condition: Q (S^2) - Q (S^1) $\geq \frac{1}{M-1}$ that presented 0.334 – 0.051 $\geq \frac{1}{5-1}$. Then, the second condition that the first order value of Q is the first order value of R also of S as showed in Table 28.

Ranking of S for values are: $\boldsymbol{A_2} > \boldsymbol{A_5} > \boldsymbol{A_1} > \boldsymbol{A_3} > \boldsymbol{A_4}$

Ranking of R for values are: $\boldsymbol{A_2} > \boldsymbol{A_3} > \boldsymbol{A_4} > \boldsymbol{A_5} > \boldsymbol{A_1}$

Ranking of Q for values are: $\boldsymbol{A_2} > \boldsymbol{A_5} > \boldsymbol{A_3} > \boldsymbol{A_1} > \boldsymbol{A_4}$

Hence, the final ranking of the alternatives $\boldsymbol{A_2} > \boldsymbol{A_5} > \boldsymbol{A_3} > \boldsymbol{A_1} > \boldsymbol{A_4}$ **is** presented. In other words, Taipei City is considered the best supplier for importing and dealing with company compared to other competitors. The worst choice is the city of Singapore as exhibited in Fig. 8. This is identical to the reality since Singapore has no natural resources and heavily relies on

Phase 4: Sorting the alternatives again using of VIKOR method combined with entropy method.

Numerical illustration for the previous supplier selection problem are as follows:

Table 13
The comparison matrix between sub criteria of environmental (EN) criteria via using the memberships.

Economic (EC)Factor	C_{11}/ **CP**	C_{12} / RP	C_{13} / CO
C_{11}/ **CP**	⟨⟨0.5, 0.5, 0.5⟩⟩	⟨⟨(0.6, 0.7, 0.8); 0.8, 0.4, 0.3⟩⟩	⟨⟨(0.9, 1.0, 1.0); 0.1, 0.2, 0.2⟩⟩
C_{12} / RP	⟨⟨(0.4, 0.5, 0.6); 0.7, 0.3, 0.2⟩⟩	⟨⟨0.5, 0.5, 0.5⟩⟩	⟨⟨(0.8, 0.9, 1.0); 0.9, 0.2, 0.3⟩⟩
C_{13} / CO	⟨⟨(0.7, 0.8, 0.9); 0.8, 0.3, 0.5⟩⟩	⟨⟨(0.1, 0.2, 0.3); 0.5, 0.1, 0.3⟩⟩	⟨⟨0.5, 0.5, 0.5⟩⟩

Table 14
The local weight of sub criteria of environmental (EN) criteria.

Economic (EC)Factor	C_{11}/ **CP**	C_{12} / RP	C_{13} / CO	Weights
C_{11}/ **CP**	⟨⟨0.5, 0.5, 0.5⟩⟩	⟨⟨(0.4, 0.5, 0.6); 0.7, 0.3, 0.2⟩⟩	⟨⟨(0.8, 0.9, 1.0); 09, 0.2, 0.3⟩⟩	0.35
C_{12} / RP	⟨⟨(0.2, 0.3, 0.4); 0.8, 0.2, 0.3⟩⟩	⟨⟨0.5, 0.5, 0.5⟩⟩	⟨⟨(0.8, 0.9, 1.0); 0.9, 0.2, 0.3⟩⟩	0.26
C_{13} / CO	⟨⟨(0.7, 0.8, 0.9); 0.8, 0.3, 0.5⟩⟩	⟨⟨(0.5, 0.6, 0.7); 0.9, 0.2, 0.1⟩⟩	⟨⟨0.5, 0.5, 0.5⟩⟩	0.39

Table 15
The comparison matrix between sub criteria of social (SO) criteria.

Social (SO)Factor	C_{21}/ VS	C_{22} / IR	C_{23} / EL
C_{21}/ VS	⟨⟨0.5, 0.5, 0.5⟩⟩	⟨⟨0.1, 0.2, 0.3⟩⟩	⟨⟨0.2, 0.3, 0.4⟩⟩
C_{22} / IR	⟨⟨0.9, 1.0, 1.0⟩⟩	⟨⟨0.5, 0.5, 0.5⟩⟩	⟨⟨0.8, 0.9, 1.0⟩⟩
C_{23} / EL	⟨⟨0.4, 0.5, 0.6⟩⟩	⟨⟨0.3, 0.4, 0.5⟩⟩	⟨⟨0.5, 0.5, 0.5⟩⟩

Table 16
The comparison matrix between sub criteria of social (SO) criteria via using the memberships.

Social (SO)Factor	C_{21}/ VS	C_{22} / IR	C_{23} / EL
C_{21}/ VS	⟨⟨0.5, 0.5, 0.5⟩⟩	⟨⟨(0.1, 0.2, 0.3); 0.5, 0.1, 0.3⟩⟩	⟨⟨(0.2, 0.3, 0.4); 0.8, 0.2, 0.3⟩⟩
C_{22} / IR	⟨⟨(0.9, 1.0, 1.0); 0.1, 0.2, 0.2⟩⟩	⟨⟨0.5, 0.5, 0.5⟩⟩	⟨⟨(0.8, 0.9, 1.0); 0.9, 0.2, 0.3⟩⟩
C_{23} / EL	⟨⟨(0.4, 0.5, 0.6); 0.7, 0.3, 0.2⟩⟩	⟨⟨(03, 0.4, 0.5); 1.0, 0.0, 0.2⟩⟩	⟨⟨0.5, 0.5, 0.5⟩⟩

Table 17
The local weight of sub criteria of social (SO) criteria.

Social (SO)Factor	C_{21}/ VS	C_{22} / IR	C_{23} / EL	Weights
C_{21}/ VS	0.5	0.16	0.26	0.22
C_{22} / IR	0.61	0.5	0.81	0.47
C_{23} / EL	0.41	0.42	0.5	0.31

Table 18
The comparison matrix between sub criteria of environmental (EN) criteria.

Environmental (EN)Factor	C_{31} / TM	C_{32} / GM	C_{33} / GL
C_{31} / TM	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$	$\langle\langle 0.8, 0.9, 1.0\rangle\rangle$	$\langle\langle 0.8, 0.9, 1.0\rangle\rangle$
C_{32} / GM	$\langle\langle 0.1, 0.2, 0.3\rangle\rangle$	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$	$\langle\langle 0.5, 0.6, 0.7\rangle\rangle$
C_{33} / GL	$\langle\langle 0.6, 0.7, 0.8\rangle\rangle$	$\langle\langle 04, 0.5, 0.6\rangle\rangle$	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$

Step 1. Calculate the T_{ij} for the matrix

Calculate the T_{ij} by the using of Eq. (24) as in the following Table 29.

Step 2. Calculate the entropy value t_{ij} for the matrix

Calculate the entropy value t_{ij} for the matrix using the two Eqs. (25) and (26)

Let m = 5, then k = $\frac{1}{\ln 5}$, k = 0.621,

Then, we calculate the value of $t_{ij} = \sum_{i=1}^{m} t_{ij} \ln(t_{ij})$ as the following for each column as the following:

$$\sum_{i=1}^{m} t_{i1}\ln(t_{i1}) = -1.603, \quad \sum_{i=1}^{m} t_{i2}\ln(t_{i2}) = -1.602,$$

$$\sum_{i=1}^{m} t_{i3}\ln(t_{i3}) = -1.589, \quad \sum_{i=1}^{m} t_{i4}\ln(t_{i4}) = -1.580,$$

$$\sum_{i=1}^{m} t_{i5}\ln(t_{i5}) = -1.591, \quad \sum_{i=1}^{m} t_{i6}\ln(t_{i6}) = -1.596,$$

$$\sum_{i=1}^{m} t_{i7}\ln(t_{i7}) = -1.594, \quad \sum_{i=1}^{m} t_{i8}\ln(t_{i8}) = -1.564,$$

$$\sum_{i=1}^{m} t_{i9}\ln(t_{i9}) = -1.593,$$

Then, we calculate the entropy value by using Eq. (25)

t_1 = (−0.621) (−1.603) = 0.995, t_2= (−0.621) (−1.602) = 0.994,
t_3= (−0.621) (−1.589) = 0.986, t_4 = (−0.621) (−1.580) = 0.981,
t_5= (−0.621) (−1.591) = 0.988, t_6 = (−0.621) (−1.596) = 0.991,
t_7= (−0.621) (−1.594) = 0.989, t_8 = (−0.621) (−1.564) = 0.971,
t_9 = (−0.621) (−1.593) = 0.989,

Step 3. Calculate the weights

Calculate the weights using Eq. (27)

w_1 = 0.043, w_2 = 0.052, w_3 = 0.121, w_4 = 0.164, w_5 = 0.103, w_6 = 0.078,

w_7 = 0.095, w_8 = 0.250, w_9 = 0.095.

W = [0.043, 0.052 0.121, 0.164, 0.103, 0.078, 0.095, 0.250, 0.095]

Step 4. Calculate the value of S_i , R_i and Q_i

In this step, follow step 3 to step 8 as in the previous illustrations. Then, we can start to sort the alternatives again after adopting entropy method (Table 30).

Calculating the S, R, and Q for each alternative using Eqs. (17)–(21) as shown in the following Table 31 and Fig. 9 present the ranking of alternatives using of entropy method.

The previous Table 27 showed a list of alternatives Q after using the equations. From the results showed follows that the first condition is not satisfied $Q(S^2) - Q(S^1) \geq \frac{1}{M-1}$ that presented 0.191 – 0.075 $\geq \frac{1}{5-1}$. So, we achieve this condition by this Eq. $Q(S^r) - Q(S^1)$

Table 19
The comparison matrix between sub criteria of environmental (EN) criteria via using the memberships.

Environmental (EN)Factor	C_{31} / TM	C_{32} / GM	C_{33} / GL
C_{31} / TM	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$	$\langle\langle\langle 0.8, 0.9, 1.0\rangle; 0.9, 0.2, 0.3\rangle\rangle$	$\langle\langle\langle 0.8, 0.9, 1.0\rangle; 0.9, 0.2, 0.3\rangle\rangle$
C_{32} / GM	$\langle\langle\langle 0.1, 0.2, 0.3\rangle; 0.5, 0.1, 0.3\rangle\rangle$	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$	$\langle\langle\langle 0.5, 0.6, 0.7\rangle; 0.9, 0.2, 0.1\rangle\rangle$
C_{33} / GL	$\langle\langle\langle 0.6, 0.7, 0.8\rangle; 0.8, 0.4, 0.3\rangle\rangle$	$\langle\langle\langle 04, 0.5, 0.6\rangle; 0.7, 0.3, 0.2\rangle\rangle$	$\langle\langle 0.5, 0.5, 0.5\rangle\rangle$

Table 20
The local weight of sub criteria of environmental (EN) criteria.

Environmental (EN)Factor	C_{31} / TM	C_{32} / GM	C_{33} / GL	Weights
C_{31} / TM	0.5	0.82	0.81	0.45
C_{32} / GM	0.16	0.5	0.59	0.24
C_{33} / GL	0.55	0.40	0.5	0.31

Table 21
The global weights of all sub-criteria.

Criteria and local weight	Sub-criteria	Local weight	Global weight
Economic (EC) criteria (0.36)	c_{11} (cost of product "CP")	0.35	0.13
	c_{12} (Revenue on product "RP")	0.26	0.09
	c_{13} (Transportation cost "CO")	0.39	0.14
Social (SO) criteria (0.31)	c_{21} (Vocational health and safety systems "VS")	0.22	0.06
	c_{22} (Information revelation "IR")	0.47	0.15
	c_{23} (Ethical issues and legal compliance "EL")	0.31	0.10
Environmental (EN) criteria (0.33)	c_{31} (Trash management "TM")	0.45	0.16
	c_{32} (Green manufacturing "GM")	0.24	0.07
	c_{33} (Green packing and labeling "GL")	0.31	0.11

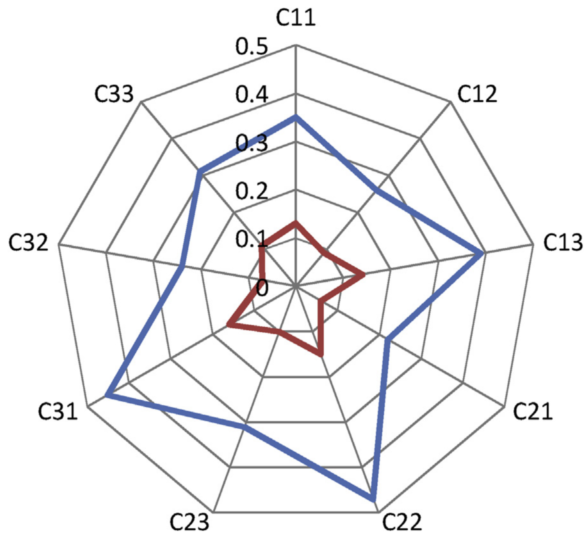

Fig. 7. Presenting the local and global weights of sub criteria.

Table 22
The evaluation matrix for alternatives with sub-criteria.

Experts	Alternatives	Sub-criteria								
		C_{11} / CP	C_{12} / RP	C_{13} / CO	C_{21} / VS	C_{22} / IR	C_{23} / EL	C_{31} / TM	C_{32} / GM	C_{33} / GL
Expert 1	A_1	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩	⟨⟨FHF⟩⟩	⟨⟨MF⟩⟩	⟨⟨LF⟩⟩	⟨⟨LF⟩⟩	⟨⟨FLF⟩⟩	⟨⟨FHF⟩⟩	⟨⟨SF⟩⟩
	A_2	⟨⟨LF⟩⟩	⟨⟨LF⟩⟩	⟨⟨FLF⟩⟩	⟨⟨MF⟩⟩	⟨⟨FHF⟩⟩	⟨⟨HF⟩⟩	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩
	A_3	⟨⟨FHF⟩⟩	⟨⟨HF⟩⟩	⟨⟨FLF⟩⟩	⟨⟨HF⟩⟩	⟨⟨SF⟩⟩	⟨⟨MF⟩⟩	⟨⟨LF⟩⟩	⟨⟨SF⟩⟩	⟨⟨HF⟩⟩
	A_4	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩	⟨⟨LF⟩⟩	⟨⟨HF⟩⟩	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩	⟨⟨LF⟩⟩	⟨⟨MF⟩⟩
	A_5	⟨⟨LF⟩⟩	⟨⟨MF⟩⟩	⟨⟨HF⟩⟩	⟨⟨SF⟩⟩	⟨⟨MF⟩⟩	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩	⟨⟨MF⟩⟩	⟨⟨SF⟩⟩
Expert 2	A_1	⟨⟨SF⟩⟩	⟨⟨FLF⟩⟩	⟨⟨FHF⟩⟩	⟨⟨LF⟩⟩	⟨⟨SF⟩⟩	⟨⟨MF⟩⟩	⟨⟨LF⟩⟩	⟨⟨FHF⟩⟩	⟨⟨MF⟩⟩
	A_2	⟨⟨MF⟩⟩	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩	⟨⟨MF⟩⟩	⟨⟨FLF⟩⟩	⟨⟨FHF⟩⟩	⟨⟨HF⟩⟩	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩
	A_3	⟨⟨FHF⟩⟩	⟨⟨LF⟩⟩	⟨⟨LF⟩⟩	⟨⟨SF⟩⟩	⟨⟨HF⟩⟩	⟨⟨HF⟩⟩	⟨⟨SF⟩⟩	⟨⟨LF⟩⟩	⟨⟨LF⟩⟩
	A_4	⟨⟨LF⟩⟩	⟨⟨MF⟩⟩	⟨⟨HF⟩⟩	⟨⟨FHF⟩⟩	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩	⟨⟨MF⟩⟩	⟨⟨FLF⟩⟩	⟨⟨FHF⟩⟩
	A_5	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩	⟨⟨HF⟩⟩	⟨⟨SF⟩⟩	⟨⟨HF⟩⟩	⟨⟨LF⟩⟩	⟨⟨FLF⟩⟩	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩
Expert 3	A_1	⟨⟨FLF⟩⟩	⟨⟨LF⟩⟩	⟨⟨LF⟩⟩	⟨⟨FHF⟩⟩	⟨⟨SF⟩⟩	⟨⟨FHF⟩⟩	⟨⟨SF⟩⟩	⟨⟨MF⟩⟩	⟨⟨SF⟩⟩
	A_2	⟨⟨SF⟩⟩	⟨⟨FHF⟩⟩	⟨⟨HF⟩⟩	⟨⟨SF⟩⟩	⟨⟨LF⟩⟩	⟨⟨FLF⟩⟩	⟨⟨LF⟩⟩	⟨⟨MF⟩⟩	⟨⟨SF⟩⟩
	A_3	⟨⟨LF⟩⟩	⟨⟨SF⟩⟩	⟨⟨MF⟩⟩	⟨⟨SF⟩⟩	⟨⟨HF⟩⟩	⟨⟨FLF⟩⟩	⟨⟨FHF⟩⟩	⟨⟨HF⟩⟩	⟨⟨SF⟩⟩
	A_4	⟨⟨SF⟩⟩	⟨⟨HF⟩⟩	⟨⟨SF⟩⟩	⟨⟨LF⟩⟩	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩	⟨⟨LF⟩⟩	⟨⟨SF⟩⟩
	A_5	⟨⟨SF⟩⟩	⟨⟨MF⟩⟩	⟨⟨SF⟩⟩	⟨⟨MF⟩⟩	⟨⟨MF⟩⟩	⟨⟨HF⟩⟩	⟨⟨LF⟩⟩	⟨⟨SF⟩⟩	⟨⟨SF⟩⟩

Table 23
The crisp value for the evaluation matrix for alternatives with sub-criteria Aggregation of the evaluation matrix for the alternatives with sub criteria of the three experts using Eq. (10).

Experts	Alternatives	Sub-criteria								
		C_{11} / CP	C_{12} / RP	C_{13} / CO	C_{21} / VS	C_{22} / IR	C_{23} / EL	C_{31} / TM	C_{32} / GM	C_{33} / GL
Expert1	A_1	0.61	0.62	0.61	0.43	0.26	0.18	0.44	0.61	0.60
	A_2	0.18	0.26	0.44	0.43	0.61	0.57	0.60	0.81	0.62
	A_3	0.61	0.57	0.44	0.57	0.81	0.43	0.18	0.62	0.57
	A_4	0.81	0.81	0.62	0.18	0.57	0.81	0.81	0.18	0.43
	A_5	0.26	0.43	0.57	0.81	0.43	0.62	0.62	0.43	0.81
Expert 2	A_1	0.62	0.44	0.61	0.18	0.62	0.43	0.18	0.61	0.43
	A_2	0.43	0.62	0.81	0.43	0.44	0.61	0.63	0.62	0.62
	A_3	0.61	0.18	0.26	0.62	0.57	0.57	0.62	0.26	0.18
	A_4	0.26	0.43	0.57	0.61	0.81	0.62	0.43	0.44	0.61
	A_5	0.62	0.62	0.57	0.62	0.57	0.26	0.44	0.81	0.62
Expert 3	A_1	0.44	0.26	0.18	0.61	0.62	0.61	0.61	0.43	0.60
	A_2	0.60	0.61	0.57	0.81	0.26	0.44	0.18	0.43	0.81
	A_3	0.18	0.81	0.43	0.62	0.57	0.44	0.61	0.57	0.60
	A_4	0.81	0.57	0.81	0.18	0.81	0.62	0.81	0.18	0.60
	A_5	0.62	0.43	0.62	0.43	0.43	0.57	0.26	0.81	0.81

Table 24
The aggregation matrix of experts' opinions for alternatives with sub-criteria.

Aggregation matrix	Alternatives	Sub-criteria								
		C_{11} / **CP**	C_{12} / **RP**	C_{13} / **CO**	C_{21}/ **VS**	C_{22} / **IR**	C_{23} / **EL**	C_{31} / **TM**	C_{32} / **GM**	C_{33} / **GL**
Experts	A_1	0.55	0.44	0.47	0.41	0.5	0.41	0.42	0.56	0.54
	A_2	0.40	0.49	0.61	0.56	0.44	0.51	0.47	0.62	0.68
	A_3	0.47	0.52	0.38	0.60	0.65	0.48	0.47	0.48	0.45
	A_4	0.63	0.60	0.67	0.32	0.73	0.66	0.68	0.27	0.55
	A_5	0.5	0.48	0.59	0.62	0.48	0.48	0.44	0.67	0.75

Table 25
The value of the cost and the benefit attributes.

The cost and benefit attributes	Alternatives	Sub-criteria								
		C_{11} / **CP**	C_{12} / RP	C_{13} / CO	C_{21}/ VS	C_{22} / IR	C_{23} / EL	C_{31} / TM	C_{32} / GM	C_{33} / GL
	A_1	0.87	1.0	0.70	0.78	0.88	1.0	0.62	0.83	0.72
	A_2	0.63	0.89	0.91	0.57	1.0	0.80	0.69	0.93	0.90
	A_3	0.75	0.84	0.57	0.53	0.67	0.85	0.69	0.71	0.60
	A_4	1.0	0.73	1.0	1.0	0.60	0.62	1.0	0.40	0.73
	A_5	0.79	0.91	0.88	0.51	0.91	0.85	0.65	1.0	1.0

Table 26
The value of the cost and the benefit attributes and the global weight.

Sub criteria and weights	C_{11} / **CP** 0.13	C_{12} / RP 0.09	C_{13} / CO 0.14	C_{21}/ VS 0.06	C_{22} / IR 0.15	C_{23} / EL 0.10	C_{31} / TM 0.16	C_{32} / GM 0.07	C_{33} / GL 0.11
A_1	0.87	1.0	0.70	0.78	0.88	1.0	0.62	0.83	0.72
A_2	0.63	0.89	0.91	0.57	1.0	0.80	0.69	0.93	0.90
A_3	0.75	0.84	0.57	0.53	0.67	0.85	0.69	0.71	0.60
A_4	1.0	0.73	1.0	1.0	0.60	0.62	1.0	0.40	0.73
A_5	0.79	0.91	0.88	0.51	0.91	0.85	0.65	1.0	1.0

Table 27
The evaluation value of each alternative S, R, Q.

	A_1	A_2	A_3	A_4	A_5
S	0.472	0.424	0.772	0.934	0.467
R	0.16	0.13	0.14	0.15	0.15
Q	0.547	0.051	0.507	0.834	0.334

Table 28
Ranking of alternatives.

Alternatives	S	R	Q
A_1	A_2	A_2	A_2
A_2	A_5	A_3	A_5
A_3	A_1	A_4	A_3
A_4	A_3	A_5	A_1
A_5	A_4	A_1	A_4

$\geq \frac{1}{M-1}$ that presented 0.727- 0.075 $\geq \frac{1}{5-1}$. Then, the second condition that the first order value of Q is the first order value of R as showed in Table 31. Therefore, the final ranking of the alternatives $\boldsymbol{A_1} > \boldsymbol{A_2} > \boldsymbol{A_5} > \boldsymbol{A_3} > \boldsymbol{A_4}$ as exhibited in Table 32 and the two final ranking presented in Table 33.

7. Evaluation based on forecasted analysis

In this section, the objective is to forecast the future perspectives of the five "Active Asian Economic Cities" (AAECs) in places, particularly when we have changed the emphasis for the economic, social and environmental criteria. This is similar to the scenario-based prediction, since it is important for the decision-makers and policy-makers to know all possible consequences, so that the alternative recommendations can be given as soon as possible to minimize any potential loss.

The method of the predicted value is based on the development of the genetic algorithm, which can be useful to blend with deep learning, machine learning and artificial intelligence [34]. Genetic algorithm is very effective to predict the outcomes as follows.

There are inputs required: 1) the outputs of phase 1–4 in Fig. 5; 2) the mean scores of experts for all scenarios in Fig. 6; and 3) the poll of the general public with at least 300 samples per participating city. For the third category, it was taken and measured based on different websites reflecting the poll opinions of the people in the participating city. The general public reflected their opinions based on specific questions related to our research. The availability of the government data can be even more useful. However, since each city's forecasted data can vary extensively, the opinions polls on the populations of the city will be a more neutral and effective. Big data methods can analyze all the data analysis very quickly and accurately.

The term "Everythingworks" means if the algorithm can calculate the forecasted results automatically. It needs to be initialized (false) before starting. The term "results" contain the forecasted values of the five AAECs. The term "Call" is to start the forecasting process. When the forecasted simulation starts smoothly, then "results" equals to one, the algorithm begins to perform calculations, known as "Compute()", based on all input data. Sometimes errors may happen during the forecasting process. "Check()" is used to identify any errors. If no errors are found, it returns to the results. The algorithm will stop when all forecasting work has been analyzed, and update all status. Eventually, the final forecasted outputs are given.

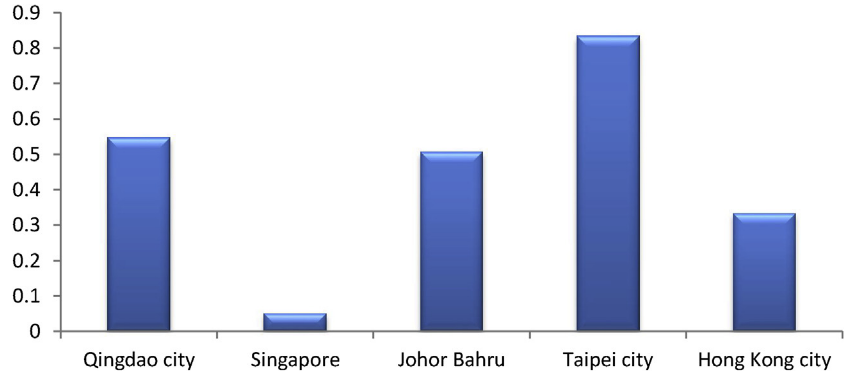

Fig. 8. Ranking the alternatives using the ANP and VIKOR methods.

Table 29
The value of T_{ij} by entropy method.

Alternatives	Sub-criteria								
	C_{11} / CP	**C_{12} / RP**	**C_{13} / CO**	**C_{21} / VS**	**C_{22} / IR**	**C_{23} / EL**	**C_{31} / TM**	**C_{32} / GM**	**C_{33} / GL**
A_1	0.22	0.17	0.17	0.16	0.18	0.16	0.17	0.22	0.18
A_2	0.16	0.19	0.22	0.22	0.16	0.20	0.19	0.24	0.23
A_3	0.18	0.21	0.14	0.24	0.23	0.19	0.19	0.18	0.15
A_4	0.25	0.24	0.25	0.13	0.26	0.26	0.27	0.10	0.19
A_5	0.20	0.19	0.22	0.25	0.17	0.19	0.18	0.26	0.25

Table 30
The value of the cost and the benefit attributes and weight obtained by entropy method.

Sub criteria and weights	**C_{11} / CP** 0.043	**C_{12}** / RP 0.052	**C_{13}** / CO 0.121	**C_{21} / VS** 0.164	**C_{22}** / IR 0.103	**C_{23}** / EL 0.078	**C_{31}** / TM 0.095	**C_{32}** / GM 0.250	**C_{33}** / GL 0.095
A_1	0.87	1.0	0.70	0.78	0.88	1.0	0.62	0.83	0.72
A_2	0.63	0.89	0.91	0.57	1.0	0.80	0.69	0.93	0.90
A_3	0.75	0.84	0.57	0.53	0.67	0.85	0.69	0.71	0.60
A_4	1.0	0.73	1.0	1.0	0.60	0.62	1.0	0.40	0.73
A_5	0.79	0.91	0.88	0.51	0.91	0.85	0.65	1.0	1.0

Table 31
The evaluation value of each alternative S, R, Q.

	A_1	A_2	A_3	A_4	A_5
S	0.436	0.405	0.747	0.547	0.381
R	0.095	0.144	0.157	0.250	0.164
Q	0.075	0.191	0.700	0.727	0.223

For the parameters, values in Fig. 9 are used as the input values, since they can be used as the starting points for forecasting. Three factors, Economic (EC), Social (S) and Environment (EV), are used by the analysis. This paper's focus is not to demonstrate neural network training with many simulations, but the use of predictive method to identify the forecasted results, and understand the rationale and explanations behind. Three scenarios will be presented as follows.

1) Scenario 1: Economic: 30%; Social: 30% and Environment: 40%

Environmental hazards can post threats to the health of the population and increase medical burden. Therefore, more governments have spent more resources and efforts on the environments. Economic development will not go ahead if they do not pass environmental checks and evaluations. Fig. 10 shows the predicted ranking of these five AAERs. Compared to Fig. 9, Qingdao City,

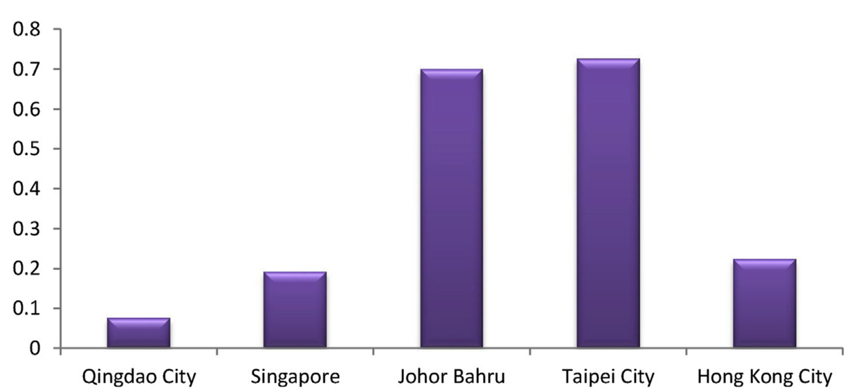

Fig. 9. Ranking the alternatives using entropy method under the neutrosophic environment.

Table 32
Ranking of alternatives by entropy method.

Alternatives	S	R	Q
A_1	A_5	A_1	A_1
A_2	A_2	A_2	A_2
A_3	A_1	A_3	A_5
A_4	A_4	A_5	A_3
A_5	A_3	A_4	A_4

Table 33
Comparison of the two methods.

Method	Ranking of Alternatives
Method 1: Using of ANP and VIKOR	$\boldsymbol{A}_2 > \boldsymbol{A}_5 > \boldsymbol{A}_3 > \boldsymbol{A}_1 > \boldsymbol{A}_4$
Method 2: Using of ANP and VIKOR with entropy	$\boldsymbol{A}_1 > \boldsymbol{A}_2 > \boldsymbol{A}_5 > \boldsymbol{A}_3 > \boldsymbol{A}_4$

Singapore and Hong Kong City can perform better. Johor Bahru and Taipei City can perform lower than values in Fig. 9. The possible reasons include the facts that in some AAECs, economic improvements are based on destructing the environments. When the environmental agenda has been the center of attention, it can affect the import and export businesses. For example, the lower scores experienced in Qingdao City can be due to the trade wars with USA, and the prohibitions from the Chinese government dealing with suppliers involved in certain sectors, such as recycling businesses. As a result, some of these businesses diverted to Taipei City.

The predicted value of Taipei City stays high while taking more recycling business suppliers. However, due to the environmental awareness and restrictions, scores are lower than in Fig. 9.

Hong Kong City stays higher than in Fig. 9 because more people from mainland China and abroad visit it and it has more demands and expectations on supplier management, particularly for recycling businesses. On the other hand, cases between Johor Bahru and Singapore are different. Johor Bahru has lower taxes, legal requirements and costs to process green wastes and recycling businesses. It is also 10 km away from Singapore. Thus, it is common for Singaporean businesses to operate in Johor Bahru.

2) Scenario 2: Economic: 40%; Social: 30% and Environment: 30%

In this scenario, the emphasis is on economic development over social and environmental criteria. This is common in Asia that many AAECs focus on economic development over all other factors. Fig. 11 shows the predicted results. Comparing with Fig. 10, the values of all AAECs go up, particularly Qingdao City, with significant values exceeding 0.35. Fig. 11 is close to the situations in the economy of East Asia and Southeast Asia, since some AAECs have better economic performance due to their government's policies and focus. Scores between Hong Kong City and Qingdao City are very close. After returning to China as the motherland, Hong Kong City has better economic performances (Fig. 12).

Singapore's focus is not on supply chain management. Some Singaporean businesses man do that in Johor Bahru due to lower tax, labor fees and more relaxed laws. Hence, Singapore has a lower score and Johor Bahru has a higher score. This observation is consistent with Fig. 10. It is common for businesses to have their offices in a more economic area and their main business operations in a developing region due to the benefits of lower taxes, lower labor and material costs and less restricted laws.

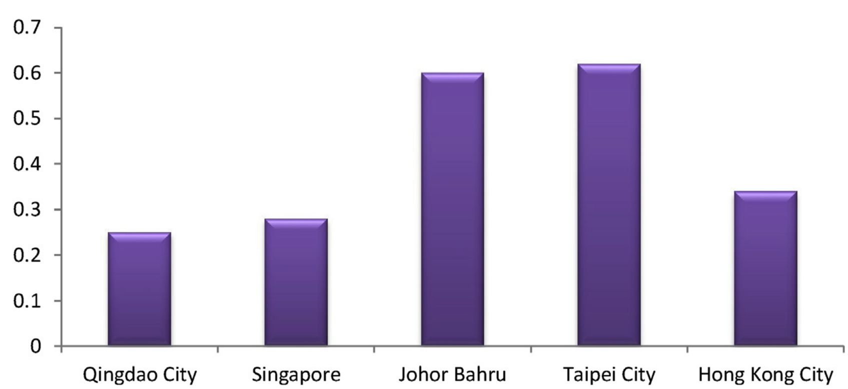

Fig. 10. The predicted ranking the alternatives using entropy method under the neutrosophic environment, with environmental emphasis.

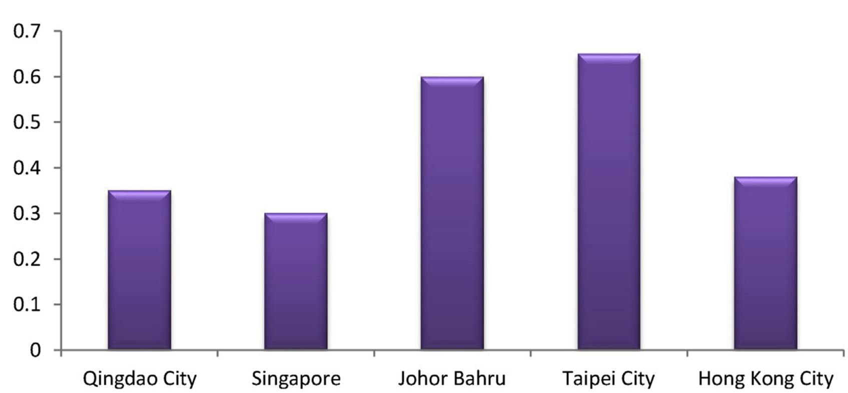

Fig. 11. The predicted ranking the alternatives using entropy method under the neutrosophic environment, with economic emphasis.

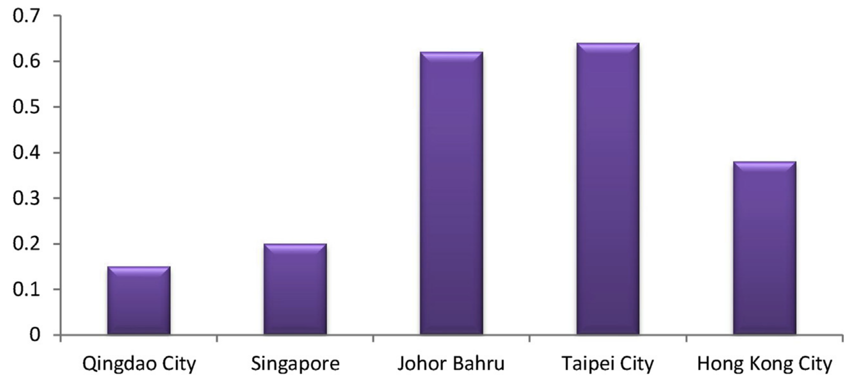

Fig. 12. The predicted ranking the alternatives using entropy method under the neutrosophic environment, with social emphasis.

3) Scenario 3: Social: 40%; Economic: 30% and Environment: 30%

The third scenario is focused on the social emphasis. It means the general public has more influences on the economic development. Fig. 11 shows Qingdao City has the lowest score, since a lot of policies are dependent on the government. Any decisions from the government can influence and even overturn the market demands and response. Singapore has the second lowest values. After the post-Lee Kuan Yew era, Singapore has become more liberal and allows free trade without government interference. However, there are still rooms for development. These may include lowering some taxes for smart manufacturing sector, since they may need green inputs and generate environmental-friendly outputs for recycling purposes.

Taipei City has the highest score due to the freedom to do free-trade with any cities. Since the decision from Qingdao City is not to take in more wastes, Taipei City has taken over recycling businesses. This is the same as Johor Bahru, the second best performer. However, despite of their higher scores, it is also partly because they have lower labor fees and transaction fees. Some international businesses seem to take more advantages of that. Additionally, Hong Kong City performs better in this aspect, as it has accelerated economic development and has strengthened its recycling businesses.

8. Discussion

8.1. Research contributions

This paper presents our neutrosophic analysis. It starts with the theory and the systematic steps to analyze. We use both the ANP-VIKOR framework and expert review, and apply social, economic and environmental factors in our analysis. We then demonstrate scores in each factor and apply it to macroeconomic cases. Furthermore, we develop a Genetic algorithm to predict the scores for five selected AAECs. By varying social, economic and environmental factors, we get different predicted outputs, which can help decision-makers to make better and more accurate decisions. We provide our rationale and explanations for scores in our predictive analysis.

8.2. Limitation of this research

While no research work can be perfect, the limitation of this research is as follows. First, our neutrosophic analysis requires the inputs from the experts before getting the required scores by hands. It is not easy to find experts meeting our requirements. Second, the forecasted results may improve its validity by having more input from the general public's polls, which tend to be harder to collect. Even if we use the web crawling method collecting and analyzing data from different sources, it may not present the best outputs.

Third, this only shows one aspects of analysis for those five AAECs. Qingdao City can perform much better in other aspects of economic development. One obvious reason for its low score is due to the trade war with USA and the prohibition of Chinese government on certain goods and regulations. If those policy-related criteria are not included, they may have different performance measurement, however, that is not the focus of this research. Similarly, even though Taipei City and Johor Bahru perform well, it is also partly because of the cheaper labor and transaction fees than their competing cities. The average salary in first-tier cities in mainland China has already surpassed the mean average salary in Taipei City. Johor Bahru also offers cheaper alternative with more options not bound by regulations than Singapore. However, the geo-economic research is not our focus. Our objective is to demonstrate that our proposed method can calculate key measurement for major import cities and provide fair and reliable forecasted outcomes.

9. Conclusion and future work

Among several problems in MCGDM, the most concerning problem is the selection process of the sustainable suppliers. As a result, we proposed a new framework involving with four phases for solving this problem. Our framework could integrate two techniques ANP and VIKOR in neutrosophic environment by using triangular neutrosophic numbers to present the linguist variables. Neutrosophic number could consider all aspects of making a decision (i.e. agree, not sure and falsity). The ANP method used to weight the elements of the problem as it considered the feedback and interdependencies. We used the VIKOR to rank alternatives to avoid comparisons in ANP. The proposed framework is suitable for implementing in real cases. respectively, we listed phases where the first phase included how to select the experts and shows that it is not an easy process, presented criteria, sub criteria and alternatives that must be identified, the inner and outer interdependencies that should be determined and the feedback. The second phase is the calculating of the weights of criteria by using of the ANP method because it considered the interdependencies and feedback between elements. The third phase, ranks the alternatives using the VIKOR method. In the last phase, comparing the result of the suggested ANP and VIKOR technique by other method, such as entropy method, to notice the difference in the results of ranking of the alternatives. Finally, the suggested framework of the ANP and VIKOR technique was used to solve a real case study about an importing corporation and select the best supplier, which depend on accurate information integrated by experts. The final ranking of alternatives showed that Taipei City has the best suppliers for imports. According to the results, Taipei City is considered the best in the manufacturing process of its products, based on the three factors: economic, environment and social. Singapore is considered the worst alternative. We also use genetic algorithm to compute predicted values for those five AAECs while varying economic, environmental and social criteria. Forecasted results show Taipei city was still considered the best option, followed by Johr Bahru. Qingdao city and Singapore are considered the worst performer. However, this research only shows one aspect of each participating city's development and supplier strategy. In summary, we successfully demonstrated our proposed work as a valid and useful method for importing cities and provide forecasted outcomes.

Future work will include the development of a more robust Genetic algorithm to predict more AAECs including Tokyo, Shanghai, Seoul and other cities specializing in imports and exports. More cases will be analyzed and discussed to gain a deeper understanding on social, economic and environmental developments in AAECs. We plan to develop our work so that it can be applied to more economically active cities and offer more accurate analysis and forecasted outputs.

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