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An Integrated Neutrosophic SWARA and VIKOR Method for Ranking Risks of Green Supply Chain

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Abstract: The green supply chain (GSC) plays a vital role for companies and organizations. Though there are several risks thread GSC Hence, these risks need to be ranked for companies. So, the goal of this study ranking these risks under a neutrosophic environment due to this problem contains uncertain information. So, this study proposed a multi-criteria decision making (MCDM) for dealing with conflicting criteria and used MCDM methods. This study introduces an integrated model with Stepwise Weight Assessment Ratio Analysis (SWARA) and visekriterijumsko kompromisno rangiranje (VIKOR). The SWARA method is used to calculate the weights of criteria and the VIKOR method is used to rank the risks of GSC based on six main criteria and twenty sub-criteria with ten risks (alternatives). Then the proposed model was evaluated by a numerical example. Finally, the sensitivity analysis is conducted.

Keywords: Green Supply Chain (GSC), Neutrosophic, SWARA, VIKOR, Risks, SVNSs

1. **Introduction**

Green Supply Chain (GSC) introduces several benefits and advantages to companies like increasing the financial power and enable companies to share their market strongly by improving the capacity of the environment and reduce the negative impact of environmental[1]. The gaining advantage competitive and keep it is a vital role for the company in performing the creativities green in GSC[2, 3]. The success of establishments in the supply chain becomes more difficult[4].

There are several risks when performing the initiatives green in GSC[5]. Reduce cost and increase customer satisfaction are the goals for improving performance in the supply chain[6]. The risks of GSC make many problems in operations and reduce GSC performance[7]. There are many problems that may result from risks of GSC like negative impact of environmental, issues of quality, failure in operations, reduce performance, and disarray of supply materials[8]. So, these risks are necessary to analysis and ranking for companies for adoption the initiatives green in GSC.

The analysis and rank risks in GSC contain vague, inconsistent, and uncertain information[7]. To overcome this uncertainty and vague information some studies proposed fuzzy sets. They used linguistic terms for their assessment. But the fuzzy set cannot deal with indeterminacy [9]. So, this study proposed the neutrosophic set to overcome this uncertainty information. The neutrosophic set is generalized to fuzzy sets. It is contained with truth, indeterminacy, and false (T.I,F). The neutrosophic sets are proposed in several fields like manufacturing, healthcare and others [10-12]. In this paper proposed he single valued neutrosophic sets (SVNSs). The SVNSs is a subset of neutrosophic sets. It work with three value (T,I,F).

The GSC contains many conflict criteria. So, use multi-criteria decision-making (MCDM) to deal with this problem. This study proposed two MCDM methods. First, the SWARA method to calculate the weights of criteria. The SWARA has two advantages first, the criteria are compensatory. Second, the criteria are independent of each other. Then the VIKOR method is applied to rank the risks of GSC [13]. The VIKOR method is used to solve problems with conflicting criteria [14]. This paper used the VIKOR method for ranking the risks of GSC.

The rest of this paper is organized as follows: the literature review is presented in section 2. Section 3 introduces the methodology of this paper. Section 4 introduces the numerical example to validate the methodology. The sensitivity analysis is presented in section 5. Finally, section 6 introduces the conclusion of this paper.

2. **Literature Review**

There are several works to evaluate and analyze the risks of GSC[15, 16]. For instance Allen H.Hu et al.[17] used the analysis of effects and failures mode to rank and analysis the risks of the green component to with the European Union in compliance. They used the fuzzy AHP to calculate the weights of four criteria. Then the risks are ranked for each green component. Zhen-kun Yang and Jian Li [18] are ranked the risks of GSC and describe the operations of GSC. They used the fuzzy AHP to calcite the weights of the criteria and then rank the risks of GSC. The aim of their study to introduce the risk control of organization and reliability for selection of supply chain.

Dan-li Du et al. [19] used the gray theory for assessing the risks manufacturing of GSC. The aim of their study that provides stability of running the GSC and evade risks appearing. Li Qianlei [20] used the systematic analysis to recognize the risks of products of agriculture GSC and introduce measures risks management for agriculture products GSC. Xiaojun Wang et al. [7] proposed two phase fuzzy AHP for evaluation risks of GSC.

This problem contains uncertain information[21]. Wei Wang et al. [22] discuss the demand uncertainty in the GSC. Kuo-Jui Wu et al. [23] discuss uncertainty for exploring decisive factors in GSC practice. They used the fuzzy DEMATEL to overcome this uncertainty. To overcome this uncertainty information proposed single-valued neutrosophic sets. M.Abdel-Baset et al. [24] proposed single-valued neutrosophic sets to assess the GSC management practices. The risks of GSC contain different conflicting criteria so, the MCDM is proposed to deal with these criteria. [25] Morteza Yazdani proposed an integrated MCDM for GSC. Hsiu Mei Wong Chen et al. [26] proposed the fuzzy MCDM methods for GS selection.

This study proposed the SWARA method for calculating the weights of criteria. Serap Akcan and Mehmet Ali Taş [27] proposed the SWARA method for green supplier assessment to decrease environmental risk factors. Selçuk Perçin [28] proposed a fuzzy SWARA method for outsourcing provider selection. After calculating the weights of criteria then needs to rank the risks of GSC. The VIKOR method is used to rank the risks of GSC. Reza Rostamzadeh et al. [29] proposed the fuzzy VIKOR method for assessment GSC management practices. Xiaolu Zhang and Xiaoming Xing [30] introduce the VIKOR method for assessing the GSC initiatives.

From the literature review, no research takes into consideration the indeterminacy value. So, in this study introduce the SVNSs to overcome this uncertain information. Then the SWARA and VIKOR methods are not used in previous research with this problem. So, the SWARA is used to calcite the weights of criteria and the VIKOR method to rank the risks of GSC.

3. Methodology

The methodology of this study is proposed for ranking the risks of GSC, which it contains from two main stages. The first stage collects criteria and risks dimension and proposed the SWARA method to calculate the weights of criteria. The second stage proposed the VIKOR method to rank the risks of GSC.

3.1. SWARA Method

This method is used to calculate the weights of criteria. It is a relatively simple use. Fig 1. Show the SWARA steps. The steps of SWARA is organized as follow [13]:

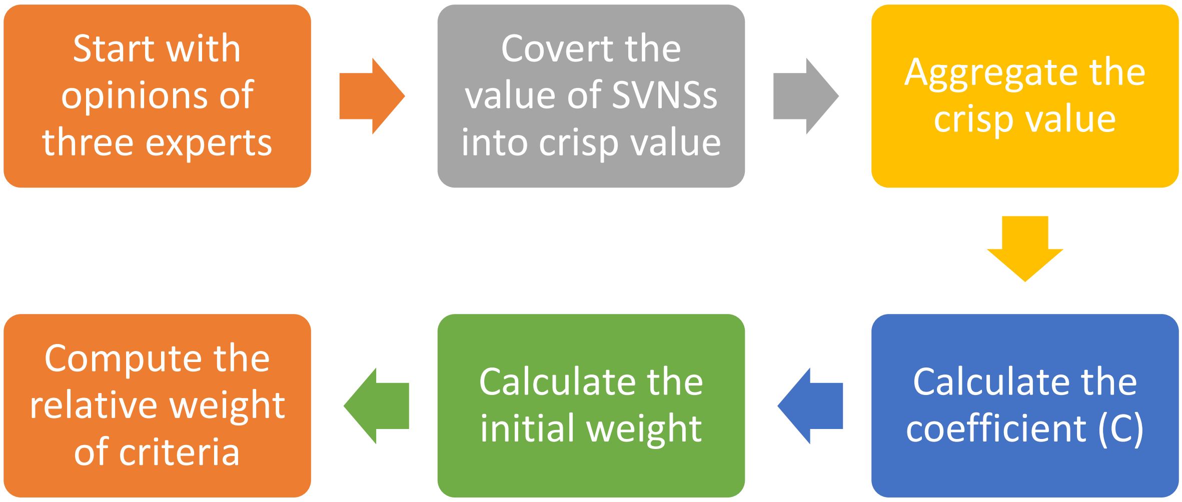

Fig 1. The steps of the SWARA method

Step 1. Start with the opinions of three experts and decision-makers with the linguistic terms in Table 1.

Step 2. Convert the value of single-valued neutrosophic numbers (SVNNs) into crisp value by using the following score function

$$s(P_m^D) = \frac{2 + T_m^D - I_m^D - F_m^D}{3} \tag{1}$$

T_m^D, I_m^D, F_m^D Presents truth, indeterminacy, and falsity of the SVNNs and D refers to decision-makers

Step 3. Aggregate the crisp value to obtain one value by using the following equation

$$P_m = \frac{\sum_{D=1}^{D} P_m}{D} \tag{2}$$

Step 4. Calculate the coefficient (C) by using the following equation

$$C_m = \begin{cases} 1, & m = 1 \\ P_{m+1}, & m > 1 \end{cases} \quad m = 1,2,3, \ldots .n \; number\ of\ criteria \tag{3}$$

Step 5. Calculate the initial weight by using the following equation

$$A_m = \begin{cases} 1, & m = 1 \\ \frac{A_{m-1}}{C_m}, & m > 1 \end{cases} \quad m = 1,2,3, \ldots .n \; number\ of\ criteria \tag{4}$$

Step 6. Compute the relative weight of criteria by using the following equation

$$W_m = \frac{A_m}{\sum_{m=1}^{n} A_m} \tag{5}$$

3.2 VIKOR Method

The VIKOR method is used to rank the risks of GSC Fig 2. Show the steps of the VIKOR method. The steps of the VIKOR method is organized as follow [31]:

Fig 2. The steps of the VIKOR method

Step 7. Start with building the decision matrix between the criteria and alternatives (risks) by opinions of experts with the linguistic term in Table 1 by using the following equation. Then convert the SVNNs to the crisp value by Eq. (1). Then combine the decision matrix into one matrix by using Eq. (2).

$$\mathrm{P^D} = \begin{bmatrix} \mathrm{P^D_{11}} & \cdots & \mathrm{P^D_{1y}} \\ \vdots & \ddots & \vdots \\ \mathrm{P^D_{m1}} & \cdots & \mathrm{P^D_{my}} \end{bmatrix} \quad m = 1,2,3,\dots n\,;\, y = 1,2,3,\dots x$$

(6)

Step 8. Calculate the best and worst solution for positive and negative criteria

Best solution $P_m{}^{+} = (P_{my})_{max}$ for positive criteria $P_m{}^{+} = (P_{my})_{min}$ for negative criteria (7)

Worst solution $P_m{}^{-} = (P_{my})_{min}$ for positive criteria $P_m{}^{-} = (P_{my})_{max}$ for negative criteria (8)

Step 9. Calculate the value of g_m , h_m by using the following equation

$$g_m = \sum_{y=1}^{x}\left(W_y * \frac{P_m^{+} - P_{my}}{P_m^{+} - P_m^{-}}\right) \tag{9}$$

$$h_m = \max_y\left(W_y * \frac{P_m^{+} - P_{my}}{P_m^{+} - P_m^{-}}\right) \tag{10}$$

Step 10. Calculate the value of Z_m by using the following equation

$$Z_m = f * \frac{g_m - g^*}{g^- - g^*} + (1 - f) * \frac{h_m - h^*}{h^- - h^*} \tag{11}$$

Where $g^* = \min g_m, g^- = \max g_m$, $h^* = \min h_m, h^- = \max h_m$ and f is recognized as a weight for the strategy of maximum group utility, whereas $(1-f)$ is the weight of the separate remorse. Usually, the value of f is set as 0.5. Though, f can set any value from 0 to 1.

Step 11. Rank the risks according to ascending value of Z_m

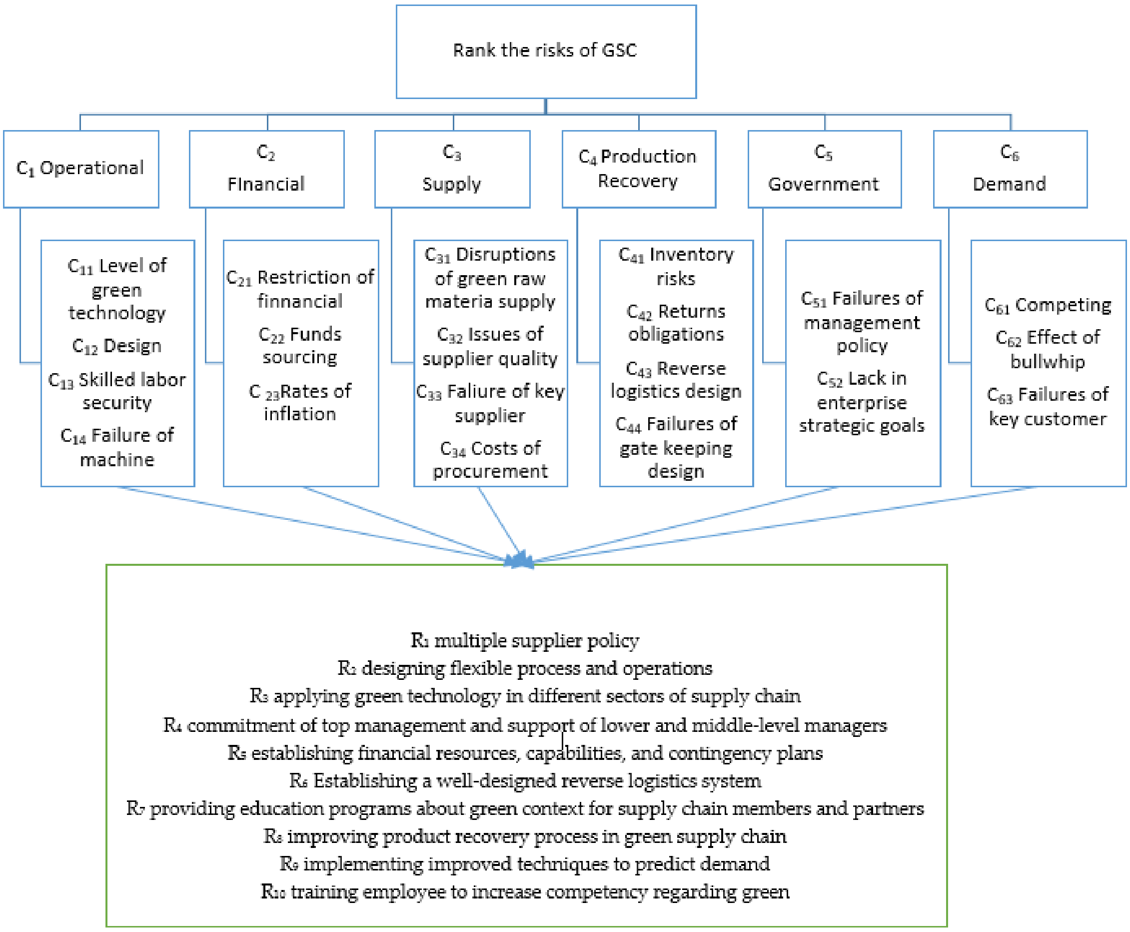

Fig 3. The criteria and risks (alternatives) of GSC

4. Numerical Example and discussion

The criteria and risks of GSC are extracted from the literature review. Fig 3. shows the criteria and alternatives of this problem. Firstly, the weights of criteria are obtained from section 3.1 by the SWARA method. This problem introduces the three decision-makers and the value of SVNNs is presented in Table 1. The SVNNs contain from (T,I,F). After taking the opinions of experts the three value (T,I,F) is converted to one value by score function by Eq. (1). Then aggregate the three values of three decision-makers into one value by using Eq. (2). Then the coefficient value is obtained by using Eq. (3). Then the initial weight is obtained by using Eq. (4). Then the weights of main and sub-criteria are obtained by using Eq. (5) in Table 2.

The weights of main criteria found that the operational risks are the highest value with 0.369 and demand risks is the lowest weight with value 0.04. The weights of sub-criteria found that the green technology level is the height weight with value 0.1617 and failures of getting keeping design risks is the lowest weight value 0.00655. Fig 4. Show the weights of the main criteria. Fig 5. Show the weights of sub-criteria.

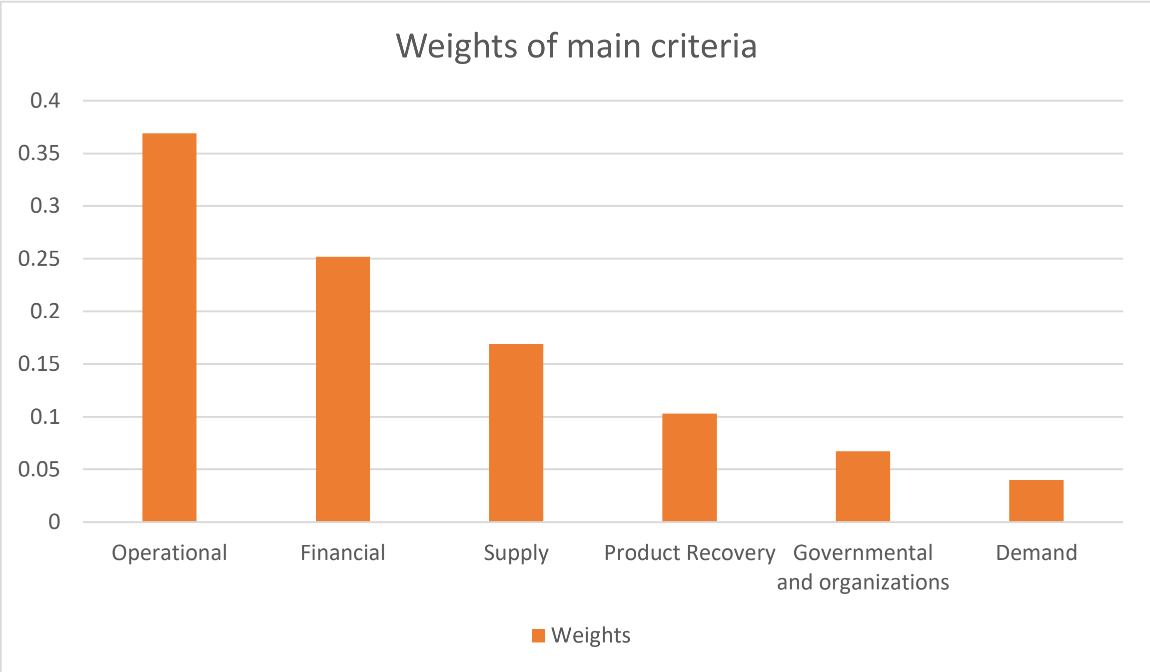

Fig 4. The weights of main criteria.

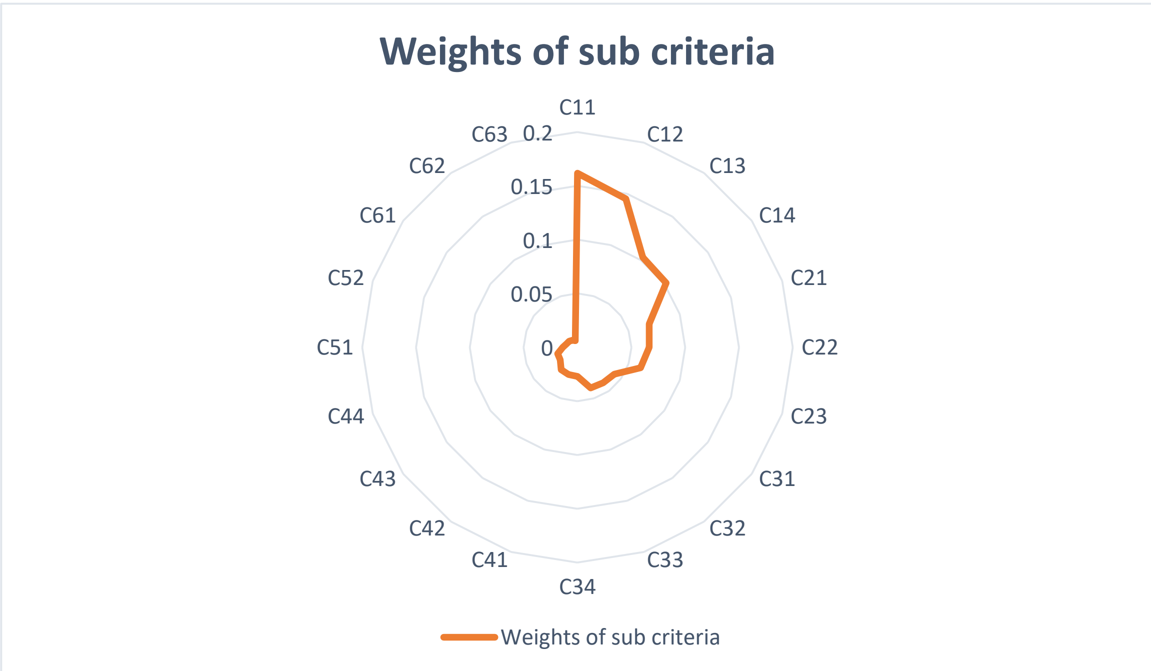

Fig 5. The weights of sub criteria.

Table 1. SVNSs scale.

Linguistic Term	Single valued neutrosophic numbers (SVNNs)

Very Wicked	<0.15,0.8,0.8>
Wicked	<0.25,0.7,0.7>
Medium Wicked	<0.35,0.6,0.6>
Medium	<0.45,0.5,0.45>
Medium Moral	<0.6,0.4,0.35>
Moral	<0.75,0.35,0.25>
Very Moral	<0.85,0.2,0.2>

Table 2. The weights of main and sub criteria.

Main Criteria	Weights	Sub Criteria	Weights
		C_{11}	0.161754
C_1	0.369	C_{12}	0.103247
		C_{13}	0.061742
		C_{14}	0.042257
		C_{21}	0.066624
C_2		C_{22}	0.025625
	0.252	C_{23}	0.010752
		C_{31}	0.145019
C_3		C_{32}	0.070173
	0.169	C_{33}	0.027164
		C_{34}	0.009644
		C_{41}	0.10184
C_4		C_{42}	0.040736
		C_{43}	0.019872
	0.103	C_{44}	0.006551
C_5		C_{51}	0.02644
	0.067	C_{52}	0.01356
		C_{61}	0.039717
C_6		C_{62}	0.019219
	0.04	C_{63}	0.008064

Applying the VIKOR method for ranking the risks of GSC. Start with building the decision matrix between criteria and risks with the SVNNs in Table 1 by opinions of three experts by Eq. (6). Then covert the SVNNs to the crisp value by using Eq. (1). Then combine the three decision matrix into one matrix by using Eq. (2) in Table 3. Then the best and worst solution is obtaining by using Eqs. (7,8) , the procurement criteria are the negative criteria and the rest of the criteria is positive criteria. The value of g_m , h_m is obtained by Eqs. (9,10) in Table 4. Then the value of Z_m is obtained by using Eq. (11) in Table 4. Finally, the risks of GSC is ranking according to ascending order of Z_m in Table 4.

As result of VIKOR, the R_7 is the highest rank and the R_3 is the lowest rank. Fig 6. Show the rank of risks by VIKOR method.

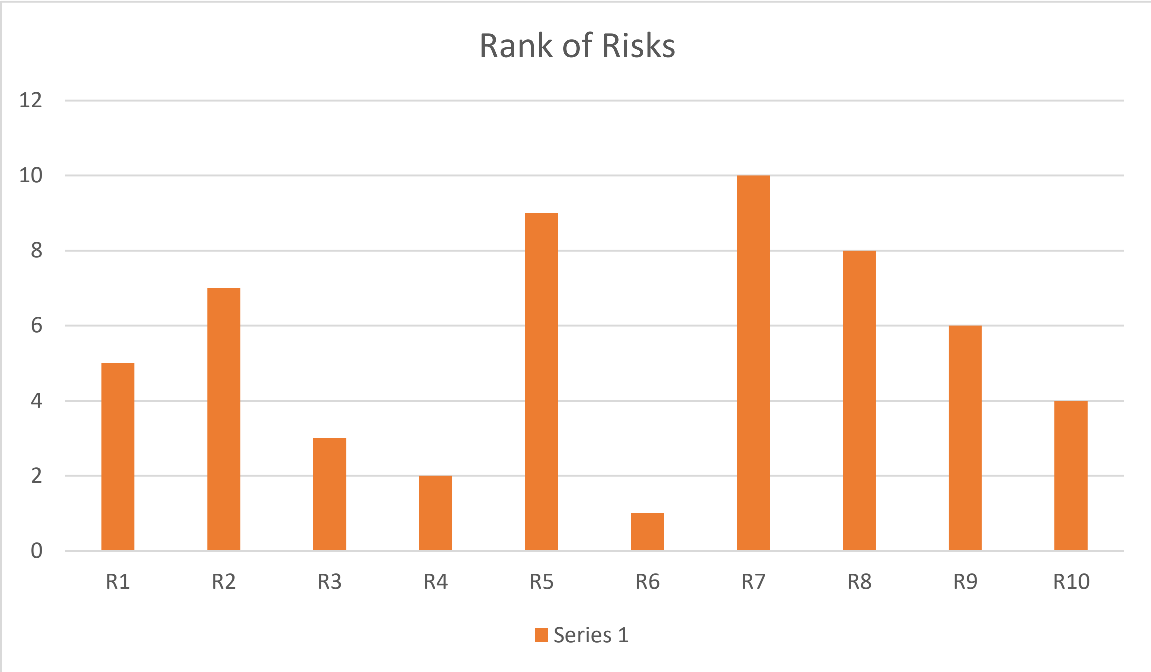

Fig 6. The rank of Risks GSC

Table 3. The decision matrix between criteria and alternatives.

Criteria/Risks	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}
R_1	0.6055	0.4277	0.2833	0.6778	0.6778	0.6055	0.6778	0.6444	0.427	0.283
R_2	0.6444	0.7833	0.5	0.6778	0.7500	0.6055	0.6055	0.7500	0.427	0.5
R_3	0.3555	0.4277	0.5333	0.5722	0.6444	0.5	0.6055	0.5333	0.427	0.783
R_4	0.2833	0.7833	0.7833	0.4277	0.7500	0.6778	0.5333	0.4611	0.677	0.783
R_5	0.7833	0.6055	0.6055	0.5	0.4277	0.4277	0.7500	0.5722	0.750	0.711
R_6	0.711	0.677	0.2833	0.283	0.5333	0.427	0.355	0.283	0.572	0.750
R_7	0.816	0.750	0.6055	0.750	0.7500	0.750	0.355	0.638	0.427	0.783
R_8	0.677	0.427	0.7833	0.2833	0.7500	0.533	0.716	0.783	0.750	0.283
R_9	0.677	0.572	0.5	0.5722	0.3555	0.750	0.711	0.572	0.5	0.355
R_{10}	0.716	0.283	0.4277	0.7830	0.7167	0.816	0.283	0.427	0.355	0.750

	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{51}	C_{52}	C_{61}	C_{62}	C_{63}
R_1	0.644	0.605	0.461	0.750	0.355	0.783	0.750	0.427	0.605	0.750
R_2	0.783	0.427	0.355	0.677	0.533	0.644	0.355	0.283	0.605	0.572
R_3	0.533	0.750	0.605	0.716	0.5	0.5	0.711	0.605	0.5	0.638
R_4	0.605	0.283	0.783	0.5	0.750	0.283	0.750	0.572	0.750	0.638
R_5	0.572	0.605	0.644	0.283	0.783	0.427	0.427	0.750	0.783	0.572
R_6	0.355	0.283	0.283	0.283	0.533	0.716	0.283	0.750	0.427	0.533
R_7	0.283	0.716	0.750	0.355	0.783	0.750	0.427	0.572	0.644	0.783

R_8	0.355	0.750	0.355	0.427	0.750	0.5	0.427	0.711	0.355	0.2833
R_9	0.750	0.716	0.572	0.750	0.750	0.605	0.716	0.605	0.605	0.2833
R_{10}	0.427	0.461	0.605	0.750	0.572	0.783	0.644	0.5	0.750	0.7167

Table 4. The value of g_m, h_m, z_m and rank of risks

Risks	g_m	h_m	z_m	Rank
R_1	0.46789	0.07342	0.400352	5
R_2	0.38739	0.070318	0.287022	7
R_3	0.50237	0.139849	0.760587	3
R_4	0.47686	0.161754	0.834264	2
R_5	0.33777	0.061229	0.182796	9
R_6	0.61233	0.145019	0.919877	1
R_7	0.20363	0.057324	0.000001	10
R_8	0.30981	0.07342	0.206966	8
R_9	0.4121	0.066624	0.299557	6
R_{10}	0.47943	0.103247	0.557282	4

5. Sensitivity Analysis

The weights of criteria affect the rank of risks. So, this paper introduces seven scenarios for changing the weights of criteria in Table 5. Then the weights of sub-criteria are changed in Table 6. Fig 7. shows the rank of risks under different scenarios.

The next step combines the rank with different scenarios into one rank. First, the highest rank takes 10 points and the next take 9 points, and so on [31]. Then calculate the total points. Table 7. Show the aggregation rank under different scenarios. Fig 8. shows the Final rank under different scenarios.

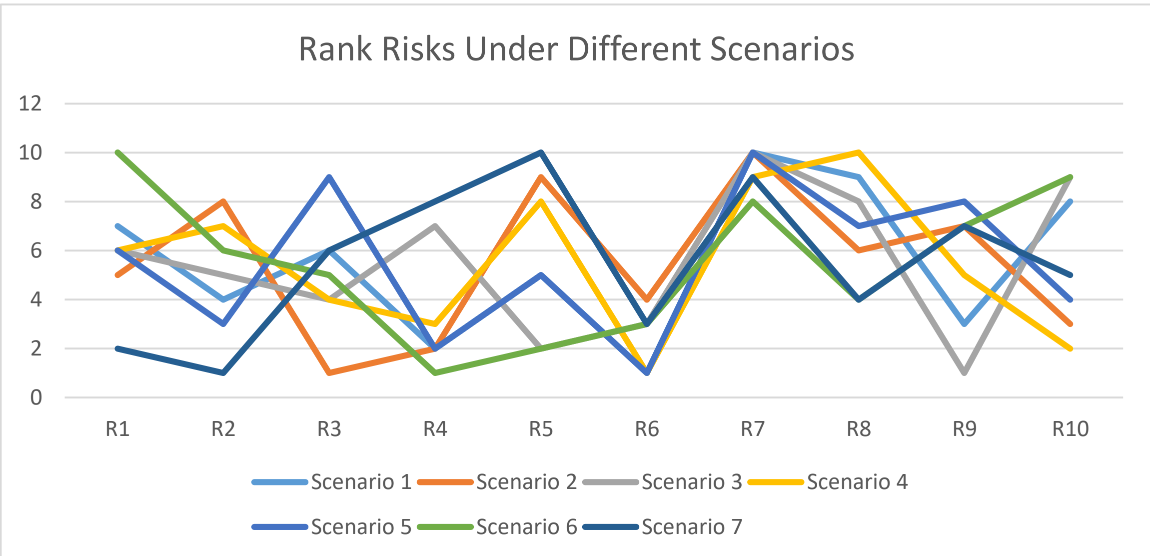

Fig 7. The rank of risks under seven scenarios

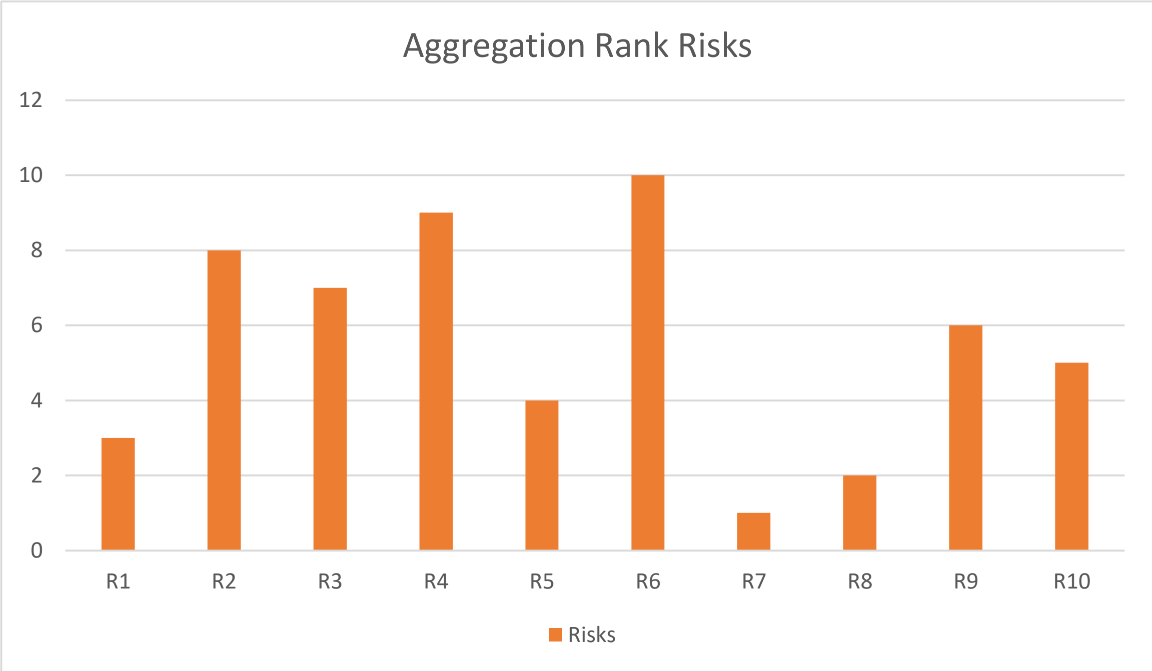

Fig 8. The Aggregation rank risks under different scenarios

Table 5. Seven scenarios of weights changes

Scenarios	Operational	Financial	Supply	Production Recovery	Government	Demand
Scenario 1	1/6	1/6	1/6	1/6	1/6	1/6
Scenario 2	0.5	0.1	0.1	0.1	0.1	0.1
Scenario 3	0.1	0.5	0.1	0.1	0.1	0.1
Scenario 4	0.1	0.1	0.5	0.1	0.1	0.1
Scenario 5	0.1	0.1	0.1	0.5	0.1	0.1
Scenario 6	0.1	0.1	0.1	0.1	0.5	0.1
Scenario 7	0.1	0.1	0.1	0.1	0.1	0.5

Table 6. Seven scenarios of sub criteria weights

Criteria	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
C_{11}	0.219178	0.043836	0.043836	0.043836	0.043836	0.043836	0.219178
C_{12}	0.139901	0.02798	0.02798	0.02798	0.02798	0.02798	0.139901
C_{13}	0.083661	0.016732	0.016732	0.016732	0.016732	0.016732	0.083661
C_{14}	0.057259	0.011452	0.011452	0.011452	0.011452	0.011452	0.057259
C_{21}	0.064683	0.323416	0.064683	0.064683	0.064683	0.064683	0.064683
C_{22}	0.024878	0.124391	0.024878	0.024878	0.024878	0.024878	0.024878
C_{23}	0.010439	0.052193	0.010439	0.010439	0.010439	0.010439	0.010439
C_{31}	0.057547	0.057547	0.287737	0.057547	0.057547	0.057547	0.057547
C_{32}	0.027846	0.027846	0.139232	0.027846	0.027846	0.027846	0.027846
C_{33}	0.010779	0.010779	0.053897	0.010779	0.010779	0.010779	0.010779

C_{34}	0.003827	0.003827	0.019135	0.003827	0.003827	0.003827	0.003827
C_{41}	0.060261	0.060261	0.060261	0.301303	0.060261	0.060261	0.060261
C_{42}	0.024104	0.024104	0.024104	0.120521	0.024104	0.024104	0.024104
C_{43}	0.011759	0.011759	0.011759	0.058794	0.011759	0.011759	0.011759
C_{44}	0.003876	0.003876	0.003876	0.019382	0.003876	0.003876	0.003876
C_{51}	0.066101	0.066101	0.066101	0.066101	0.330503	0.066101	0.066101
C_{52}	0.033899	0.033899	0.033899	0.033899	0.169497	0.033899	0.033899
C_{61}	0.05928	0.05928	0.05928	0.05928	0.05928	0.296398	0.05928
C_{62}	0.028685	0.028685	0.028685	0.028685	0.028685	0.143423	0.028685
C_{63}	0.012036	0.012036	0.012036	0.012036	0.012036	0.060178	0.012036

Table 7. The aggregation rank under different scenarios

Risks	Total Points	Rank
R_1	42	3
R_2	34	8
R_3	35	7
R_4	25	9
R_5	41	4
R_6	16	10
R_7	66	1
R_8	48	2
R_9	38	6
R_{10}	40	5

6. Conclusions

GSC plays a vital part in enhancement the ecological performance of companies. But the GSC has many risks. So, these risks need to rank for companies and organizations. This work proposed a hybrid neutrosophic MCDM for ranking the risks of GSC using SWARA and VIKOR methods under a neutrosophic environment. The SVNSs are proposed to overcome the uncertainty of information. The SWARA is used to calculate the weights of criteria and the VIKOR method is used to rank the risks of GSC. The proposed methodology is tested by a numerical example with twenty criteria and ten risks (alternatives).

The main contributions in this study proposed a neutrosophic environment to deal with indeterminacy value due to no previous study deal with the indeterminacy value. The SWARA and VIKOR method not used in previous research. In the future study, used other MCDM methods like PRPMETHEE II and ELECTRE.

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