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Supplier Selection towards Baijiu Supply Chain Sustainability from a Chinese Perspective

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Abstract: Because of the global concern with environmental protection and social responsibility, there has been an increased research focus on sustainable supplier selection. Baijiu is the most popular Chinese alcoholic beverage, the production and consumption of which has a significant impact on the economy, the environment, and the society. Due to increased Chinese economic growth, there has been significant pressure to ensure supplier selection sustainability across the Baijiu supply chain. However, to date, there has little research on the integration of the economic, environmental, and social dimensions in supplier selection research. To go some way to filling this gap, this paper evaluates Baijiu supply chain supplier sustainability by first developing a sustainable supplier criteria system that integrates the economic, environmental, and social dimensions after which an improved fuzzy DEMATEL (Decision Making Trial and Evaluation Laboratory) method is proposed to analyse the criteria relationships. Finally, the framework is applied to a case study at a large Baijiu enterprise in China, from which it was found that the method was feasible and effective. This paper develops an effective systematic approach that decision-makers can use to select sustainable suppliers for Baijiu enterprises.

1. Introduction

Baijiu (Chinese liquor) is an important part of Chinese culture and Chinese daily life and makes a significant contribution to China's economy [1-3]. Liquor culture has a long history in China and currently China is the largest global producer and consumer of distilled spirits, with consumption accounting for one-third of total global consumption [4,5]. Baijiu supply chain has a significant importance in the global market place and it creates growth opportunities for society and the economy in China [6]. As the most popular Chinese alcoholic beverage, the Baijiu production and consumption supply chain has significant economic, environmental and social influences [5,7].

As there are many global liquor supply chain growth opportunities, sustainability has become an important prerequisite when sourcing sustainable agricultural raw materials [6,8]. In recent years, the Baijiu industry has experienced significant changes in China [9]. In 2016, total production was approx-imately 13.58 billion litres, an increase of 3.23% from 2015, total sales revenue was 612,57 billion CNY, an increase of 10.07%, and total industry pro t was 79.72 billion CNY, an increase of 9.24%. Over the previous decade, Baijiu production experienced a 340% increase from 3.97 billion litres in 2006 to 13.58 billion litres in 2016, an average annual growth rate of 22.00%, with a commensurate increase in consumption. However, due to industrial structural adjustments, the demand imbalance in the supply chain has worsened, and the corporate Baijiu industry structure remains poor with small enterprises accounting for about six sevenths of the industry structure and medium and large enterprises accounting for only one-seventh. Because of the changing economic environment, the Baijiu supply chain is facing erce domestic and international competition. The Chinese liquor plasticizer scandal in 2012 resulted in industry sector stock market losses of 32.7 billion CNY, with investigations revealing that the plasticizer was released into the liquor through contact with production equipment such as latex tubing, which served to highlight the importance of supplier selection across the supply chain.

Industrial production can have a signi cant in uence on the sustainability of the natural environment and citizen health [10]. As customers and stakeholders have begun to attach importance to sustainable products, many countries have employed policies and strategies to achieve sustainable manufacturing. Elkington believed that the sustainability in business eld includes economic performance, environmental protection and social responsibility [11]. The science of sustainability assessment has progressed e orts to advance supplier selection [12]. Because of the increased focus on environmental issues and need to demonstrate corporate social responsibility, many rms have been attempting to ensure that their activities are more sustainable, which can have signi cant implications on supplier selection in such areas as purchasing [13,14]. Past supplier selection and evaluation processes tended to be dominated by concerns related to price, quality and delivery [15]. Green purchasing, however, requires the inclusion of supplier selection environmental criteria, which in turn has developed into green supplier selection processes [16]. With the development of network technology and economic globalization, sustainable supply chain management (SSCM) includes sustainable economic, environmental and social customer and stakeholer development concerns [17-19]. The sustainable criteria for supplier measurement ensure that the supplier acts in accordance with established criteria [20]. Partnerships with suppliers are seen as fundamental to business and environmental success [11]. Therefore, sustainable supplier evaluation and selection is vital to e ective SSCM, as all members of the SCM must have sustainable development strategies [17,21].

Supplier selection, however, is a complex multi-criteria decision making (MCDM) problem. Multi-criteria decision analysis is able to handle a larger number of environmental and social criteria [22]. Over the last few decades, several MCDM methods such as AHP, DEA, TOPSIS and RankNet have proven e ective in managing supplier selection problems [6, 12, 23-27]. However, few approaches have fully expressed the relationships between the factors in uencing supply chain performances. Therefore, this study is one of the rst to use the fuzzy decision making trial and evaluation laboratory (DEMATEL) approach for sustainable supplier evaluation and selection. The fuzzy DEMATEL method has been used to solve complex problems [28], such as solar power [24], SSCM [28], supplier selection [29,30], and truck selection [31], as it can easily identify the direct and indirect relationships between the di erent indicators. Therefore, it is very suitable for the evaluation of sustainable supplier selection in the Baijiu supply chain.

Unfortunately, to date, there have been few studies focused on Baijiu supplier selection from a supply chain perspective , as most previous work has been on product or technical developments [1-3,32]. Further, previous assessments have tended to only focus on one or two sustainability dimensions and therefore there have been no practical or all-encompassing supplier selection assessment studies, which also means that no integrated sustainable dimension assessment systems have been established [20,33]. Therefore, the major contributions of this study are as follows.

For the rst time, a sustainable criteria system focused on Baijiu supplier selection is developed that considers sustainability (economic performance, environmental protection, and social responsibility) from an SCM perspective.

An improved fuzzy method is proposed to evaluate sustainable Baijiu supply chain supplier selection in China, which is the rst model to include economic criteria, an environmental index, and a social dimension for the Baijiu industry.

The proposed approach is applied to a large Baijiu enterprise in Sichuan Province, the results from which could provide decision support for the selection of sustainable suppliers, and assist in promoting the sustainable development of the Chinese Baijiu industry.

The remainder of the paper is organized as follows. Section 2 gives a literature review on sustainable supplier selection, Section 3 constructs the integrated indicator system (economic, environmental, and social dimensions) for Baijiu supply chain sustainable supplier selection, Section 4 proposes an improved fuzzy DEMATEL method, Section 5 presents the application example, and Section 6 concludes the research.

2. Literature Review

How to choose competent suppliers and how to motivate competent suppliers are the core issues of contemporary enterprise management [34]. Supplier selection and evaluation has always been a key SCM focus, with significant past research having stressed the importance of developing suitable supplier selection assessment criteria [15,35]; however, many traditional supplier selection evaluations have only included economic-oriented criteria [6]. Dickson concluded that quality was the most important criterion, followed by performance history, warranties and claims policies, production facilities and capacity, price, technical capabilities and nancial position [35]. Weber et al. analysed 74 purchasing-related articles from 1967 to 1990 and found that price had become the most important criterion, followed by delivery and quality [15]. As supplier selection is a multi-criteria problem, it has attracted signi cant attention from academia and industry [20,36,37]. For example, Kilincci and Onal proposed supplier selection criteria for a washing machine company that included product performance and service performance [38], Rezaei et al. investigated supplier selection for the airline retail industry that included product-related, supplier-related, and stragy/relationship-related criteria [39], and Van der Rhee et al. examined manufacturing managers/executive trade-o s between cost, delivery, exibility, and service features in the supplier selection process for the acceptable quality of commodity raw materials [40]. Amid et al. assessed suppliers from quality, net cost, and service perspectives [41], Chen et al. considered cost, quality, deliverability, technology, productivity, and service as the main criteria [42], Ho cited quality as the critical criterion, followed by deliverability and price [43], Gimenez and Tachizawa concluded that economic sustainability was related to operational e ciency, market share, and sales [44], and Chang et al. [29] chose product quality, product price, technology ability, service, delivery performance, stable delivery of goods, lead-time, reaction to demand change in time, production capacity, and nancial situation criteria.

The population and consumption around the world have driven major ecological pressures [12]. In recent years, there has been an increase in supplier selection research that included environmental and so-cial sustainability, indicating that supply chain management sustainability has become a more important requirement for decision-makers [13,45]. When the focal company is under pressure, it usually passes that pressure on to its suppliers [20]. Enterprises increasing need to know not only material cost, but also ecological and social behaviour of suppliers [12].

The most common environmental criteria has been carbon emissions [46]. Environmental sustain-ability requires that the footprints keep below their maximum sustainable level [47]. For example, Shaw et al. considered cost, quality rejection percentage, late delivery percentage, green house gas emissions and demand factors [48], Hsu et al. developed a system that had thirteen criteria focused on carbon management in an electronics manufacturer [49], Yu et al. applied green factors and carbon dioxide emis-sions as environmental factors [50], Govindan et al. proposed a hybrid method to select green suppliers in the food supply chain [6], and Gimenez and Tachizawa concluded that environmental sustainability was often related to energy e ciency, waste reduction, pollution, emissions, environmental accidents, social sustainability to labour conditions, diversity, connectedness within and outside the community, and quality of life [44].

The majority of the previous papers focus on the economic and environmental factors. In contrast, social aspects of sustainable development are rarely considered and even less research addresses all three dimensions together [22]. Seuring even thought the social sustainability is not taken into account [33]. However, Mani et al. mainly emphasized on social sustainable supplier selection through social criteria by applying AHP method, experts validated the social indicators including equity, safety, health, education, child and boned labour, wages, and philanthropy [36], and Goebel et al. developed a socially and environ-mental sustainable supplier selection based on ethical culture concept, results indicated that company’s ethical culture has a great in uence on how purchasing managers consider social and environmental index when selecting suppliers [37]. Sustainability also includes issues of social justice.

Because of this heightened sustainable awareness, many suitable sustainable supplier selection decision making methods have been adopted [21,44,51,52]. For example, Luthra et al. identi ed 22 sustainable supplier selection criteria and three criteria dimensions from previous research and expert opinion, and then applied these to an automobile company in India, concluding that environmental costs, product quality, product price, occupational health and safety systems, and environmental competencies were the key sustainable supplier selection criteria [51]. In other research, Buyukozkan and Cifci developed a sustainable supplier selection method with incomplete information [52], Gimenez and Tachizawa reviewed supplier selection from economic, environmental, and social dimensions [44], and Wang et al. selected sustainable suppliers for two local Chinese auto-parts companies [53]. However, there has been little research specifically focused on supplier selection frameworks for the Chinese Baijiu industry.

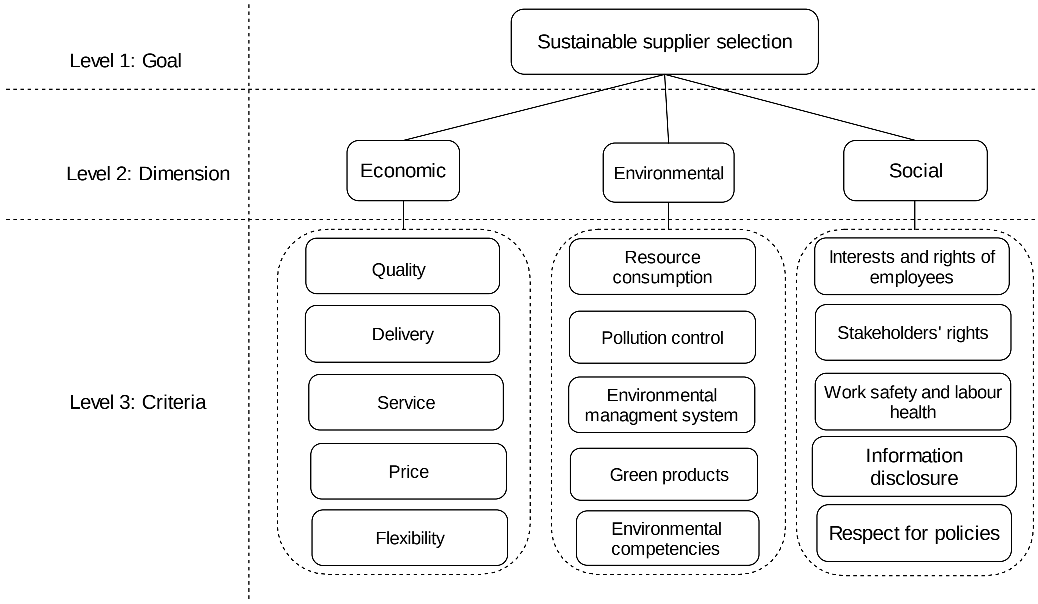

Figure 1: Sustainable supplier selection criteria

3. Sustainable Criteria System

Sustainable supplier selection is an important issue for the Baijiu making industry in supply chain management, however, none of the previous researches explicitly includes sustainable development as the main feature of the issue considered [22]. Focus companies increasingly require their suppliers to follow guidelines set by environmental and social standards [20]. The aim of this research is to bridge this gap. The speed and vitality of modern supply chains poses challenges to integrate sustainability into supplier selection [12]. From a comprehensive literature review and expert opinion, a Baijiu industry supplier selection model with fteen criteria over three dimensions is proposed, the indicators for which are shown in detail in Figure 1.

3.1. Economic Criteria

Economic criteria has generally been related to Baijiu industry cost and revenue analysis, therefore, as it is necessary to consider both supplier selection commonalities and individual company uniqueness, the ve economic indicators selected to evaluate supplier economic performance are Quality (C11), Delivery (C12), Service (C13), Price (C14), and Flexibility (C15), as detailed in the following.

3.1.1. Quality

The use value of a product is based on product quality. Dickson stated that quality was the most important supplier selection indicator [35], as product quality is at the heart of company survival and the supply chain [26,51]. Therefore, this quality indicator is related to all materials to be used in Baijiu production.

3.1.2. Delivery

Dickson and Weber both ranked delivery the second most important supplier selection index [15,35], as this is related to a supplier's ability to meet delivery schedules and react quickly to customer orders [6]; therefore, as delivery plays a decisive role in a company [26,54], lower delivery reliability can cause a chain reaction across the whole supply chain, result in a large amount of wasted resources, increase costs, and even cause the supply chain to disintegrate. As Baijiu companies generally set a delivery window for their suppliers, each supplier must deliver the goods within a specified time limit, and any delivery beyond the time limit can be rejected; therefore, this delivery condition tests a supplier's punctuality [17,55].

3.1.3. Service

Service is another important indicator for supplier selection [17,29,51], which for the Baijiu industry refers to product identification and traceability, the ability to respond to needs and changes, the value added and extended services, and after-sales service [27]. The service level promised by the supplier is very important [56].

3.1.4. Price

Weber found that price was one of the most important supplier selection indicators [15]. For Baijiu supplier selection, the price usually refers to the grain and packaging prices both of which have a signi cant in uence on the price of the nished products in the downstream enterprises [27,29,51].

3.1.5. Flexibility

The concept of flexibility rst originated as part of flexible manufacturing system (FMS) research, and refers to the ability of a system to respond to demand changes. When selecting and evaluating suppliers, liquor companies are concerned with a supplier's ability to respond to future changes, so includes production, delivery, quantity , and lead time exibilities [25,40,57].

3.2. Environmental Criteria

Under increasing competition circumstances, enterprises need to include decision-making strategies for environmental sustainability [58]. Enterprises invest a lot of resources in environmental initiatives [60]. The environmental indicators are focused on reducing the side effects caused by ineficient resources in the Baijiu supply chain; therefore the Baijiu supplier selection environmental indicators are: Resource consumption (C21), Pollution control (C22), Environmental management system (C23), Green products (C24), and Environmental competencies (C25); the details for which are given in the following.

3.2.1. Resource consumption

Resource consumption is an important indicator for the selection of green suppliers as low energy consumption can assist in achieving a low-carbon supply chain [17,26]. Therefore, for Baijiu supplier selection, resource consumption mainly refers to the resources such as the food, electricity, water, and natural gas consumed in the production process, and the fuels such as gasoline and diesel used during the raw materials and packaging materials distribution processes.

3.2.2. Pollution control

Pollution control refers to the use of technical, economic, legal, and other management tools and methods to eliminate and reduce pollutant emissions [17,26,55]. Therefore, pollution control mainly refers to supplier's waste disposal (waste water, waste solids, and waste gas) processes.

3.2.3. Environmental management system

The environmental management system is an important indicator for sustainable supplier selection and includes the management aspects associated to an organization's environmental policies, goals, and indicators [17,26]. The Global Reporting Initiative (GRI) focuses on implementation of environmental management system [12]. And the implementation of environmental management systems can help companies to reduce related risks [20]. Baijiu companies require their suppliers to have achieved the ISO14000 environmental management system standard, which is an effective tool for green company certification and indicates sustainable company development [59].

3.2.4. Green products

Green products can directly promote changes in consumption and production. The main feature of green products is the achievement of environmental protection goals through market regulation. It has become fashionable for the public to buy green products and promote green products to obtain economic benefits. Therefore, Baijiu green products are related to supplier's energy and water-conservation, and low-pollution, low-toxicity, renewable, and recyclable production processes [17,26].

3.2.5. Environmental competencies

Environmental competitiveness refers to the ability of suppliers to use environmentally friendly materials, implement clean technologies, and reduce pollution as well as the ability to demonstrate environ-mental protection in both domestic and international markets [17,26,51]. Baijiu supplier environmental competitiveness is not limited to the product but must be shown across the entire product life cycle, such as raw material procurement, manufacturing, packaging, sales, and product recycling.

3.3. Social Criteria

Government legislation and customers' awareness are among main reasons that prompt companies or organizations to pay an increased attention to environmental and social impacts of their activities [22]. Social aspects should be given more attention in future research to achieve a sustainable supply chain [22]. External pressures promote socially desired changes to rm operation [60]. The social indicators re ect the social aspects of supplier selection; therefore the social indicators are; Interests and rights of employees (C31), Stakeholders' rights (C32), Work safety and labour health (C33), Information disclosure (C34), and Respect for policies (C35), each of which is detailed in the following.

3.3.1. Interests and rights of employees

The interests and rights of employees is the main social indicator [17,26,51]. In the Baijiu industry, this includes the right to social insurance and benefits, the right to remuneration for work, the right to rest on holidays, and the right to labour security and protection.

3.3.2. Stakeholders' rights

Corporate stakeholders include shareholders, employees, creditors, suppliers, retailers, consumers, competitors, governments, public interest groups, and so on [17,26]. For Baijiu supplier selection, the stakeholders' rights refers to the protection of these legal rights as well as the protection of the moral rights of people who have a stake in the business [51].

3.3.3. Work safety and labour health

Work safety and labour health refers to the safety, health and welfare of people engaged at the sup-plier's workplace [17,26,51,57]. For Baijiu supplier selection, it includes safety auditing and evaluation, the occupational health and safety management system (OHSAS)18001, and the standard health and safety conditions.

3.3.4. Information disclosure

Information disclosure refers to the company-related information given to investors and the public in the form of a prospectuses, listing announcements, periodic reports, and interim reports [17,26,51]. Firms are increasingly reporting on their global operations and impacts [12]. And enterprises are joining forces to drive suppliers to disclose information to permit them to track performance and motivate positive improvement [12]. In the Baijiu supplier selection context, it provides customers and stakeholders with information on the materials used, the work environment, capital ows, carbon emissions, and production process hazardous substance residues.

3.3.5. Respect for policies

Respect for policies refers to a supplier's compliance with the government's laws and regulations. In the Baijiu industry, this specifically refers to a supplier's compliance with the environmental management system, occupational health and safety management system, and other regulatory issues [17,26].

4. The Proposed Methodology

The DEMATEL method developed by the Geneva Research Centre of the Battelle Memorial Insti-tute has been widely used to evaluate cause and e ect relationships [28]. While there have been many approaches for evaluating and selecting suppliers, most require extra data and seldom consider the cri-teria relationships. Therefore, when dealing with criteria causal relationships, the DEMATEL approach has been shown to be more e ective as it does not require mass data to determine the cause and effect criteria relationships. However, in the real world, many evaluation criteria are vague, uncertain, and imprecise [30]. Therefore, as fuzzy theory is used in this paper to resolve these problems, a modified fuzzy DEMATEL method is developed, as follows [28-30]:

Step 1: Determine the decision group and evaluation criteria.

Suppose H experts o er suggestions for n factors that have been identi ed from a literature review and expert opinion.

Step 2: Determine the fuzzy linguistic scales and fuzzy direct impact degrees.

A five-score fuzzy linguistic scale ($\tilde{0}$ - $\tilde{4}$) is developed to assess the relationships between the different criteria; $\tilde{0}$ = "No influence", $\tilde{1}$ = "Low influence", $\tilde{2}$ ="Medium influence", $\tilde{3}$="High influence", and $\tilde{4}$="Very high influence". The influence map example can be drawn as Figure 2. An arrow from b to a indicates the effect that b exercises on a, and the strength of effect is $\tilde{4}$. The experts make linguistic judgments based on the scale to establish a direct relation assessment criteria matrix. To evaluate and convert the expert language variables, triangular fuzzy numbers (TFN) are used, as shown in Table 1, and expressed as (l, m, u), where $l \le m \le u$. Suppose $[x_{ij}^k] = (l_{ij}^k, m_{ij}^k, u_{ij}^k)$, where $1 \le k \le K$, is the k th expert factor i impact degree j.

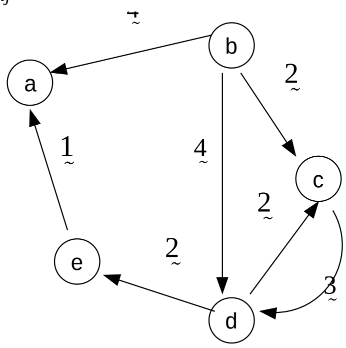

Figure 2: An influence map example.

Table 1: Fuzzy linguistic scale.

Linguistic terms	Influence Score	Corresponding triangular fuzzy numbers
No influence	$\tilde{0}$	(0,0.1,0.3)
Very low influence	$\tilde{1}$	(0.1,0.3,0.5)
Low influence	$\tilde{2}$	(0.3,0.5,0.7)
High influence	$\tilde{3}$	(0.5,0.7,0.9)
Very high influence	$\tilde{4}$	(0.7,0.9,1.0)

Step 3: Construct the initial fuzzy impact matrix.

The scores given by each expert form an $n \times n$ non-negative answer matrix, where $X^k = [x_{ij}^k] = (l_{ij}^k, m_{ij}^k, u_{ij}^k), k = 1, 2, \cdots, H$. Therefore, $X^1, X^2, \cdots, X^H$ are the answer matrices for the H experts. The diagonal elements in each answer matrix $X^k = [x_{ij}^k]_{n \times n}$ are all set to 0, indicating that no influence is given by itself. The $n \times n$ average matrix B ($B=[b_{ij}]_{n \times n}$) for all expert opinions is then calculated by averaging the scores of the H experts as follows:

$$b_{ij} = \frac{1}{H} \sum_{k=1}^{H} x_{ij}^k \tag{1}$$

Step 4: Transform the triangular fuzzy numbers into an initial direct-relation matrix.

Use Equation 2 to transform the triangular fuzzy numbers into the an initial direct-relation matrix.

$$a_{ij} = \frac{1}{3}(l_{ij}^k + m_{ij}^k + u_{ij}^k) \tag{2}$$

$A = [a_{ij}]_{n \times n}$ is the initial direct-relation matrix.

Step 5: Normalize the direct relation matrix $D = [d_{ij}]_{n \times n}$ using Equations 3 and 4.

$$s = \max(\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}) \tag{3}$$

$$D = \frac{A}{s} \tag{4}$$

Step 6: Obtain the total-relation matrix.

Total-relation matrix $T = [t_{ij}]_{n \times n}$, $i, j = 1, 2, \cdots, n$ is obtain from Equation 5. Where I expresses the identity matrix.

$$T = \lim_{m \to \infty} (D + D^2 + \cdots + D^m) = D(I - D)^{-1} \tag{5}$$

Step 7: Calculate the sum of the rows and the sum of columns using Equations 6 and 7.

$$R_i = \sum_{j=1}^{n} t_{ij} \tag{6}$$

$$C_i = \sum_{i=1}^{n} t_{ij} \tag{7}$$

Step 8: Compute the central role degree and cause degree.

$R_i + C_i$ refers to the "Prominence", which measures the importance degree of the corresponding criteria, and $R_i - C_i$ refers to the "Relation", which expresses the position of the criteria, if $R_i - C_i$ is positive, the criteria is classi ed as a cause, and if $R_i - C_i$ is negative, the criteria is classified as an effect.

Step 9: Draw the causal diagram.

The causal diagram is built from the horizontal axis $R_i + C_i$, which indicates the degree of central role, and the vertical axis $R_i - C_i$, which indicates the relationship degree.

5. Case Example

China has made unprecedented investment in sustainable development [61]. The Baijiu industry is China's largest liquor industry and one of the fast growing industry sectors in China accounting for about 60% of the country's total alcoholic beverage market. In this case example, Baijiu enterprise A, which is located in Sichuan Province, requires a more suitable supplier evaluation. The suppliers in a typical Baijiu supply chain includes grain suppliers, packaging suppliers, and water suppliers, as shown in Figure 3. The company uses solid-state fermentation, with the annual ratio of their liquor raw materials accounting for 76% of total operating costs. The top ve suppliers supply 62.27% of total annual purchases; the rst = 27.13%, the second = 21.36%, the third = 7.27%, the fourth = 3.47%, and the fth = 3.02%. The agricultural landscape is dominated by smallholder farming in China, which is the greatest challenge for supplier evaluation [62]. Most Baijiu making companies don't have good methods to evaluate or manage upstream impacts, such as supplier selection [12]. The company's previous supplier evaluation system was primarily focused on economic aspects; however, due to increasing market competition pressure and public concern in recent years, the enterprise has decided to reshape its existing supplier evaluation system to ensure the survival and development of the liquor industry.

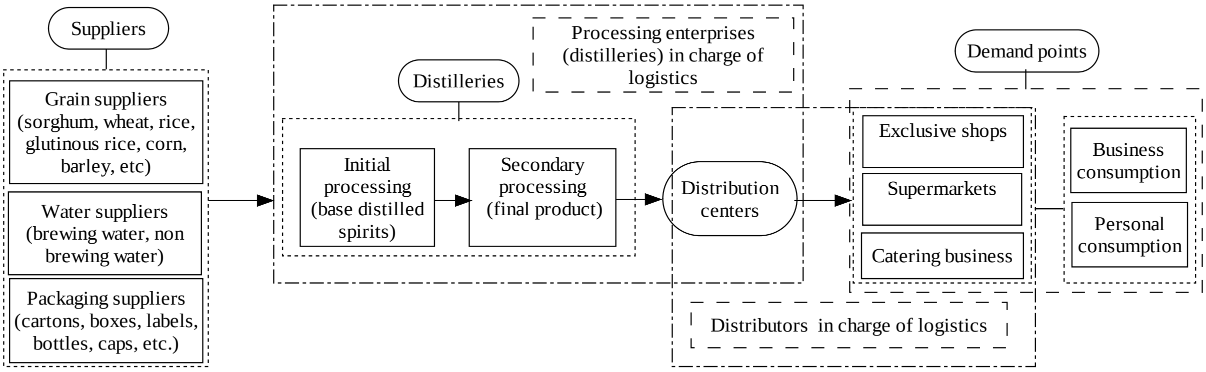

Figure 3: The Baijiu supply chain.

5.1. Method Application

In this case, the fuzzy DEMATEL method was applied to evaluate the suppliers, as follows. Step 1: Determine the panel experts and evaluation criteria.

Table 2: Fuzzy initial influence matrix 1.

	C11	C12	C13	C14	C15	C21	C22	C23
C11	(0.00,0.10,0.30)	(0.65,0.85,0.97)	(0.51,0.70,0.85)	(0.70,0.90,1.00)	(0.41,0.61,0.78)	(0.38,0.57,0.75)	(0.35,0.55,0.75)	(0.41,0.61,0.80)
C12	(0.45,0.65,0.81)	(0.00,0.10,0.30)	(0.63,0.83,0.96)	(0.57,0.77,0.94)	(0.41,0.61,0.79)	(0.35,0.55,0.74)	(0.32,0.52,0.69)	(0.37,0.57,0.75)
C13	(0.50,0.70,0.88)	(0.55,0.75,0.90)	(0.00,0.10,0.30)	(0.65,0.85,0.97)	(0.55,0.75,0.92)	(0.23,0.43,0.61)	(0.39,0.59,0.76)	(0.35,0.55,0.74)
C14	(0.65,0.85,0.97)	(0.59,0.79,0.94)	(0.66,0.86,0.98)	(0.00,0.10,0.30)	(0.50,0.70,0.87)	(0.41,0.61,0.78)	(0.46,0.66,0.83)	(0.37,0.57,0.75)
C15	(0.32,0.52,0.72)	(0.43,0.63,0.82)	(0.59,0.79,0.94)	(0.52,0.72,0.89)	(0.00,0.10,0.30)	(0.39,0.59,0.78)	(0.46,0.66,0.84)	(0.46,0.66,0.83)
C21	(0.54,0.74,0.88)	(0.41,0.61,0.78)	(0.35,0.55,0.74)	(0.59,0.79,0.94)	(0.43,0.63,0.79)	(0.00,0.10,0.30)	(0.52,0.72,0.88)	(0.61,0.81,0.95)
C22	(0.39,0.59,0.77)	(0.23,0.43,0.63)	(0.33,0.52,0.70)	(0.37,0.57,0.76)	(0.20,0.39,0.59)	(0.28,0.48,0.68)	(0.00,0.10,0.30)	(0.66,0.86,0.98)
C23	(0.39,0.59,0.77)	(0.27,0.46,0.65)	(0.30,0.50,0.70)	(0.35,0.55,0.75)	(0.20,0.39,0.59)	(0.35,0.55,0.74)	(0.52,0.72,0.85)	(0.00,0.10,0.30)
C24	(0.52,0.72,0.89)	(0.27,0.46,0.66)	(0.35,0.54,0.73)	(0.32,0.48,0.67)	(0.16,0.35,0.55)	(0.45,0.63,0.80)	(0.43,0.61,0.77)	(0.45,0.65,0.81)
C25	(0.41,0.61,0.79)	(0.25,0.45,0.65)	(0.34,0.54,0.74)	(0.35,0.55,0.75)	(0.25,0.45,0.65)	(0.55,0.75,0.90)	(0.61,0.81,0.94)	(0.59,0.79,0.92)
C31	(0.35,0.55,0.75)	(0.35,0.55,0.74)	(0.41,0.61,0.79)	(0.32,0.52,0.72)	(0.35,0.55,0.75)	(0.14,0.32,0.52)	(0.42,0.61,0.78)	(0.34,0.54,0.73)
C32	(0.50,0.70,0.86)	(0.34,0.54,0.74)	(0.32,0.52,0.72)	(0.21,0.41,0.61)	(0.26,0.46,0.66)	(0.25,0.45,0.65)	(0.30,0.50,0.69)	(0.25,0.45,0.65)
C33	(0.43,0.63,0.81)	(0.35,0.55,0.75)	(0.50,0.70,0.86)	(0.35,0.55,0.75)	(0.32,0.52,0.72)	(0.13,0.30,0.50)	(0.44,0.63,0.78)	(0.48,0.68,0.85)
C34	(0.50,0.70,0.88)	(0.43,0.63,0.80)	(0.50,0.70,0.88)	(0.52,0.72,0.88)	(0.52,0.72,0.89)	(0.50,0.70,0.87)	(0.48,0.68,0.86)	(0.48,0.68,0.85)
C35	(0.37,0.57,0.77)	(0.22,0.41,0.61)	(0.34,0.54,0.74)	(0.18,0.37,0.57)	(0.21,0.41,0.61)	(0.37,0.57,0.77)	(0.45,0.65,0.83)	(0.43,0.63,0.80)

Table 3: Fuzzy initial influence matrix 2

	C24	C25	C31	C32	C33	C34	C35
C11	(0.46,0.66,0.85)	(0.48,0.68,0.85)	(0.59,0.79,0.94)	(0.66,0.86,0.98)	(0.38,0.57,0.75)	(0.54,0.74,0.90)	(0.48,0.68,0.84)
C12	(0.35,0.55,0.74)	(0.55,0.75,0.89)	(0.57,0.77,0.92)	(0.63,0.83,0.95)	(0.45,0.65,0.81)	(0.50,0.70,0.85)	(0.46,0.66,0.82)
C13	(0.39,0.59,0.77)	(0.55,0.75,0.90)	(0.57,0.77,0.93)	(0.61,0.81,0.95)	(0.39,0.59.0.79)	(0.57,0.77,0.94)	(0.57,0.77,0.93)
C14	(0.46,0.66,0.83)	(0.50,0.70,0.85)	(0.46,0.66,0.85)	(0.59,0.79,0.94)	(0.35,0.55,0.75)	(0.35,0.55,0.74)	(0.37,0.57,0.75)
C15	(0.45,0.65,0.80)	(0.55,0.75,0.89)	(0.52,0.72,0.88)	(0.57,0.77,0.93)	(0.45,0.65,0.80)	(0.46,0.66,0.83)	(0.46,0.66,0.84)
C21	(0.48,0.68,0.86)	(0.61,0.81,0.95)	(0.35,0.55,0.75)	(0.43,0.63,0.82)	(0.41,0.61,0.77)	(0.45,0.65,0.80)	(0.54,0.74,0.90)
C22	(0.57,0.77,0.93)	(0.65,0.85,0.95)	(0.50,0.70,0.86)	(0.48,0.68,0.85)	(0.59,0.79,0.93)	(0.52,0.72,0.88)	(0.57,0.77,0.94)
C23	(0.55,0.75,0.91)	(0.45,0.65,0.82)	(0.34,0.54,0.73)	(0.35,0.55,0.73)	(0.46,0.66,0.82)	(0.37,0.57,0.77)	(0.37,0.57,0.75)
C24	(0.00,0.10,0.30)	(0.39,0.57,0.75)	(0.37,0.57,0.75)	(0.39,0.59,0.76)	(0.39,0.57,0.75)	(0.40,0.59,0.77)	(0.43,0.63,0.82)
C25	(0.57,0.77,0.92)	(0.00,0.10,0.30)	(0.50,0.70,0.87)	(0.46,0.66,0.83)	(0.61,0.81,0.95)	(0.50,0.70,0.86)	(0.54,0.74,0.90)
C31	(0.32,0.52,0.71)	(0.37,0.57,0.76)	(0.00,0.10,0.30)	(0.39,0.59,0.77)	(0.45,0.65,0.81)	(0.32,0.52,0.71)	(0.38,0.57,0.75)
C32	(0.30,0.50,0.69)	(0.34,0.54,0.73)	(0.34,0.54,0.74)	(0.00,0.10,0.30)	(0.32,0.52,0.72)	(0.26,0.46,0.66)	(0.25,0.41,0.61)
C33	(0.49,0.68,0.84)	(0.50,0.70,0.86)	(0.66,0.86,0.97)	(0.57,0.77,0.92)	(0.00,0.10,0.30)	(0.45,0.65,0.81)	(0.57,0.77,0.92)
C34	(0.48,0.68,0.85)	(0.34,0.54,0.74)	(0.39,0.59,0.76)	(0.45,0.65,0.81)	(0.54,0.74,0.88)	(0.00,0.10,0.30)	(0.39,0.59,0.77)
C35	(0.48,0.68,0.86)	(0.45,0.65,0.85)	(0.50,0.70,0.86)	(0.43,0.63,0.83)	(0.37,0.57,0.75)	(0.34,0.54,0.73)	(0.00,0.10,0.30)

Table 4: Direct impact matrix.

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C25	C31	C32	C33	C34	C35
C11	0.133	0.821	0.685	0.867	0.600	0.570	0.555	0.606	0.658	0.673	0.773	0.836	0.570	0.724	0.667
C12	0.633	0.133	0.806	0.761	0.603	0.567	0.509	0.404	0.548	0.733	0.755	0.803	0.633	0.685	0.734
C13	0.694	0.736	0.133	0.821	0.742	0.421	0.582	0.548	0.585	0.736	0.758	0.791	0.591	0.761	0.758
C14	0.821	0.773	0.836	0.133	0.691	0.600	0.652	0.567	0.652	0.685	0.658	0.773	0.552	0.548	0.567
C15	0.518	0.624	0.773	0.709	0.133	0.588	0.655	0.652	0.630	0.733	0.706	0.758	0.630	0.652	0.655
C21	0.600	0.548	0.773	0.615	0.706	0.133	0.739	0.788	0.758	0.791	0.624	0.597	0.63	0.691	0.585
C22	0.585	0.427	0.515	0.57	0.394	0.482	0.133	0.836	0.758	0.815	0.688	0.670	0.770	0.706	0.761
C23	0.585	0.461	0.500	0.555	0.394	0.548	0.697	0.133	0.739	0.636	0.533	0.545	0.648	0.573	0.567
C24	0.709	0.467	0.536	0.491	0.358	0.624	0.603	0.636	0.133	0.573	0.567	0.582	0.570	0.588	0.624
C25	0.603	0.445	0.536	0.552	0.445	0.736	0.785	0.767	0.755	0.133	0.691	0.652	0.788	0.688	0.724
C31	0.555	0.548	0.603	0.518	0.555	0.324	0.603	0.533	0.515	0.57	0.133	0.585	0.633	0.515	0.570
C32	0.688	0.536	0.518	0.409	0.464	0.445	0.497	0.445	0.497	0.533	0.536	0.133	0.518	0.464	0.424
C33	0.621	0.552	0.688	0.552	0.518	0.309	0.615	0.670	0.670	0.688	0.833	0.755	0.133	0.633	0.755
C34	0.694	0.618	0.694	0.706	0.709	0.691	0.676	0.670	0.670	0.536	0.582	0.633	0.718	0.133	0.585
C35	0.573	0.412	0.536	0.376	0.409	0.573	0.639	0.618	0.676	0.645	0.688	0.627	0.567	0.533	0.133

Table 5: Normalized direct impact matrix.

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C25	C31	C32	C33	C34	C35
C11	0.014	0.084	0.070	0.089	0.062	0.059	0.057	0.062	0.068	0.069	0.079	0.086	0.059	0.074	0.068
C12	0.065	0.014	0.083	0.078	0.062	0.058	0.052	0.041	0.056	0.075	0.078	0.082	0.065	0.070	0.075
C13	0.071	0.076	0.014	0.084	0.076	0.043	0.060	0.056	0.060	0.076	0.078	0.081	0.061	0.078	0.078
C14	0.084	0.079	0.086	0.014	0.071	0.062	0.067	0.058	0.067	0.070	0.068	0.079	0.057	0.056	0.058
C15	0.053	0.064	0.079	0.073	0.014	0.060	0.067	0.067	0.065	0.075	0.072	0.078	0.065	0.067	0.067
C21	0.062	0.056	0.079	0.063	0.072	0.014	0.076	0.081	0.078	0.081	0.064	0.061	0.065	0.071	0.060
C22	0.060	0.044	0.053	0.059	0.040	0.049	0.014	0.086	0.078	0.084	0.071	0.069	0.079	0.072	0.078
C23	0.060	0.047	0.051	0.057	0.040	0.056	0.072	0.014	0.076	0.065	0.055	0.056	0.067	0.059	0.058
C24	0.073	0.048	0.055	0.050	0.037	0.064	0.062	0.065	0.014	0.059	0.058	0.060	0.059	0.060	0.064
C25	0.062	0.046	0.055	0.057	0.046	0.076	0.081	0.079	0.078	0.014	0.071	0.067	0.081	0.071	0.074
C31	0.057	0.056	0.062	0.053	0.057	0.033	0.062	0.055	0.053	0.059	0.014	0.060	0.065	0.053	0.059
C32	0.071	0.055	0.053	0.042	0.048	0.046	0.051	0.046	0.051	0.055	0.055	0.014	0.053	0.048	0.044
C33	0.064	0.057	0.071	0.057	0.053	0.032	0.063	0.069	0.069	0.071	0.086	0.078	0.014	0.065	0.078
C34	0.071	0.063	0.071	0.072	0.073	0.071	0.069	0.069	0.069	0.055	0.060	0.060	0.065	0.014	0.074
C35	0.059	0.042	0.055	0.039	0.042	0.059	0.066	0.063	0.069	0.066	0.071	0.064	0.058	0.055	0.014

Table 6: The total-relation matrix.

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C25	C31	C32	C33	C34	C35
C11	0.679	0.678	0.735	0.718	0.629	0.620	0.712	0.712	0.743	0.759	0.774	0.791	0.709	0.724	0.744
C12	0.700	0.588	0.719	0.682	0.606	0.596	0.682	0.667	0.705	0.736	0.744	0.760	0.689	0.694	0.723
C13	0.728	0.666	0.676	0.709	0.638	0.602	0.710	0.702	0.731	0.760	0.768	0.782	0.707	0.722	0.748
C14	0.733	0.663	0.736	0.637	0.627	0.612	0.709	0.697	0.73	0.748	0.751	0.773	0.696	0.696	0.723
C15	0.696	0.640	0.721	0.683	0.565	0.604	0.701	0.696	0.719	0.743	0.746	0.761	0.695	0.697	0.722
C21	0.716	0.645	0.734	0.686	0.631	0.570	0.722	0.722	0.745	0.762	0.751	0.760	0.708	0.713	0.729
C22	0.677	0.599	0.672	0.645	0.569	0.573	0.627	0.69	0.707	0.725	0.718	0.727	0.684	0.678	0.707
C23	0.617	0.548	0.610	0.587	0.517	0.528	0.621	0.563	0.643	0.645	0.640	0.650	0.613	0.606	0.627
C24	0.625	0.546	0.610	0.578	0.512	0.532	0.609	0.608	0.581	0.636	0.640	0.650	0.602	0.604	0.629
C25	0.693	0.614	0.688	0.658	0.587	0.609	0.704	0.699	0.722	0.675	0.734	0.740	0.700	0.690	0.718
C31	0.59	0.536	0.596	0.562	0.513	0.487	0.589	0.578	0.598	0.615	0.577	0.630	0.589	0.577	0.604
C32	0.561	0.498	0.547	0.512	0.469	0.463	0.538	0.529	0.554	0.568	0.573	0.541	0.537	0.532	0.547
C33	0.673	0.604	0.680	0.637	0.574	0.550	0.665	0.666	0.690	0.704	0.724	0.727	0.615	0.663	0.698
C34	0.708	0.637	0.711	0.680	0.618	0.610	0.700	0.695	0.720	0.721	0.731	0.742	0.691	0.643	0.724
C35	0.605	0.534	0.602	0.560	0.510	0.521	0.606	0.600	0.627	0.635	0.644	0.647	0.596	0.592	0.574

Table 7: Results.

Quality (C11)	10.726	10.001	20.727	0.726	1
Delivery (C12)	10.291	8.997	19.289	1.294	8

Service (C13)	10.648	10.035	20.684	0.613	2
Price (C14)	10.532	9.533	20.065	0.999	5
Flexibility (C15)	10.388	8.565	18.953	1.823	13
Resource consumption (C21)	10.594	8.479	19.073	2.115	11
Pollution control (C22)	9.999	9.897	19.896	0.103	6
Environmental management system (C23)	9.014	9.823	18.837	-0.809	14
Green products (C24)	8.961	10.214	19.174	-1.253	9
Environmental competencies (C25)	10.232	10.430	20.662	-0.198	3
Interests and rights of employees (C31)	8.640	10.513	19.152	-1.873	10
Stakeholders’ rights (C32)	7.969	10.682	18.650	-2.713	15
Work safety and labour health (C33)	9.869	9.831	19.700	0.039	7
Information disclosure (C34)	10.329	9.832	20.161	0.497	4
Respect for policies (C35)	8.853	10.216	19.070	-1.363	12

Enterprise A chose a team of eleven experts from di erent departments to evaluate the supplier sustainability indicators; a deputy general manager responsible for enterprise supplier coordination, a representative of the technical department, a purchasing manager, a representative from the production department, a representative from the quality assurance department, a representative from the nance department, a professor, two suppliers (one from packaging materials, the other a food supplier), and a customer representative. All experts were highly familiar with their respective elds and pro cient in decision making. From the literature analysis and the expert opinions, 15 sustainable supplier criteria were identi ed for the three economic, environmental, and social dimensions, as shown in Figure 1.

Step 2: Determine the fuzzy linguistic scales and fuzzy direct impact degrees.

Each expert gave their opinions regarding the relationships between the 15 indicators using the applied fuzzy linguistic variables shown in Table 1.

Step 3: Construct the fuzzy initial impact matrix.

The average value of the fuzzy linguistic variables for the 11 experts were determined using Equation 1, after which the fuzzy initial impact matrix was obtained as shown in Tables 2 and 3.

Step 4: Defuzzify to determine the direct impact matrix.

Equation 2 was used to defuzzify the initial fuzzy in uence matrix and drive the direct in uence matrix, as shown in Table 4.

Step 5: Calculate the normalized direct impact matrix.

Equation 3 was used to determine the sum of the direct in uence matrix, after which the maximum value was then divided by the direct in uence matrix. The normalized direct impact matrix was then obtained using Equation 4, as shown in Table 5.

Step 6: Determine the total-relationship matrix.

Step 7: Calculate the sum of the rows and the sum of the columns. Compute the dispatcher group and the receiver group.

Equation 6 was used to sum the rows and determine the dispatcher group R, and Equation 7 was used to sum the columns and determine receiver group C. The results are shown in Table 7.

Step 8: Compute the central role degree and cause degree.

$R_i + C_i$ is the central role degree and $R_i - C_i$ is the cause degree, the results for which are shown in Table 7.

Step 9: Draw up the causal diagram.

The causal diagram was drawn using $(R_i + C_i, R_i - C_i)$ as the coordinates, as shown in Figure 4.

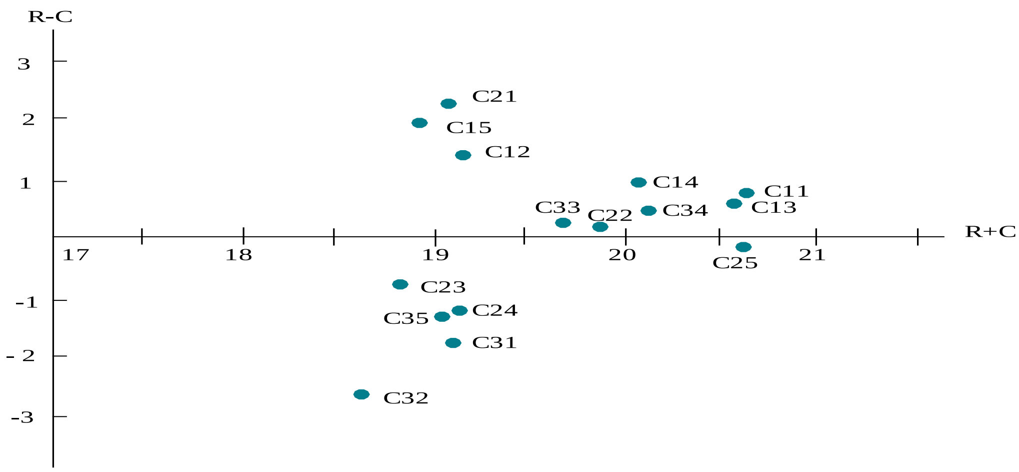

Figure 4: Causal diagram.

5.2. Results and Discussion

Fuzzy DEMATEL method was applied to analyse the supplier evaluation indicators for Baijiu enterprise A, and the corresponding results were obtained. This section evaluates the supplier selection indicators from three aspects: importance degree analysis, cause group analysis, and effect group analysis.

5.2.1. Importance degree analysis

The fteen assessment criteria for the Baijiu supply chain were ranked by degree of importance from the Ri + Ci; C11 > C13 > C25 > C34 > C14 > C22 > C33 > C12 > C24 > C31 > C21 > C35 > C15 > C23 > C32. Based on the R + C score obtained in Table 7, Quality (C11), Service (C13), Environmental competencies (C25), Information disclosure (C34), and Price (C14) were the ve most important, with the associated values being 20.727, 20.684, 20.662, 20.161, and 20.065. Flexibility (C15), Environmental management system (C23), and Stakeholders' rights(C32) were ranked the least important with the associated values being 18.953, 18.831, and 18.650.

If an $R_i - C_i$ cause degree was greater than 0, this indicated that the factor in uenced the other indi-cators. As can be seen in Table 7, Quality (C11), Delivery (C12), Service (C13), Price (C14), Flexibility (C15), Resource consumption (C21), Pollution control (C22), Work safety and labour health (C33), and Information disclosure (C34) were classi ed in the cause group; If Ri Ci was negative, the criteria were categorized as an effect; therefore, Environmental management system (C23), Green products (C24), Environmental competencies (C25), Interests and rights of employees (C31), Stakeholders' rights (C32), and Respect for policies (C35) were identi ed as effects.

Baijiu companies need to improve supplier selection across three dimensions, each of which include ve indicators. This research indicated that the purchasing managers needed to focus on supplier Quality (C11), Service (C13), Environmental competitiveness (C25), Information disclosure (C34), and Price (C14).

5.2.2. Cause group indicators

Cause group analysis is very important for Baijiu enterprise supplier selection. Figure 4 indicates that Resource consumption (C21) had the highest $R_i - C_i$ value of 2.115, which indicated that it had a strong in uence on the overall supply chain. However, because its $R_i - C_i$ value of 19.073 was relatively low, and the impact degree was only 10.594, this indicated that the supplier's Resource consumption had a high impact on the other indicators, but was impacted comparatively less by the other factors. Generally, as the Baijiu industry consumes a great deal of grain, water, and energy, Resource consumption is very important across the whole supply chain.

Flexibility (C15) was the second highest factor with an $R_i - C_i$ value of 1.823; however, its centrality value was 18.953 and the impact degree was 10.388, indicating that while this factor could easily a ect other elements, it was less in uenced by the other elements. Overall, this indicated that it was important for Baijiu suppliers to have exibility for sustainable industry development.

Delivery (C12) ranked third with $R_i - C_i$ value of 1.294, a Centrality value of 19.289 and an impact R of 10.291, indicating that was a causal element that impacted other elements, while also being in uenced by other factors. Price (C14) was the fourth highest factor with an $R_i - C_i$ value of 0.999, the $R_i + C_i$ value ranked fth, and the centrality was 20.065. Quality (C11) had an $R_i - C_i$ value 0.726 and an $R_i + C_i$ value of 20.727, which was the highest importance degree of all indicators and consistent with Chang et al.'s ndings [29], indicating that this factor was a ected by other factors, but also had an impact on other factors. Service (C12) had an $R_i - C_i$ value 0.613 and an $R_i + C_i$ 20.684, Information disclosure (C34) had an Ri Ci of 0.497, and an $R_i + C_i$ of 20.161, Pollution control (C22) had an $R_i - C_i$ of 0.103 and an $R_i + C_i$ of 19.896, and Work safety and occupational health (C33) had an $R_i - C_i$ of 0.039 and an $R_i + C_i$ of 19.700.

5.2.3. Effect group indicators

Indicators in the e ect group were easily a ected by other indicators, and therefore did not have a direct in uence on the supply chain; however, they are important to the overall system. The stakeholders' interest (C32) had the lowest $R_i - C_i$ value of -2.713, which indicated that this indicator had the highest influence; that is, all cause indicators impacted Baijiu supply chain stakeholder interests. The other indicators were as follows; the interests and rights of employees (C31) had an Ri Ci value of -1.873, Respect for policies (C35) had an $R_i - C_i$ value of -1.363, Green product (C24) had an $R_i - C_i$ value of -1.253, and Environmental competencies (C25) had an $R_i - C_i$ value of -0.198. Environmental competencies (C25) had the highest $R_i + C_i$ of 20.662 in the effect group, which indicated the importance of this indicator.

6. Conclusions

Supplier selection is an important decision making problem for most enterprises. Traditional supplier selection has tended to focus on the economic dimension; however, as environmental and social concerns have risen, sustainable supplier selection that integrates economic, environmental, and social factors is now necessary.

This paper applied a fuzzy DEMATEL method to analyse Baijiu sustainable supplier selection and identify the causal interactions between the sustainable supplier indicators. Based on a literature review and expert opinion, this paper identi ed 5 main indicators for each of the economic, environmental, and social dimensions. After analyses it was found that Quality (C11), Delivery (C12), Service (C13), Price (C14), Flexibility (C15), Resource consumption (C21), Pollution control (C22), Work safety and labour health (C33), and Information disclosure (C34) were classi ed as causes, and Environmental management system (C23), Green products (C24), Environmental competencies (C25), the interests and rights of employees (C31), Stakeholders' rights (C32), and Respect for policies (C35) were classi ed as e ects. It was revealed that Baijiu supply chain purchasing managers should pay particular attention to the Quality (C11), Service (C13), Environmental competitiveness (C25), Information disclosure (C34), and Price (C14) indicators.

This study is the first to systematically evaluate sustainable Baijiu supply chain supplier selection in China. In comparison to the broad observations of previous work based mainly on the economic dimension, the analysis in this paper a ords some tentative insight into the economic, environmental, and social dimensions of Baijiu supply chain supplier selection. This methodology could assist Baijiu enterprises select suitable sustainable suppliers and realize sustainable supply chain development. In future research, more concrete Baijiu industry indicators are to be established for a more in-depth study of Baijiu supply chain supplier selection, and a di erent multi-criteria decision making method could be used. This paper provides managerial insights for decision makers in Baijiu industry to select sustainable supplier who considering economic, environmental and social impact. However, the method introduced in this paper could be useful to other international alcoholic beverage enterprises seeking to develop sustainable supply chain management.

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