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Sustainable performance measurement of Baijiu supply chain in China

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Abstract: Sustainable supply chain management has received great concern academics' and practitioners' interest in recent years. Baijiu industry plays an important part in Chinese economy and has a great influence on people's life. In this paper, sustainable index based on economic, environmental, and social are identified from supply chain perspective. A hybrid multi-criteria decision making framework is used to assess the index, and the method is applied to a case example at a Baijiu company in China. The case example finds that economic dimension was the most important aspect with environmental second and social third. The results also verify the effectiveness of the proposed framework. This paper develops an effective and systematic approach for decision makers to conduct evaluations and select optimal alternatives for Baijiu companies.

1. Introduction

Sustainable development is commonly defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. It has become an important task in the new era [2]. Sustainability in business is the triple bottom line (TBL) approach, which encompasses economic consideration, environmental influence and societal concerns [3]. Sustainable supply chain management has received great concern academics' and practitioners' interest in recent years [4,5].

The Baijiu (Chinese liquor) industry in China makes an important contribution to the national economy [6]. Baijiu plays an important part in Chinese culture [7]. However, Baijiu industry faces fierce competition from multiple places. The supply and demand of Baijiu industry are imbalance, and the product structures of Baijiu industry are unreasonable. In addition to pressure on economic benefits, Baijiu industry faces pressure on environmental protection and social responsibility. Therefore, Baijiu industry is seeking a sustainable supply chain performance measurement for future development.

This paper makes three contributions. First, we provide a performance assessment system towards sustainability for Baijiu supply chain. Second, we present a fuzzy hybrid method to assess the performance. Third, we apply the framework to a real case study in a Chinese Baijiu company to evaluate the effective of the method.

The remainder of the paper is organized as follows. A literature review on sustainable performance assessment in supply chain is presented in section 2. Assessment criteria of Baijiu sustainable supply chain are developed in section 3. A hybrid method is proposed in section 4. A case example is applied to section 5. And conclusions are in section 6.

2. Literature review

Baijiu (Chinese liquor) is a traditional indigenous distilled spirit prepared from grain fermentation, which is the most popular alcoholic beverage in China [8,9]. The contribution of Baijiu industry to the local economy is significant and indispensable [6]. However, there are some gaps in performance assessment. Most performance assessments of Baijiu industry pay attention to product or technology, few of them focus on supply chain [6,7]; most studies emphasis on one or two dimension of sustainable supply chain management in Baijiu industry, few integrate all of the sustainable three dimensions [10]; most researches used one single method to evaluate the performance, few of them applied hybrid method.

Guo et al. found that pollution problems in Baijiu industry cause gradual deterioration of the ambient environmental and adverse impacts on the local community. They proposed and assessed a series of cleaner production options. It provides theoretical and practical support for extensive application of cleaner production technologies and sustainable development in the alcohol industry of China [6]. Few studies researched on environmental assessment of Chinese liquor production [10]. The results confirm that the reform strategies for the Chinese liquor enterprise should be performed to decrease the water consumption, promote the utilization efficiency of water, improve recycle and reuse of by-products, reduce the pollutant discharge, and enhance waste treat efficiency [10]. Zeigler reviewed the relations between trade agreements and alcohol control policy, and examined the role of the alcohol industry in supporting and attempting to influence trade policy [11]. Therefore, there is an urgent need to develop a suitable framework to assess performance of Baijiu sustainable supply chain management.

3. Sustainable performance criteria in Baijiu supply chain

There are three dimensions in Baijiu sustainable supply chain performance assessment: economic contribution, environmental performance, and social responsibility. The proposed framework here has fifteen criteria across the three dimensions, and five for each dimension, as shown in Figure 1.

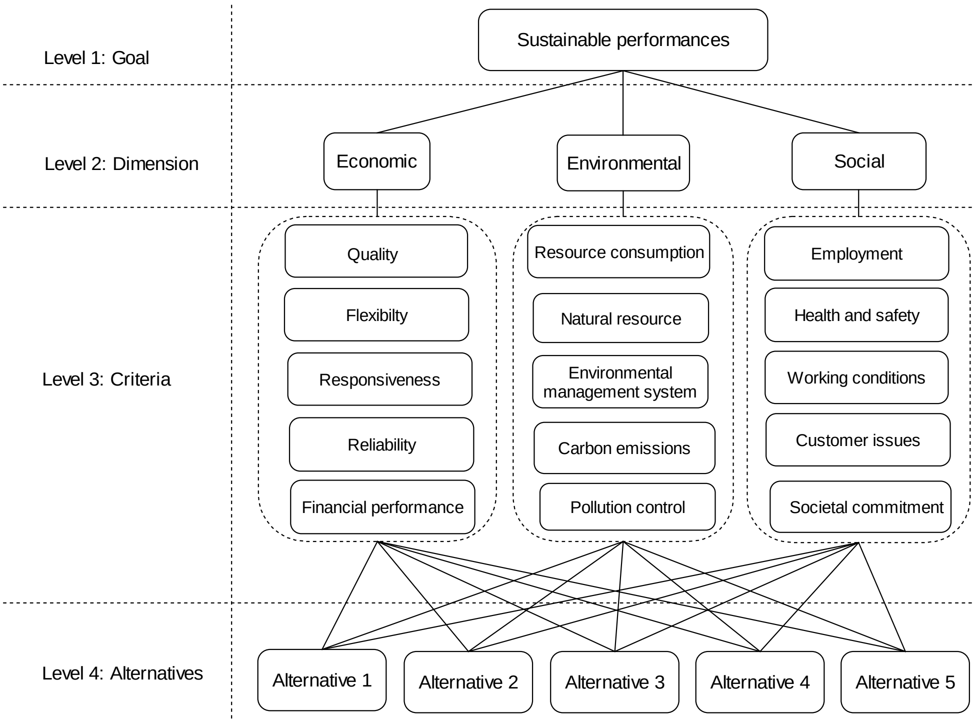

Figure 1: Hierarchical structure of Baijiu sustainable performances.

4. Hybrid Framework

In the real world there are many situations in which problems must deal with vague and imprecise information that usually involves uncertainty in their definition frameworks. It is hard to provide numerical precise information when the knowledge is vague. The use of linguistic modelling in problems dealing with non-probabilistic uncertainty seems logic and has produced successful results in different fields. This success would not have been possible without methodologies to carry out the processes of computing with words (CW) that implies the use of linguistic information.

MCDM is a powerful tool used widely for solving the problems with multiple, and usually conflicting, criteria [12]. The MCDM technique is used to structure the problem in a systematic manner, so decision makers can examine and scale the problem as per the requirements. The objective of this paper is to rank the best alternative from the group of alternatives. FAHP is used to determine the weight of different criteria, and FTOPSIS is used to select the best alternative.

5.1. Fuzzy set theory.

Decision making is very difficult for vague and uncertain environment. This vagueness and uncertainty can be handled by using fuzzy set theory, which was proposed by Zadeh [13]. A fuzzy set is defined by a membership function that maps elements to degrees of membership within a certain interval, which is usually [0, 1]. If the value assigned is 0, the element does not belong to the set. If the value assigned is 1, the element belongs completely to the set. Finally, if the value lies within the interval, the element has a certain degree of membership.

A tilde '$\sim$' is placed above a symbol if the symbol represents a fuzzy set. We consider triangular fuzzy number (TFN) to describe a fuzzy event as denoted as (l,m,u), as shown in Figure 2. The parameters l, m and u respectively denote the smallest possible value, the most promising value, and the largest possible value of a fuzzy event. Some basic definitions of the fuzzy sets and fuzzy numbers are discussed below [14,15].

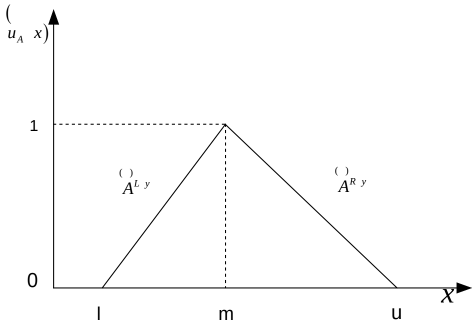

Figure 2: A triangular fuzzy number, Ã.

Definition 1. A fuzzy set $\tilde{A}$ in X is defined by:

$$\tilde{A}=\{x,u_A(x)\},\quad x\in X \quad (1)$$

In which $u_A(x):X\to[0,1]$ is the membership function of $\tilde{A}$ and $u_A(x)$ is the degree of pertinence of x in $\tilde{A}$ if $u_A(x)$ equals 0, x does not belong to the fuzzy set $\tilde{A}$. If $u_A(x)$ equals 1, x completely belongs to the fuzzy set $\tilde{A}$.

Definition 2. The membership function of a triangular fuzzy number $\tilde{A}$, denoted by triplet (l,m,u), is defined as:

$$u_A(x)=\begin{cases}0 & x<l\\ \dfrac{x-l}{m-l} & l\le x\le m\\ \dfrac{u-x}{u-m} & m\le x\le u\\ 0 & x>u\end{cases} \quad (2)$$

in which l,m and u are real numbers with $l<m<u$.

The degree of membership of a fuzzy number for left and right side representation is given by:

$$\tilde{A}=(A^{L(y)},A^{R(y)}) \quad (3)$$

$$\tilde{A}=(l+(m-l)y,u+(u-m)y),\quad y\in[0,1] \qquad (4)$$

Definition 3. If $\tilde{A}_1=(l_1,m_1,u_1)$ and $\tilde{A}_2=(l_2,m_2,u_2)$ are two triangular fuzzy numbers, as shown in Figure 3, then the operational laws of addition, multiplication, subtraction, division and reciprocal can be expressed as follows:

$$\tilde{A}_1 + \tilde{A}_2 = (l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (5)$$

$$\tilde{A}_1 \times \tilde{A}_2 = (l_1, m_1, u_1) \times (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (6)$$

$$\lambda \times \tilde{A}_1 = (\lambda, \lambda, \lambda) \times (l_1, m_1, u_1) = (\lambda l_1, \lambda m_1, \lambda u_1), \lambda > 0 \quad (7)$$

$$\tilde{A}_1 - \tilde{A}_2 = (l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \quad (8)$$

$$\tilde{A}_1 \div \tilde{A}_2 = (l_1, m_1, u_1) \div (l_2, m_2, u_2) = (l_1 \div l_2, m_1 \div m_2, u_1 \div u_2) \quad (9)$$

$$\tilde{A}_1^{-1} = (l_1, m_1, u_1)^{-1} = (\frac{1}{l_1}, \frac{1}{m_1}, \frac{1}{u_1}) \quad (10)$$

Definition 4. The distance between $\tilde{A}_1$ and $\tilde{A}_2$ given by the vertex method as in Eq.(11)

$$d(\tilde{A}_1, \tilde{A}_2) = \sqrt{\frac{1}{3}[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2]} \quad (11)$$

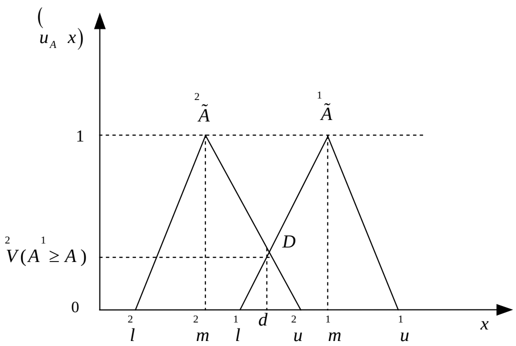

Figure 3: Intersection between $\tilde{A}_1$ and $\tilde{A}_2$

5.2. Fuzzy AHP

AHP is a quantitative technique that structures a multi-criteria decision making solution [15]. Fuzzy AHP methods combine AHP with fuzzy set theory to solve hierarchical fuzzy problems. The fuzzy AHP can capture uncertain imprecise judgement of experts by handling linguistic variables. Recently the fuzzy AHP is widely used to solve multi-criteria decision problems in few other fields.

Step1: Define scale of relative importance

Triangular fuzzy numbers $\tilde{1}$ to $\tilde{9}$ are applied to describe the scale program (Table 1).

Table 1: Scale of relative importance used in the pairwise comparison matrix.

Intensity of important	Linguistic variables	Membership function
$\tilde{1}$	Equally important/preferred	(1,1,1)
$\tilde{2}$	Between $\tilde{1}$ and $\tilde{3}$	(1,2,3)
$\tilde{3}$	Weakly important/preferred	(2,3,4)
$\tilde{4}$	Between $\tilde{3}$ and $\tilde{5}$	(3,4,5)
$\tilde{5}$	Strongly more important/preferred	(4,5,6)
$\tilde{6}$	Between $\tilde{5}$ and $\tilde{7}$	(5,6,7)
$\tilde{7}$	Very strongly important/preferred	(6,7,8)
$\tilde{8}$	Between $\tilde{7}$ and $\tilde{9}$	(7,8,9)
$\tilde{9}$	Extremely more important/preferred	(8,9,10)

Step 2: Construct fuzzy pairwise comparison matrix

Pairwise comparison matrices are established among all the criteria in the dimensions of the hierarchy system based on experts' preferences, as shown in matrix $\tilde{A}$.

$$\tilde{A} = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{nn} \end{bmatrix} \quad (12)$$

Where $\tilde{a}_{ii} = 1, \tilde{a}_{ji} = 1/\tilde{a}_{ij}, \tilde{a}_{ij} \neq 0$.

Step 3: Evaluate fuzzy weights

To use geometric mean technique to define the fuzzy geometric mean and fuzzy weights of each criterion by Eq.(13) and Eq.(14).

$$\tilde{r}_i = (\prod_{j=1}^{n} \tilde{a}_{ij})^{\frac{1}{n}} \quad (13)$$

$$\tilde{w}_i = \tilde{r}_i / \sum_{i=1}^{n} \tilde{r}_i \quad (14)$$

Where $\tilde{a}_{ij}$ is fuzzy comparison value of criterion i to criterion j, $\tilde{r}$ is the fuzzy geometric mean of the fuzzy comparison value of criterion i to each criterion and $\tilde{w}_i$ is the fuzzy weight of the i th criterion which can be indicated by a TFN, $\tilde{w}_i = (lw_i, mw_i, uw_i)$. The lw_i, mw_i and uw_i are the lower, middle and upper values of the fuzzy weight of the i th criterion.

Step 4: Check consistency

The consistency ratio (CR) for each of the matrix and overall inconsistency for the hierarchy are calculated in order to control the results of this method. When the crisp comparison matrix A is consistent, it means the fuzzy comparison matrix $\tilde{A}$ is also consistent. The consistency can be checked as follows:

(1) Calculate the largest Eigen value of the matrix by using Eq.(15)

$$Aw = \lambda_{\max} w \quad (15)$$

(2) The Consistency Ratio(CR) is used to estimate directly the consistency of pairwise comparisons. The CR is computed by using Eq.(16)

$$CR = \frac{CI}{RI} \quad (16)$$

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (17)$$

Where CI is consistency index. RI is random index, which is shown in Table 2, and n is matrix size.

Table 2: the random consistency index（RI）.

Size (n)	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

5.3. Fuzzy TOPSIS

TOPSIS (Technique for order performance by similarity to ideal solution) was first presented by Hwang and Yoon [16]. It is based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS). In the traditional process of TOPSIS, the performance ratings and the weights of the criteria are given as crisp values [17]. But in real life, crisp values are not always possible. A better approach may be to use linguistic assessments insteadx` of numerical values since human judgements are often vague and cannot estimate with exact crisp values [13]. Fuzzy set theory can be used to present linguistic value. Therefore, fuzzy TOPSIS method is very suitable for solving real life application problems under fuzzy environment [17].

Step 1: Select the alternatives and get the linguistic assessment

The importance weights of various criteria and the ratings of qualitative criteria are considered as linguistic variables. There linguistic variables can be expressed in positive triangular fuzzy numbers as Table 3.

Table3: Linguistic variables for the ratings [17].

Very poor(VP)	(0,0,1)
Poor(P)	(0,1,3)
Medium poor(MP)	(1,3,5)
Fair(F)	(3,5,7)
Medium good(MG)	(5.7.9)
Good(G)	(7.9.10)
Very good(VG)	(9,10,10)

Assume that there is a decision group has K decision makers, then the importance of the criteria and the rating of alternatives with respect to each criterion can be calculated as

$$\tilde{x}_{ij} = \frac{1}{k}[\tilde{x}_{ij}^{1}(+)\tilde{x}_{ij}^{2}(+)...(+)\tilde{x}_{ij}^{K}] \quad (18)$$

$$\tilde{w}_{j} = \frac{1}{k}[\tilde{w}_{j}^{1}(+)\tilde{w}_{j}^{2}(+)...(+)\tilde{w}_{j}^{K}] \quad (19)$$

Where $\tilde{x}_{ij}^{K}$ and $\tilde{w}_{j}^{K}$ are rating and the importance weight of the Kth decision maker.

Step 2: Choose the appropriate linguistic values and the linguistic ratings for alternatives with respect to criteria.

Step 3: Aggregate the weight of criteria to get the aggregated fuzzy weight $\tilde{w}_j$ of criteria C_j, and pool the decision makers' opinions to get the aggregated fuzzy rating $\tilde{x}_{ij}$ of alternative A_i under criterion C_j.

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}$$

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, ..., \tilde{w}_n]$$

Where $\tilde{x}_{ij}$, $\forall i, j$ and $\tilde{w}_j$, $j = 1, 2, ..., n$ are linguistic variables. These linguistic variables can be described by triangular fuzzy numbers, $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\tilde{w}_j = (\tilde{w}_{j1}, \tilde{w}_{j2}, \tilde{w}_{j3})$.

We can get the normalized fuzzy decision matrix denoted by $\tilde{R}$.

$\tilde{R} = [\tilde{r}_{ij}]_{m \times n}$ (20)

Step 4: Construct the normalized fuzzy decision matrix

Where B and C are the set of benefit criteria and cost criteria, respectively, and

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right),\ j \in B$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{a_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{b_{ij}}\right),\ j \in C$$

$$c_j^* = \max_i c_{ij} \text{ if } j \in B$$

$$a_j^- = \min_i a_{ij} \text{ if } j \in C$$

The normalization method mentioned above is to preserve the property that the ranges of normalized triangular fuzzy numbers belong to [0, 1].

Step 5: Construct the weighted normalized matrix

We can construct the weighted normalized fuzzy decision matrix as

$\tilde{V} = [\tilde{v}_{ij}]_{m \times n},\ i = 1, 2, ..., m,\ j = 1, 2, ..., n$ (21)

Where $\tilde{v}_{ij} = \tilde{r}_{ij}(\cdot)\tilde{w}_j$.

Step 6: Determine the fuzzy positive ideal solutions (FPIS) and fuzzy negative ideal solutions (FNIS)

The FPIS and FNIS are given as follows:

$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, ..., \tilde{v}_n^*)$,(22)

$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, ..., \tilde{v}_n^-)$, (23)

Where $\tilde{v}_j^* = (1,1,1)$ and $\tilde{v}_j^- = (0,0,0)$, $j = 1, 2, ..., n$.

Step 7: Calculate the distance of each alternative from FPIS and FNIS respectively.

The distance of each alternative from FPIS and FNIS are calculated as

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*),\ i = 1, 2, ..., m \quad (24)$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-),\ j = 1, 2, ..., n \quad (25)$$

Step 8: Calculate the closeness coefficient of each alternative.

The closeness coefficient of each alternative is calculated as

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \quad i = 1, 2, ..., m \quad (26)$$

Step 9: Rank the alternatives

According to the closeness coefficient, the ranking order of all alternatives can be determined in decreasing order.

6.Case example

In this study, we evaluate the sustainable supply chain performance in one of the largest and the most competitive Baijiu company in Sichuan Province, where has a significant position in Chinese Baijiu industry. The criteria were identified by a decision group of twelve experts who were highly skilled in their profession field and were proficient in decision making.

6.1. Hierarchical structure

There are fifteen criteria across three dimensions in the real case example. The hierarchical structure had four-level decision making. Sustainable performance measure was the objective level; three dimensions were the second level; fifteen criteria were the third level; and the alternatives were the fourth level, as shown in Fig. 1.

6.2. Determining weights by fuzzy AHP

In this step, experts are asked to make pairwise comparisons of fifteen criteria across three dimensions by adopted Table 1. Through calculating by fuzzy AHP method, the fuzzy pairwise comparison matrix of the dimensions was obtained in Table 4, and the fuzzy comparison matrices for the economic, environmental and social criteria were determined in Tables 5–7. The results of Table 4-7 was presented in Table 8.

Table 4: Fuzzy pairwise comparison matrix of the dimensions.

Dimension	Economic	Environmental	Social
Economic	(1,1,1)	(1.1892,1.7151,2.2134)	(1.0000,1.6420,2.2572)
Environmental	(0.4518,0.5830,0.8409)	(1,1,1)	(1.0054,1.4422,1.9064)
Social	(0.4430,0.6090,1.0000)	(0.5246,0.6934,0.9946)	(1,1,1)
Weight	(0.4337,0.4546,0.4408)	(0.3147,0.3039,0.3018)	(0.2517,0.2415,0.2574)
MSw	0.4430	0.3068	0.2502

Table 5: Fuzzy pairwise comparison matrix for the economic criteria.

	Eco1	Eco2	Eco3	Eco4	Eco5
Eco	(1,1,1)	(2.2134,2.9658,	(1.8942,2.4521,	(0.9902,1.2165,	(0.9763,1.1126,

1		3.7224)	3.1665)	1.5131)	1.2409)
Eco 2	(0.2686,0.3372, 0.4518)	(1,1,1)	(0.6389,0.8454, 1.1210)	(0.6551,0.7923, 0.9701)	(0.5571,0.6710, 0.8529)
Eco 3	(0.3158,0.4078, 0.5279)	(0.8921,1.1828 , 1.5651)	(1,1,1)	(0.5706,0.7311, 0.9265)	(0.5756,0.7208, 0.9125)
Eco 4	(0.6609,0.8221, 1.0099)	(1.0309,1.2621, 1.5264)	(1.0793,1.3677, 1.7526)	(1,1,1)	(0.8130,0.9583, 1.1713)
Eco 5	(0.8059,0.8988, 1.024)	(1.1725,1.4903, 1.7952)	(1.0959,1.3873, 1.7373)	(0.8538,1.0435, 1.2301)	(1,1,1)
Weight	(0.3009,0.3020, 0.2995)	(0.1307,0.1311, 0.1355)	(0.1413,0.1454, 0.1501)	(0.2052,0.2033, 0.2030)	(0.2219,0.2182, 0.2120)
MSw	0.3008	0.1324	0.1456	0.2038	0.2174

Table 6: Fuzzy pairwise comparison matrix for the environmental criteria.

	Env1	Env2	Env3	Env4	Env5
1	(1,1,1)	(2.1211,2.7525,3.4792)	(1.2599,1.6581,2.0089)	(1.2181,1.7741,2.5534)	(0.8879,1.1697,1.5
2	(0.2874,0.3633,0.4714)	(1,1,1)	(0.8409,1.2438,1.6893)	(0.7791,1.1081,1.4282)	(0.4903,0.7418,1.1
3	(0.4978,0.6031,0.7937)	(0.5920,0.8040,1.1892)	(1,1,1)	(0.9583,1.5874,2.2232)	(0.5587,0.7937,1.1
4	(0.3916,0.5637,0.8210)	(0.7002,0.9024,1.2836)	(0.5637,0.7749,1.2272)	(1,1,1)	(0.5022,0.7002,1.0
5	(0.6516,0.8549,1.1263)	(0.8936,1.3480,2.0396)	(0.8503,1.2599,1.7897)	(0.9347,1.4282,1.9913)	(1,1,1)
nt	(0.2546,0.2615,0.2585)	(0.1773,0.1750,0.1681)	(0.1851,0.1832,0.1811)	(0.1762,0.1706,0.1697)	(0.2068,0.2097,0.2
v	0.2582	0.1735	0.1831	0.1721	0.2130

Table 7: Fuzzy pairwise comparison matrix for the social criteria.

	Soc1	Soc2	Soc3	Soc4	Soc5
	(1,1,1)	(1.3466,1.7473,2.2300)	(2.3190,2.9368,3.6147)	(1.2272,1.6085,2.1646)	(2.6925,3.4040,4.0
	(0.4914,0.6424,0.8138)	(1,1,1)	(2.2671,3.1806,4.0395)	(1.2025,1.7526,2.3681)	(1.4983,2.0584,2.5
	(0.2766,0.3405,0.4312)	(0.2476,0.3144,0.4411)	(1,1,1)	(1.1956,1.6244,2.1800)	(1.8877,2.3940,3.2
	(0.4620,0.6217,0.7691)	(0.4223,0.5706,0.8316)	(0.4587,0.6156,0.8364)	(1,1,1)	(0.9668,1.3765,1.8
	(0.2451,0.2938,0.3714)	(0.3862,0.4858,0.6674)	(0.3089,0.4177,0.5297)	(0.5455,0.7265,1.0344)	(1,1,1)

nt	(0.3558,0.3480,0.3402)	(0.2564,0.2663,0.2643)	(0.1536,0.1499,0.1538)	(0.1367,0.1404,0.1444)	(0.0975,0.0953,0.0
y	0.3480	0.2624	0.1524	0.1405	0.0967

Table 8: Final priority for the sustainable performances.

Dimension	Dimension weight	*CR*	Criteria	Relative weight	Relative rank	Global weight	Global weight
Economic	0.4430	0.0267	Eco1	0.3008	1	0.1333	1
			Eco2	0.1324	5	0.0587	9
			Eco3	0.1456	4	0.0645	8
			Eco4	0.2038	3	0.0903	3
			Eco5	0.2174	2	0.0963	2
Environmental	0.3068	0.0908	Env1	0.2582	1	0.0792	5
			Env2	0.1735	4	0.0532	11
			Env3	0.1831	3	0.0562	10
			Env4	0.1721	5	0.0528	12
			Env5	0.2130	2	0.0654	7
Social	0.2502	0.0754	Soc1	0.3480	1	0.0871	4
			Soc2	0.2624	2	0.0656	6
			Soc3	0.1524	3	0.0381	13
			Soc4	0.1405	4	0.0352	14
			Soc5	0.0967	5	0.0242	15

6.3. Selecting alternatives by fuzzy TOPSIS

The weights of all the experts were of the same importance in this study. The experts were asked to develop a fuzzy assessment matrix by method shown in Table 3. Alternatives A1-A5 are solutions given by Baijiu company. The fuzzy decision matrix for the alternatives was determined by fuzzy TOPSIS method in Table 9, the fuzzy normalized decision matrix was obtained in Table 10, and the fuzzy weighted normalized decision matrix was given in Table 11. The final assessment and ranking of solutions were obtained in Table 12.

Table 9: Fuzzy decision matrix for the alternatives.

	Eco1	Eco2	Eco3	Eco4	Eco5
A1	(6.5833,7.8333,8.5000)	(5.3333,7.0000,8.3333)	(5.9167,7.6667,8.8333)	(6.5000,8.0000,8.9167)	(6.7500,8.2500,9.0000)
A2	(6.5000,8.3333,9.4167)	(5.2500,6.9167,8.2500)	(5.0833,6.8333,8.2500)	(5.4167,7.1667,8.5000)	(6.3333,8.1667,9.3333)
A3	(4.8333,6.5833,8.0833)	(5.5000,7.5000,8.8333)	(4.0000,5.6667,7.2500)	(5.6667,7.5000,8.8333)	(4.3333,6.3333,8.0833)
A4	(5.0833,6.5833,7.7500)	(4.2500,6.0833,7.7500)	(4.3333,5.8333,7.0833)	(5.1667,6.7500,8.0000)	(4.1667,5.8333,7.2500)
A5	(4.0833,6.0000,7.8333)	(5.2500,6.5833,7.5833)	(4.6667,5.8333,6.9167)	(6.8333,8.5000,9.5000)	(5.8333,7.7500,9.0000)

	Env1	Env2	Env3	Env4	Env5
A1	(7.1667,8.7500,9.5833)	(4.1667,5.8333,7.3333)	(4.6667,6.1667,7.4167)	(4.7500,6.0000,7.0833)	(3.8333,5.6667,7.4167)
A2	(5.6667,7.1667,8.0833)	(4.0000,5.8333,7.5833)	(4.8333,6.5000,7.8333)	(4.6667,6.5833,8.0833)	(3.5000,5.0833,6.5833)
A3	(4.9167,6.7500,8.2500)	(2.9167,4.5000,6.2500)	(3.5000,5.3333,7.2500)	(4.0000,5.7500,7.4167)	(3.0833,4.8333,6.5833)
A4	(5.2500,7.0000,8.2500)	(4.2500,6.1667,7.9167)	(5.0000,6.9167,8.5000)	(5.5000,7.3333,8.7500)	(2.7500,4.6667,6.5833)
A5	(4.6667,6.1667,7.4167)	(2.9167,4.4167,6.0833)	(4.9167,6.5000,8.000)	(4.0000,6.0000,7.8333)	(4.0000,6.0000,7.8333)
	Soc1	Soc2	Soc3	Soc4	Soc5
A1	(5.2500,7.1667,8.5833)	(5.8333,7.6667,8.9167)	(6.5833,8.0000,8.8333)	(7.5000,8.9167,9.5000)	(5.2500,6.8333,8.0000)
A2	(5.5833,7.0833,8.1667)	(5.6667,7.2500,8.3333)	(4.7500,6.3333,7.6667)	(5.5833,7.2500,8.4167)	(4.6667,6.2500,7.6667)
A3	(5.0000,6.7500,8.1667)	(5.6667,7.5833,9.0833)	(5.2500,7.0833,8.4167)	(5.1667,6.9167,8.2500)	(4.6667,6.5000,8.0833)
A4	(3.9167,5.7500,7.4167)	(3.7500,5.6667,7.5000)	(3.9167,5.7500,7.4167)	(5.3333,7.2500,8.7500)	(4.7500,6.5000,8.0000)
A5	(4.1667,5.5833,7.0000)	(4.6667,6.3333,7.5833)	(6.3333,8.0000,9.2500)	(6.5000,8.2500,9.3333)	(4.8333,6.4167,7.7500)

Table 10: Fuzzy normalized decision matrix.

	Eco1	Eco2	Eco3	Eco4	Eco5
A1	(0.6991,0.8319,0.9027)	(0.6038,0.7925,0.9434)	(0.6698,0.8679,1.0000)	(0.6842,0.8421,0.9386)	(0.7232,0.8839,0.9643)
A2	(0.6903,0.8850,1.0000)	(0.5943,0.7830,0.9340)	(0.5755,0.7736,0.9340)	(0.5702,0.7544,0.8947)	(0.6786,0.8750,1.0000)
A3	(0.5133,0.6991,0.8584)	(0.6226,0.8491,1.0000)	(0.4528,0.6415,0.8208)	(0.5965,0.7895,0.9298)	(0.4643,0.6786,0.8661)
A4	(0.5398,0.6991,0.8230)	(0.4811,0.6887,0.8774)	(0.4906,0.6604,0.8019)	(0.5439,0.7105,0.8421)	(0.4464,0.6250,0.7768)
A5	(0.4336,0.6372,0.8319)	(0.5943,0.7453,0.8585)	(0.5283,0.6604,0.7830)	(0.7193,0.8947,1.0000)	(0.6250,0.8304,0.9643)
	Env1	Env2	Env3	Env4	Env5
A1	(0.7478,0.9130,1.0000)	(0.5263,0.7368,0.9263)	(0.5490,0.7255,0.8725)	(0.5429,0.6857,0.8095)	(0.4894,0.7234,0.9468)
A2	(0.5913,0.7478,0.8435)	(0.5053,0.7368,0.9579)	(0.5686,0.7647,0.9216)	(0.5333,0.7524,0.9238)	(0.4468,0.6489,0.8404)
A3	(0.5130,0.7043,0.8609)	(0.3684,0.5684,0.7895)	(0.4118,0.6275,0.8529)	(0.4571,0.6571,0.8476)	(0.3936,0.6170,0.8404)
A4	(0.5478,0.7304,0.8609)	(0.5368,0.7789,1.0000)	(0.5882,0.8137,1.0000)	(0.6286,0.8381,1.0000)	(0.3511,0.5957,0.8404)
A5	(0.4870,0.6435,0.7739)	(0.3684,0.5579,0.7684)	(0.5784,0.7353,0.8627)	(0.5238,0.7429,0.9143)	(0.5106,0.7660,1.000)

	Soc1	Soc2	Soc3	Soc4	Soc5
A1	(0.6117,0.8350,1.0000)	(0.6422,0.8440,0.9817)	(0.7117,0.8649,0.9550)	(0.7895,0.9386,1.0000)	(0.6495 ,0.8454,0.9897)
A2	(0.6505,0.8252,0.9515)	(0.6239,0.7982,0.9174)	(0.5135,0.6847,0.8288)	(0.5877,0.7632,0.8860)	(0.5773,0.7732,0.9485)
A3	(0.5825,0.7864,0.9515)	(0.6239,0.8349,1.0000)	(0.5676,0.7658,0.9099)	(0.5439,0.7281,0.8684)	(0.5773,0.8041,1.0000)
A4	(0.4563,0.6699,0.8641)	(0.4128,0.6239,0.8257)	(0.4234,0.6216,0.8018)	(0.5614,0.7632,0.9211)	(0.5876,0.8041,0.9897)
A5	(0.4854,0.6505,0.8155)	(0.5138,0.6972,0.8349)	(0.6847,0.8649,1.0000)	(0.6842,0.8684,0.9825)	(0.5979,0.7938,0.9588)

Table 11: Fuzzy weighted normalized decision matrix.

	Eco1	Eco2	Eco3	Eco4	Eco5
A1	(0.0932,0.1109,0.1203)	(0.0354,0.0465,0.0553)	(0.0432,0.0560,0.0645)	(0.0618,0.0760,0.0848)	(0.0696,0.0851,0.0929)
A2	(0.0920,0.1179,0.1333)	(0.0349,0.0459,0.0548)	(0.0371,0.0499,0.0602)	(0.0515,0.0681,0.0808)	(0.0653,0.0843,0.0963)
A3	(0.0684,0.0932,0.1144)	(0.0365,0.0498,0.0587)	(0.0292,0.0414,0.0529)	(0.0539,0.0713,0.0840)	(0.0447,0.0653,0.0834)
A4	(0.0719,0.0932,0.1097)	(0.0282,0.0404,0.0515)	(0.0316,0.0426,0.0517)	(0.0491,0.0642,0.0760)	(0.0430,0.0602,0.0748)
A5	(0.0578,0.0849,0.1109)	(0.0349,0.0437,0.0504)	(0.0341,0.0426,0.0505)	(0.0650,0.0808,0.0903)	(0.0602,0.0800,0.0929)
	Env1	Env2	Env3	Env4	Env5
A1	(0.0592,0.0723,0.0792)	(0.0280,0.0392,0.0493)	(0.0308,0.0408,0.0490)	(0.0287,0.0362,0.0427)	(0.0320,0.0473,0.0619)
A2	(0.0468,0.0592,0.0668)	(0.0269,0.0392,0.0510)	(0.0319,0.0430,0.0518)	(0.0282,0.0397,0.0488)	(0.0292,0.0424,0.0549)
A3	(0.0406,0.0558,0.0682)	(0.0196,0.0302,0.0420)	(0.0231,0.0353,0.0479)	(0.0241,0.0347,0.0448)	(0.0257,0.0403,0.0549)
A4	(0.0434,0.0579,0.0682)	(0.0286,0.0415,0.0532)	(0.0330,0.0457,0.0562)	(0.0332,0.0443,0.0528)	(0.0229,0.0389,0.0549)
A5	(0.0386,0.0510,0.0613)	(0.0196,0.0297,0.0409)	(0.0325,0.0413,0.0485)	(0.0277,0.0392,0.0483)	(0.0334,0.0501,0.0654)
	Soc1	Soc2	Soc3	Soc4	Soc5
A1	(0.0533,0.0727,0.0871)	(0.0422,0.0554,0.0644)	(0.0271,0.0330,0.0364)	(0.0278,0.0330,0.0352)	(0.0157,0.0205,0.0239)
A2	(0.0566,0.0719,0.0828)	(0.0410,0.0524,0.0602)	(0.0196,0.0261,0.0316)	(0.0207,0.0268,0.0311)	(0.0140,0.0187,0.0229)
A3	(0.0507,0.0685,0.0828)	(0.0410,0.0548,0.0656)	(0.0216,0.0292,0.0347)	(0.0191,0.0256,0.0305)	(0.0140,0.0195,0.0242)
A4	(0.0397,0.0583,0.0752)	(0.0271,0.0410,0.0542)	(0.0161,0.0237,0.0306)	(0.0197,0.0268,0.0324)	(0.0142,0.0195,0.0239)
A5	(0.0423,0.0566,0.0710)	(0.0337,0.0458,0.0548)	(0.0261,0.0330,0.0381)	(0.0241,0.0305,0.0345)	(0.0145,0.0192,0.0232)

Table 12: Final evaluation and ranking of alternatives.

Alternatives	d_i^*	d_i^-	CC_i	Rank
A1	14.1940	0.8167	0.0544	1
A2	14.2312	0.7819	0.0521	2
A3	14.2955	0.7225	0.0481	4
A4	14.3124	0.7049	0.0469	5
A5	14.2830	0.7316	0.0487	3

6.4. Results and discussions

The priority of ranking for the sustainable measurement criteria dimensions for Baijiu supply chain was economic-environmental-social, as depicted in Table 4. Previous studies believed that environmental dimension should be given the first priority, however, the conclusion here differs from these studies. Baijiu industry improves the green production environmental settings in recent years.

The order of the economic criteria was Eco1>Eco5>Eco4>Eco3>Eco1, as shown in Table 5. “Quality (Eco1)” had the highest priority. “Financial performance (Eco5) ranked the second priority after “Quality (Eco1)”, “Reliability (Eco4)” ranked the third place, “Responsiveness (Eco 3)” was the fourth criteria, and “Flexibility (Eco1)” was the last in the list.

The associated environmental criteria were ranked Env1> Env5> Env3> Env2> Env4, as shown in Table 6. It indicates that Resource consumption(0.2582)>Pollution control (0.2130)>Environmental management system(0.1831)>Natural environment (0.1735)>Carbon emissions (0.1721). Resource consumption is the most important criteria, and Pollution control ranked after it. Baijiu industry pays attention to resource conservation and pollution control in the environmental dimension of supply chain operations. The third ranked index is Environmental management system. Natural environment ranked in the fourth place, and Carbon emissions was the last ranked in the environmental dimension.

The order of the social criteria was Soc1 > Soc2 > Soc3 > Soc4 > Soc5, as shown in Table 7. Employment (0.3480)>Health and safety (0.2624)>Working conditions (0.1524)>customer issues (0.1405)>Social commitment (0.0967). Companies in China believe that job creation is the most important corporate social responsibility. Baijiu industry belongs to food field, therefore, health and safety is very important for the whole supply chain. Working conditions was ranked the third place, Customer issues ranked the fourth, and the societal commitment was the last important index.

The overall ranking of all criteria was obtained as Eco1> Eco5>Eco4>Soc1>Env1>Soc2>Env5>Eco3>Eco2>Env3>Env2>Env4>Soc3>Soc4>Soc5, as described in Table 8. Based on fuzzy AHP, Quality(Eco1), Financial performance (Eco2), Reliability (Eco3), Employment (Soc1) and Resource consumption (Env1) were the top five most important performance criteria in Baijiu supply chain with respective values of 0.1333，0.0963，0.0903，0.0871, and 0.0792. Social commitment (Soc5), Customer issues (Soc4), and Working conditions (Soc3) were the least important criteria with respective values of 0.0242，0.0352, and 0.0381.

The solutions from most important to least were A1 > A2 > A5 > A3 > A4 as shown in Table 12, A1 with the value of 0.0544 was the best solution for Baijiu company, and A4 with a value 0.0469 was the least important solution for the company.

7. Conclusions

In this paper, we researched the performance measurement of Baijiu sustainable supply chain. Through literature review and expert opinion, fifteen criteria across three dimensions are identified. A hybrid fuzzy multi-criteria decision making method was developed in Baijiu sustainable supply chain management. And the case example is provided to test the effective of the proposed method. The results from the study indicate that economic is the most important dimension, and environmental is the least important dimension. The results from the study provide a new insight for Baijiu sustainable supply chain management.

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