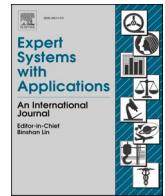




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# An integrated rough-fuzzy WINGS-ISM method with an application in ASSCM

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## ABSTRACT

Environmental deterioration, the COVID-19 pandemic and the Russian-Ukrainian conflict had brought chronic and dramatic impacts on agricultural supply chain around the world, resulting in high inflation rates and unavoidable costs. In order to reduce the adverse impacts and achieve sustainability in agricultural supply chain, it's necessary to scientifically explore composite indicators interlinked with agricultural sustainable supply chain management (ASSCM). The current study developed an integrated rough-fuzzy WINGS-ISM method to reveal the hierarchical and causal structure of indicators. It is found that environmental legislation, regulation, licensing, and government subsidies are the main drivers of ASSCM. Specifically, the government can guide the sustainable development of ASSCM by regulating the business environment. The financial support needs to be enlarged to optimize the structure in science and technology of ASSCM. Moreover, corporates and organizations are highly motivated by the increasing awareness of social responsibility and sustainability consciousness to improve the economic performance and achieve the ASSCM goals. A comparative analysis is proposed to illustrate the practicality and reliability of the results obtained from the proposed method, which can be utilized as a reference in ASSCM.

## 1. Introduction

Recently, the world has witnessed the widespread COVID-19 pandemic and the dramatic impact of the Russian-Ukrainian conflict. These impacts have created challenges to the supply chain that can provide humans with different types of industrial raw materials and food security. As a result of the shortage of effective supply, price of raw materials as grain, gas, and oil had soared and some supply chains were even broken; world economic development has been challenged as well. It caves governments, business managers and agriculture managers to be more concerned about the sustainability of agriculture supply chain (ASC) (Ge, Nolan, Gray, Goetz, & Han, 2016; Vempiliyath, Thakur, & Hargaden, 2021). In addition, ASC can ensure the security and stability of any nation, which is complex due to the unpredictable influencing factors, such as climate, region conflicts and epidemics (K Govindan

et al., 2015; Ruiz-Benitez et al., 2018). Therefore, there has been a great deal of interest in obtaining sustainable development of ASC; the measurement plays a major role in agricultural sustainable supply chain management (ASSCM).

An efficient and rational ASSCM has plentiful merit for the societies, including guarantee agriculture supply quantity and optimize resource allocation (Nematollahi & Tajbakhsh, 2020). However, when ASCs are at risk, food security, economic sustainability, and social stability can all be affected as raw materials become scarce. To ensure sustainability within natural resources constraints, ASSCM needs to focus on the improvement by using complex metrics and evaluating performance. However, current supply chain management (SCM) measurement frameworks always ignore the sustainability metrics and it is unrealistic to ensure their validity due to the uncertain risks. Therefore, it is essential to consider the sustainable indicators to estimate and inspect

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**Table 1**  
The difference among the methods.

Method	Interdependency	Intensity of Influence	The power of indicators	Fuzzy Logic	Rough Logic
ANP	N	N	Y	N	N
DEMATEL	Y	Y	N	N	N
WINGS	Y	Y	Y	N	N
F-WINGS	Y	Y	Y	Y	N
Rough-F-WINGS	Y	Y	Y	Y	Y

the performance of ASSCM (Park & Li, 2021; Zhuo & Ji, 2019).

The decision-making methods can accomplish excellent analysis in complex environments with imprecise, incomplete, or uncertain information. Uncertainty is a fundamental feature of the real world and is inevitable in estimation, optimization, and other processes. Therefore, it's hard to use an exact numerical value to evaluate the degree of interaction between indicators in the estimating process. Under such a limitation, it is worthwhile to further investigate how to estimate with more explicit, efficient, and realistic information. Due to the dynamic complexity of ASSCM and the limitation of experts' experience, experts can only express their estimates in rough terms when they are unfamiliar with the given indicators. That means that the reliability of experts' assessments may be variable. To overcome this issue, the Fuzzy Logic is an useful technology for Multi-Criteria Decision-Making (MCDM), which can deal with information that is partial and ambiguous. Formalizing rational decisions in the absence of precise or computational ambiguity is necessary to make rational decisions (S.-M. Chen & Chang, 2016), which can be utilized by translating the linguistic scale into numerical values (Bakioğlu & Atahan, 2021).

Using the rough set method, group fuzzy judgements can be aggregated since it can cope with the subjectivity and diversity of various DMs (Pamućar et al., 2018). With the combination of the fuzzy set and rough sets, ambiguity of a single DM can be dealt with through the fuzzy set and diversity of multiple DMs can be handled through the rough set (Zhang et al., 2020). Compared to other representations, rough sets have advantages of being more flexibly and realistic in representing uncertain information and effectively maintaining initial information (Tang et al., 2020). Therefore, it is necessary to utilize the rough sets to express various interrelationship evaluations between indicators through domain experts in ASSCM.

The fuzzy set can express the subjective views of experts, and it is combined with several MCDM methods to assess the indicators of Sustainable Supply Chain Management (SSCM) (Gupta and Barua, 2018; Liu et al., 2019; Singh and Sarkar, 2020; Tirkolaee et al., 2020). However, the judgments of group decision-makers (DMs) are often unclear and varied, which may lead to erroneous evaluations. In contrast to the fuzzy sets, rough sets can not only handle the vagueness of single DM, but also various DMs (Pourmehdi et al., 2021; Zhang et al., 2020). Rough set can aggregate the group fuzzy assessments, which could control the diversity and subjectivity of numerous DMs (Tang et al., 2020). Considering the advantages of rough sets in identifying the fuzzy preferences of DMs, rough set and fuzzy set can solve the uncertain information from different DMs.

The estimation of the complex correlations in ASSCM is a typical MCDM process, which aims to identify the significant indicators and the relationships between them by soft computing. Based on the comprehensive experience of experts and practitioners handling with the uncertain information, several methods have been established to determine hierarchical relationship within the indicators that do not always correspond to historical quantitative data.

Table 1 shows the differences among the differences among the uncertain MCDM methods for incomplete or imprecise information problems and the method illustrated in this study. The Analytic Hierarchy Process (AHP) approach has been utilized as one of most common

MCDM methods in ASSCM, with an independence assumption that there are no effects between indicators (Demirel et al., 2012; Saaty, 2013). However, indicators in ASSCM always have intricate influential relationships. To overcome this issue, multipool methods have been established to identify the hierarchical relationship within the indicators, such as Interpretive Structural Modeling (ISM) (Mandic et al., 2015), Decision Experimentation and Evaluation Laboratory (DEMATEL), and Weighted Influence Nonlinear Gauge System (WINGS) (Michnik, 2013). Unlike DEMATEL, ANP and DEMATEL-ANP methods (Demirel et al., 2012; Yucenur et al., 2011; Abdullah et al., 2021), the WINGS method allows the analysis of relationships and strengths of indicators, which are ignored in DEMATEL (Wang et al., 2021).

Apparently, the WINGS method has an advantage in identifying the complex relationships within indicators. Unlike ANP, DEMATEL and combination DEMATEL-ANP approaches (Agrawal et al., 2020; Z. Chen et al., 2019; Hashmi et al., 2021), this study integrates WINGS and ISM method with rough-fuzzy logic to extract the dependencies in diverse and fuzzy decision environment. Moreover, the ISM method could account for the hierarchical structure of interrelationships, which cannot be determined with the DEMATEL method (A. Kumar & Dixit, 2018), as well as the WINGS method. Moreover, WINGS can calculate the intensity of relationship and strength of indicators, which cannot be determined by ISM (Trivedi et al., 2021). Therefore, these drawbacks can be addressed by integrating these two methods. Reviewing the literature, there is no such an instance of integrating the fuzzy set, rough set, WINGS, and ISM approaches to solve the ambiguous problems.

In addition, analyzing the interrelationships and impacts between metrics is more complex and difficult when the indicators do not have a hierarchically structured in ASSCM. It is essential to identify accurate hierarchical and interrelationship structure by combining WINGS and ISM techniques because both contain processes that can be connected to visualize the relationship through the structured maps, such as the relation/prominence values in WINGS and the dependence/driving values in ISM. Nonetheless, while WINGS analyzes the causal relationship within the indicators, the ISM method can enhance the accuracy of the analysis by dividing the indicators into different hierarchical levels.

In summary, the WINGS method can analyze the direction and strength of indicators, as well as the strength of criteria; it also can visually measure the strength of direct and indirect relationships between indicators by means of graphs. ISM can decompose a complex system into subsystems. So far, few studies have combined WINGS and ISM method. The current study paper first integrates the grouped rough-fuzzy logic and WINGS-ISM approach to get the dependencies in a diverse fuzzy decision environment of ASSCM. Thus, the rough-fuzzy WINGS-ISM is innovative in this field, which allows aggregating numerous fuzzy information and visualizing the hierarchical structure through graphical representations.

The main contributions of this work list as:

- A novel integrated MCDM system is developed to identify the interrelationship of the indicators.
- Rough and fuzzy set are extended to the WINGS method as a feasible technique to handle the subjective ambiguity and variety of group choices.
- WINGS is combined with the ISM method for the first time, allowing the visualization of the structure to analyze the direction and relationship of indicators, as well as the strength of the indicator.
- The applicability of this method is discussed with a practical implication to explore the hierarchical relationships among the indicators in ASSCM.

The remainder shows as follows. Section 2 concentrates on the literature Reviews. Section 3 illustrates the Rough fuzzy WINGS-ISM research methodology. Section 4 shows empirical analysis. Section 5 carries out a comparative analysis. Section 6 covers conclusions and implications of this paper. Whereas, the limitations and

recommendations for further studies list in Section 7.

## 2. Literature Reviews

### 2.1. The influencing indicators of ASSCM

SSCM encompasses economic environmental, and social indicators, which is an important issue in the world under resource and environmental constraints (Govindan et al., 2015; Jeng, 2015). Comparing the scope of SSCM and Green SCM, an accepted proposal shows that SSCM is an extended mode of GSCM, which includes only economic and environmental indicators (Govindan et al., 2015). Sustainable supply chains have become a constructive engine for minimizing negative environmental consequences, optimizing organizational legal concerns, improving ecological efficiency, and eventually enhancing economic stability, which are referred to by industrial and corporate leaders as a sustainable strategy (Lin et al., 2018).

Economic criteria can be commonly describe as costs and benefits (Nematollahi & Tajbakhsh, 2020). Social features have received significantly less attention compared to economic and environmental dimensions, having difficulties in measuring them (Ge et al., 2016). These criteria mainly include environmental costs, ecological costs, supply chain costs, greenhouse gas emissions and waste generation, public health, and maximizing total job creation, all of which demand further attention organically or conventionally. Overviewing the publications of GSCM and SSCM from 2010 to 2021. the criteria encompass product quality, marketing channels, government subsidies, demand, degradation, modelling, and technique (Aylak, 2021; Leng et al., 2019; Lim-Camacho et al., 2017; Yu et al., 2020).

As one of the primary characteristic, many sustainability indicators are studied for supplier selection, supply chain changes and disruptions, such as government requirements, businesses requirements, competitive interests, consumer demands, employee demands, corporate culture, social development, environmental regulations, stakeholder satisfaction, and social responsibility, which become more interesting than ever before in understanding current issues of SSCM (Chandrasekaran and Ranganathan, 2017; Jiang et al., 2022; Leng et al., 2019; Panetto et al., 2020).

How to respond to customer demands is the key issue of SSCM, which influences the optimization planning. It is always categorized as a specific or uncertain metric (K Govindan et al., 2015; Nematollahi and Tajbakhsh, 2020). Some models based on customer demand have consider specific demand or uncertain demand conditions through the use stochastic programming (Ge et al., 2016). If it is possible to include socio-cultural aspects and integrated demand substitution, the needs of other projects will be fulfilled. As a result, the volume of negative environmental implications may be reduced, and consumer satisfaction may increase to a high level (Nematollahi and Tajbakhsh, 2020; Panetto et al., 2020). Also demand substitution is an alternative to achieve relative consumer satisfaction while lowering the cost of scarcity.

### 2.2. Applications of MCDM technique

Under an inconstant environment, the evaluation of indicators in ASSCM has become a complicated hierarchical MCDM problem with complex intertwined relationship. Thus, scholars proposed more effective methods to directly represent the interrelationships between elements, including ANP (Saaty, 2013), Interpretive Structural Modeling (ISM) (Mathiyazhagan et al., 2013), DEMATEL (Liu et al., 2019), and WINGS (Wang et al., 2021). The ANP method has independent assumption that there is no influence between indicators. It has been utilized in many areas as product service system (Z. Chen et al., 2019), transport system (A. Kumar & Anbanandam, 2020), supply chain management (Demirel et al., 2012).

ISM can identify the influence level of the indicators, decompose them into different levels, and distinguish the relationships by graphic

model, but ISM cannot calculate the strength between the indicators (A. Kumar & Dixit, 2018; Kumar et al., 2021a). ISM extends in many fields as e-waste management (A. Kumar & Dixit, 2018), environmental sustainability (Gani et al., 2022), green supply management (Mathiyazhagan et al., 2013), building information (RezaHoseini et al., 2021), fuel consumption (He et al., 2021), electric vehicle charging station (Liang et al., 2022), circular economy enablers (Patel et al., 2021), corporate social responsibility (Usmani et al., 2022), social media sharing (Dedeoglu et al., 2020), healthcare supply chain (Desingh & Baskaran, 2022), transportation management (Trivedi et al., 2021), agriculture supply chain (Kumar et al., 2021b), agri-food supply chain (Srivastava & Dashora, 2021).

Unlike traditional MCDM approaches, the DEMATEL approach can illustrate the relationships and causal-effect structure of indicators using experts' judgments (L. Abdullah & Rahim, 2020; Asan et al., 2018). DEMATEL can graphically visualize interrelationships with the direction and intensity of the effects (F. Abdullah et al., 2022), which has been widely used in energy industry carbon neutrality (You & Yi, 2022), product design (Karasan et al., 2022), ecological security (Du & Li, 2022), risk assessment (Ahmadi et al., 2020), circular economy (Govindan et al., 2022), smart construction (Xiahou et al., 2022), urban sustainability (L. Abdullah & Rahim, 2020), and supply chain (Buyukozkan & Guler, 2021).

The advantage of the WINGS approach over DEMATEL is that the strength of the indicators is considered. This is because the entire degree of influence between indicators is determined by a mixed relationship rather than simply sum of the intensity of influence (Michnik, 2013). So far, it has been utilized in green building development (Wang et al., 2021), automotive industry (Kaviani et al., 2020), technology projects (Hadi Mousavi-Nasab & Sotoudeh-Anvari, 2020).

## 3. Methodology

### 3.1. Triangular fuzzy numbers

For describing the vagueness of human cognitive processes, fuzzy set theory is established by Zadeh. A triangular fuzzy number can be described like  $\tilde{p} = (e, i, s)$ , where  $e \leq i \leq s$ , then the membership function and basic operations can be described as follows (Buyüközkan & Çifçi, 2012).

$$f_{\tilde{p}}(x) = \begin{cases} 0, & x < e \text{ or } x > s \\ \frac{x - e}{i - e}, & e \leq x \leq i \\ \frac{s - x}{s - i}, & i \leq x \leq s \end{cases}$$

- (1)  $\tilde{p}_1 + \tilde{p}_2 = (e_1 + e_2, i_1 + i_2, s_1 + s_2)$ ;
- (2)  $\tilde{p}_1 - \tilde{p}_2 = (e_1 - e_2, i_1 - i_2, s_1 - s_2)$ ;
- (3)  $\tilde{p}_1 \times \tilde{p}_2 = (e_1 \times e_2, i_1 \times i_2, s_1 \times s_2)$ ;
- (4)  $\tilde{p}_1 \div \tilde{p}_2 = (e_1 \div e_2, i_1 \div i_2, s_1 \div s_2)$ .

$$e_1, e_2 > 0, i_1, i_2 > 0, s_1, s_2 > 0.$$

### 3.2. Rough numbers

Supposed that there is a set of  $s$  classes of decision-makers,  $A = \{a_{ij}^1, a_{ij}^2, \dots, a_{ij}^k, \dots, a_{ij}^s\}$  is ordered by  $a_{ij}^1 < a_{ij}^2 < \dots < a_{ij}^k < a_{ij}^s$ .  $Y$  is a random item of  $U$ , which includes all items (Z. Chen et al., 2019). Then the lowest and highest limit approximation of  $a_{ij}^k$  could be shown as:

$$\underline{Apr}(a_{ij}^k) = \cup \{Y \in U, A(Y) \leq a_{ij}^k\}; \overline{Apr}(a_{ij}^k) = \cup \{Y \in U, A(Y) \geq a_{ij}^k\}.$$

Then  $a_{ij}^k$  can be described using the rough number defined as  $\underline{Lim}(a_{ij}^k)$  and  $\overline{Lim}(a_{ij}^k)$ :

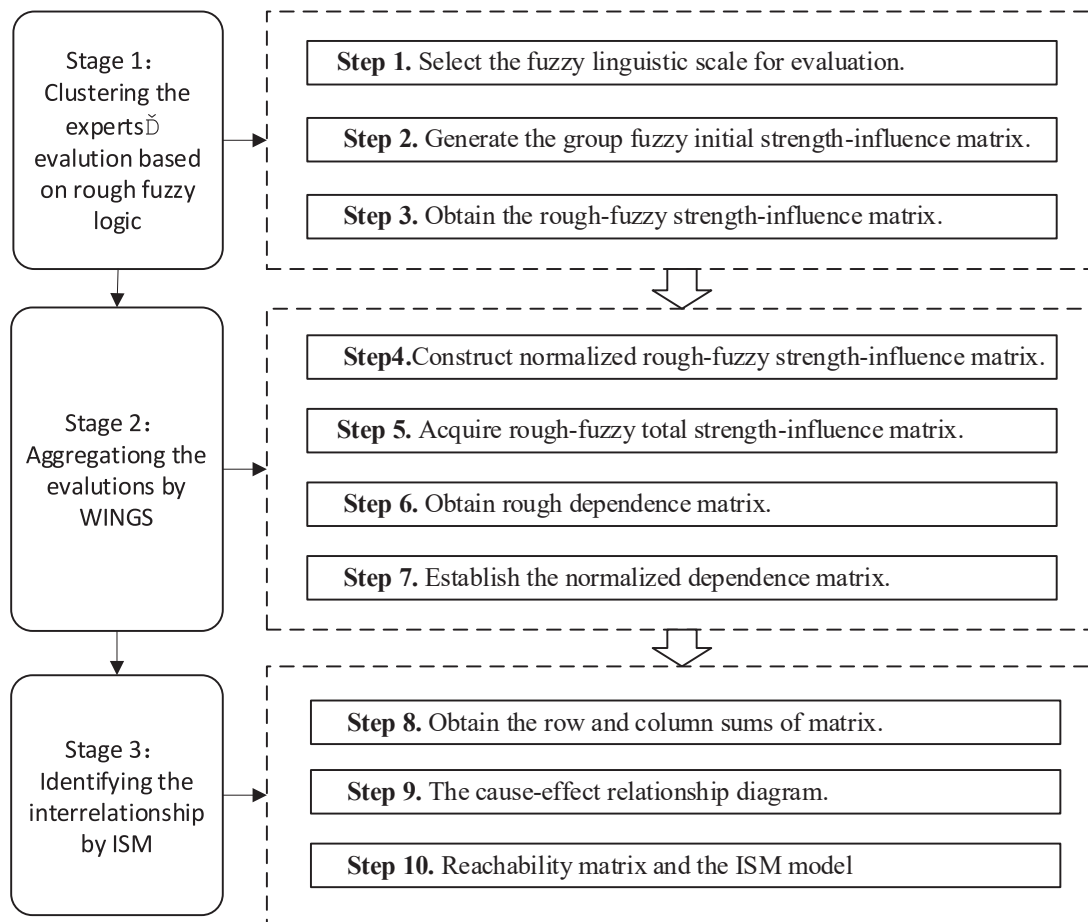


Fig. 1. Flowchart of the proposed rough-fuzzy WINGS-ISM model.

Table 2

The fuzzy linguistic scale with corresponding triangular fuzzy numbers.

Fuzzy linguistic scale	Abbreviations	Triangular fuzzy numbers
None	N	(0,0,1)
Low	L	(1,2,3)
Medium	M	(3,4,5)
High	H	(5,6,7)
Very high	VH	(7,8,8)

$$\underline{Lim}(a_{ij}^k) = \left( \prod_{s=1}^{N_i^L} x_i \right)^{1/N_i^L}; \overline{Lim}(a_{ij}^k) = \left( \prod_{s=1}^{N_i^U} y_i \right)^{1/N_i^U}$$

where  $x_i$  and  $y_i$  are the lowest and highest limit approximation of  $a_{ij}^k, N_i^L$  and  $N_i^U$  which are the number of the element in lowest and highest limit set.

The form could be described as follows:

$$AN(a_{ij}^k) = [\underline{Lim}(a_{ij}^k), \overline{Lim}(a_{ij}^k)] = [a_{ij}^{kL}, a_{ij}^{kU}]$$

where  $a_{ij}^{kL}$  and  $a_{ij}^{kU}$  are the lowest and highest limit.

The average rough number  $AN(\hat{a}_{ij})$  can be described by:

$$AN(\hat{a}_{ij}) = [a_{ij}^L, a_{ij}^U] \text{ and } a_{ij}^L = \left( \prod_{k=1}^s a_{ij}^{kL} \right)^{1/s}, a_{ij}^U = \left( \prod_{k=1}^s a_{ij}^{kU} \right)^{1/s}.$$

where  $a_{ij}^L$  and  $a_{ij}^U$  are the lowest and highest limit respectively, and  $s$  respects the number of decision-makers.

### 3.3. Rough-fuzzy WINGS method

The flowchart of rough-fuzzy WINGS-ISM shows in Fig. 1, and the main steps are described as follows:

**Step 1.** Define the fuzzy linguistic scale.

The fuzzy linguistic scale with matching triangular fuzzy numbers list in Table 2.

**Step 2.** Calculate the group fuzzy initial strength-influence matrix.

There are  $s$  experts to evaluate the importance and relationship among the influencing indicators. Then the fuzzy strength-influence matrix of the  $k$ th expert could be described like:

$$\tilde{F}_k = \begin{bmatrix} \tilde{f}_{11}^k & \tilde{f}_{12}^k & \dots & \tilde{f}_{1n}^k \\ \tilde{f}_{21}^k & \tilde{f}_{22}^k & \dots & \tilde{f}_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{f}_{n1}^k & \tilde{f}_{n2}^k & \dots & \tilde{f}_{nn}^k \end{bmatrix}, k = 1, 2, \dots, s. \tag{1}$$

where  $\tilde{f}_{ij}^k = (l_{ij}^k, m_{ij}^k, u_{ij}^k)$  is the triangular fuzzy number, which presents the score of indicator  $i$  on indicator  $j$  presented by the  $k$ th expert.

The group fuzzy initial strength-influence matrix of  $s$  experts is described by:

$$\tilde{F} = \begin{bmatrix} \tilde{f}_{11} & \tilde{f}_{12} & \dots & \tilde{f}_{1n} \\ \tilde{f}_{21} & \tilde{f}_{22} & \dots & \tilde{f}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{f}_{n1} & \tilde{f}_{n2} & \dots & \tilde{f}_{nn} \end{bmatrix} \tag{2}$$

$$\tilde{f}_{ij} = (\tilde{l}_{ij}, \tilde{m}_{ij}, \tilde{u}_{ij}), \text{ and } \tilde{l}_{ij} = \{l_{ij}^1, l_{ij}^2, \dots, l_{ij}^s\}, \tilde{m}_{ij} = \{m_{ij}^1, m_{ij}^2, \dots, m_{ij}^s\}, \tilde{u}_{ij} = \{u_{ij}^1, u_{ij}^2, \dots, u_{ij}^s\}.$$

**Step 3.** Acquire the rough-fuzzy strength-influence matrix.

The rough number form of  $l_{ij}^k, m_{ij}^k$  and  $u_{ij}^k$  can be described by:

$$\begin{aligned} AN(l_{ij}^k) &= [\underline{Lim}(l_{ij}^k), \overline{Lim}(l_{ij}^k)] = [l_{ij}^{kL}, l_{ij}^{kU}]; \\ AN(m_{ij}^k) &= [\underline{Lim}(m_{ij}^k), \overline{Lim}(m_{ij}^k)] = [m_{ij}^{kL}, m_{ij}^{kU}]; \\ AN(u_{ij}^k) &= [\underline{Lim}(u_{ij}^k), \overline{Lim}(u_{ij}^k)] = [u_{ij}^{kL}, u_{ij}^{kU}]. \end{aligned} \tag{3}$$

Then the average rough number  $AN(\hat{l}_{ij}), AN(\hat{m}_{ij})$  and  $AN(\hat{u}_{ij})$  can be described by:

$$\begin{aligned} AN(\hat{l}_{ij}) &= [l_{ij}^L, l_{ij}^U] = \left[ \left( \prod_{k=1}^s l_{ij}^{kL} \right)^{1/s}, \left( \prod_{k=1}^s l_{ij}^{kU} \right)^{1/s} \right]; \\ AN(\hat{m}_{ij}) &= [m_{ij}^L, m_{ij}^U] = \left[ \left( \prod_{k=1}^s m_{ij}^{kL} \right)^{1/s}, \left( \prod_{k=1}^s m_{ij}^{kU} \right)^{1/s} \right]; \\ AN(\hat{u}_{ij}) &= [u_{ij}^L, u_{ij}^U] = \left[ \left( \prod_{k=1}^s u_{ij}^{kL} \right)^{1/s}, \left( \prod_{k=1}^s u_{ij}^{kU} \right)^{1/s} \right]. \end{aligned} \tag{4}$$

Therefore, the rough form of triangular fuzzy number  $\hat{f}_{ij}$  can be described as follow:

$$AN(\hat{f}_{ij}) = [\hat{f}_{ij}^L, \hat{f}_{ij}^U] \text{ and } \hat{f}_{ij}^L = (l_{ij}^L, m_{ij}^L, u_{ij}^L), \hat{f}_{ij}^U = (l_{ij}^U, m_{ij}^U, u_{ij}^U). \tag{5}$$

The initial strength-influence matrix as:

$$AN(\tilde{F}) = \begin{bmatrix} AN(\hat{f}_{11}) & AN(\hat{f}_{12}) & \dots & AN(\hat{f}_{1n}) \\ AN(\hat{f}_{21}) & AN(\hat{f}_{22}) & \dots & AN(\hat{f}_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ AN(\hat{f}_{n1}) & AN(\hat{f}_{n2}) & \dots & AN(\hat{f}_{nn}) \end{bmatrix} \tag{6}$$

**Step 4.** Obtain normalized rough-fuzzy strength-influence matrix.

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

$$AN(\hat{r}_{ij}) = \frac{AN(\hat{f}_{ij})}{AN(t)} \text{ and } AN(t) = \left[ \sum_{i=1}^n \sum_{j=1}^n u_{ij}^L, \sum_{i=1}^n \sum_{j=1}^n u_{ij}^U \right], \quad i,$$

$j \in \{1, 2, \dots, n\}.$

The element of matrix  $AN(\tilde{R})$  is defined as  $AN(\hat{r}_{ij}) =$

$$\left[ (r_{ij}^{LL}, r_{ij}^{ML}, r_{ij}^{UL}), (r_{ij}^{LU}, r_{ij}^{MU}, r_{ij}^{UU}) \right].$$

Therefore,  $AN(\hat{r}_{ij})$  can be written as:

$$AN(\hat{r}_{ij}) = \left[ \left( \frac{l_{ij}^L}{\sum_{i=1}^n \sum_{j=1}^n u_{ij}^L}, \frac{m_{ij}^L}{\sum_{i=1}^n \sum_{j=1}^n u_{ij}^L}, \frac{u_{ij}^L}{\sum_{i=1}^n \sum_{j=1}^n u_{ij}^L} \right), \left( \frac{l_{ij}^U}{\sum_{i=1}^n \sum_{j=1}^n u_{ij}^U}, \frac{m_{ij}^U}{\sum_{i=1}^n \sum_{j=1}^n u_{ij}^U}, \frac{u_{ij}^U}{\sum_{i=1}^n \sum_{j=1}^n u_{ij}^U} \right) \right] \tag{7}$$

**Step 5.** Acquire rough-fuzzy total strength-influence matrix.

The matrix  $AN(\tilde{Y})$  can be obtained by.

$$AN(\tilde{Y}) = AN(\tilde{R}) (1 - AN(\tilde{R}))^{-1} \tag{8}$$

$$\text{Let } AN(\tilde{Y}) = [AN(\hat{y}_{ij})]_{n \times n}, \text{ where } AN(\hat{y}_{ij}) = \left[ (y_{ij}^{LL}, y_{ij}^{ML}, y_{ij}^{UL}), (y_{ij}^{LU}, y_{ij}^{MU}, y_{ij}^{UU}) \right], \text{ then:}$$

$$Y_{iL} = [y_{ij}^{LL}]_{n \times n} = R_U (1 - R_U)^{-1} \text{ and } Y_{iU} = [y_{ij}^{LU}]_{n \times n} = R_{iU} (1 - R_{iU})^{-1}$$

Sim-

ilarly,  $Y_{mL} = [y_{ij}^{mL}]_{n \times n}, Y_{mU} = [y_{ij}^{mU}]_{n \times n}, Y_{uL} = [y_{ij}^{uL}]_{n \times n}$  and  $Y_{uU} = [y_{ij}^{uU}]_{n \times n}$  can be acquired.

**Step 6.** Obtain rough dependence matrix.

Let  $AN(Y) = [AN(y_{ij})]_{n \times n}$ , where  $AN(\hat{y}_{ij}) = [y_{ij}^L, y_{ij}^U]$ , then  $y_{ij}^L$  and  $y_{ij}^U$  can be calculated as follows:

$$y_{ij}^L = \frac{y_{ij}^{LL} + 4y_{ij}^{ML} + y_{ij}^{UL}}{6}, \tag{9}$$

$$y_{ij}^U = \frac{y_{ij}^{LU} + 4y_{ij}^{MU} + y_{ij}^{UU}}{6}$$

**Step 7.** Obtain the normalized dependence matrix.

Let  $Y = [y_{ij}]_{n \times n}$ , where the element  $y_{ij}$  is calculated as follow:

$$y_{ij} = (1 - \lambda_{ij})y_{ij}^L + \lambda_{ij}y_{ij}^U, 0 < \lambda_{ij} < 1 \tag{10}$$

where  $\lambda_{ij}$  represents the optimistic indicator, and the rough weight  $AN(y_{ij}) = [y_{ij}^L, y_{ij}^U]$  can be transform into crisp value  $y_{ij}$ . The certain value 0.5 presents the moderate attribute and if judgements are optimistic, then  $\lambda_{ij}$  can take a larger value ( $\lambda_{ij} > 0.5$ ).

**Step 8.** Calculate the row and column sums of matrix Y.

The sums of rows (H) and the sums of columns(L) can be defined in the normalized dependence matrix Y as.

$$H = [H_i] = \sum_{i=1}^n y_{ij}, i = 1, 2, \dots, n \tag{11}$$

$$L = [L_j] = \sum_{j=1}^n y_{ij}, j = 1, 2, \dots, n \tag{12}$$

H depicts the entire effect of indicator i as causal influence on residual indicators, and L describes the degree of residual indicators influencing on indicator j.

**Step 9.** The cause-effect relationship graph.

The value of (H + L) presents the entire prominence degree of the element. A positive value represents dominating degree, whereas a negative value presents that the indicator is influenced by others. The horizontal axis and vertical axis of the causal diagram are represented by (H + L) and (H-L). In comparison with the traditional DEMATEL methods, the WINGS is more suitable with considering the power of indicators for study on real-world situations. The degree of interrelationship among components, as well as the prominence and influence of indicators in the network, can be illustrated by the WINGS approach.

**Step 10.** Reachability matrix and the ISM model.

Assume the influencing degree of the indicator to other indicators surpasses the threshold, this indicates that the indicator has impact on another indicator. While the value is less than the threshold, the indicator has no influence on other indicators. With the analysis of reachability matrix, the ISM model can be created by taking the interrelationships into account through graphic derivation.

## 4. Empirical analysis and research results

### 4.1. Data collection

ASSCM incorporates all three environmental, social, and economic elements, which is important for academics and practitioners facing the limitation of resources and environment. Due to the complex influence from politics, wars, technologies, transportation, and economic transactions across nations, ASSCM has become extremely difficult recently, which need critical focus. According to the review of literature and opinions from academic or industry experts, fourteen important indicators were selected from three dimensions as government, economic, and society to make availability and typicality rating of each indicator for ASSCM, denoted as environmental legislation(C1), government supervision(C2), government subsidies(C3), green technology(C4), stakeholders' pressures(C5), customer requirement(C6), sustainability consciousness(C7), sustainable design(C8), agricultural product quality

**Table 3**  
The strength-influence matrix from evaluation of eight experts.

	C1	C2	C3	...	C13	C14
C1	4,4,4,3,4,4,2,3	4,4,3,3,3,2,2,2	4,4,3,3,3,2,3,3	...	4,4,2,3,4,4,3,2	4,4,2,3,4,4,3,4
C2	4,2,3,2,4,3,2,3	4,4,4,3,4,4,3,4	4,4,3,3,3,2,2,3	...	4,4,3,3,4,4,2,2	4,4,2,3,4,4,2,4
C3	3,1,3,2,1,4,2,3	3,1,4,3,1,4,2,3	3,3,4,4,1,4,2,3	...	4,3,3,3,1,4,2,2	4,3,2,3,2,4,3,4
C4	3,1,3,1,3,4,2,4	2,1,3,3,1,4,2,3	2,2,2,3,3,3,3,4	...	1,3,4,3,4,4,2,3	1,3,3,3,4,4,3,4
C5	3,2,4,3,2,3,3,4	3,2,3,2,1,3,3,3	2,3,3,3,3,2,3,4	...	1,3,2,2,1,4,2,3	1,3,2,2,2,1,1,3
C6	2,3,3,3,2,4,2,3	2,3,3,3,2,4,3,3	2,3,2,4,2,4,2,4	...	1,3,2,2,1,4,3,3	1,3,2,2,2,4,2,3
C7	3,0,3,4,2,3,3,2	2,1,3,4,2,3,3,1	2,1,3,4,2,2,2,2	...	1,4,3,2,1,4,2,3	1,3,3,3,2,3,3,2
C8	2,1,4,4,2,4,2,2	3,0,3,4,1,4,2,1	2,1,3,4,1,3,2,2	...	1,1,4,2,3,4,2,3	1,2,3,3,3,4,3,2
C9	3,3,3,3,4,4,3,3	2,3,3,4,1,4,3,2	2,3,3,3,2,4,3,3	...	1,3,2,3,2,4,2,3	1,3,2,2,3,4,2,3
C10	3,4,3,3,2,4,3,4	3,3,3,3,1,4,2,3	3,3,4,3,2,4,3,3	...	4,3,2,3,1,4,3,3	4,3,2,2,3,4,2,3
C11	3,0,3,2,1,4,2,3	2,0,3,3,1,4,3,3	3,0,3,4,1,4,3,3	...	4,1,3,3,1,4,2,3	3,0,2,2,1,2,2,3
C12	3,0,4,2,1,4,2,1	2,0,3,2,1,4,2,2	2,0,3,3,1,3,2,3	...	4,0,2,3,2,4,2,2	3,0,3,3,1,2,2,1
C13	3,3,3,2,1,3,3,3	3,2,3,2,2,3,3,3	2,2,4,3,2,3,3,2	...	3,2,3,3,1,4,3,4	1,2,3,3,3,2,2,1
C14	4,1,3,2,3,2,2,2	3,1,2,3,3,2,3,2	3,1,3,3,2,2,3,1	...	1,1,2,3,3,4,2,2	4,1,4,4,3,4,4,1

**Table 4**  
The rough-fuzzy initial strength-influence matrix.

	C1	C2	C3	...	C13	C14
C1	[(5.21,6.21,6.82), (6.73,7.73,7.85)] ]	[(3.81,4.81,5.75), (5.71,6.71,7.21)] ]	[(4.60,5.60,6.54), (5.89,6.89,7.43)] ]	...	[(4.50,5.50,6.25), (6.46,7.46,7.67)] ]	[(5.21,6.21,6.82), (6.73,7.73,7.85)] ]
C2	[(3.81,4.81,5.75), (5.71,6.71,7.21)] ]	[(6.13,7.13,7.56), (6.88,7.88,7.94)] ]	[(4.17,5.17,6.10), (5.83,6.83,7.35)] ]	...	[(4.50,5.50,6.25), (6.46,7.46,7.67)] ]	[(4.80,5.80,6.41), (6.65,7.65,7.76)] ]
C3	[(2.45,3.45,4.44), (5.04,6.04,6.75)] ]	[(2.77,3.77,4.71), (5.65,6.65,7.15)] ]	[(3.68,4.68,5.53), (6.20,7.20,7.53)] ]	...	[(3.21,4.21,5.15), (5.74,6.74,7.23)] ]	[(4.29,5.29,6.15), (6.19,7.19,7.53)] ]
C4	[(2.77,3.77,4.71), (5.65,6.65,7.15)] ]	[(2.45,3.45,4.44), (5.04,6.04,6.75)] ]	[(3.76,4.76,5.74), (5.26,6.26,6.99)] ]	...	[(3.68,4.68,5.53), (6.20,7.20,7.53)] ]	[(4.19,5.19,6.05), (6.21,7.21,7.57)] ]
C5	[(4.17,5.17,6.10), (5.83,6.83,7.35)] ]	[(3.21,4.21,5.21), (4.73,5.73,6.73)] ]	[(4.11,5.11,6.10), (5.40,6.40,7.14)] ]	...	[(2.26,3.26,4.25), (4.79,5.79,6.49)] ]	[(1.81,2.81,3.81), (3.71,4.71,5.71)] ]
C6	[(3.76,4.76,5.74), (5.26,6.26,6.99)] ]	[(4.11,5.11,6.10), (5.40,6.40,7.14)] ]	[(3.71,4.71,5.57), (5.81,6.81,7.16)] ]	...	[(2.45,3.45,4.44), (5.04,6.04,6.75)] ]	[(2.72,3.72,4.70), (4.83,5.83,6.54)] ]
C7	[(2.87,3.58,4.56), (5.27,6.25,6.98)] ]	[(2.45,3.45,4.44), (5.04,6.04,6.75)] ]	[(2.60,3.60,4.59), (4.47,5.47,6.18)] ]	...	[(2.50,3.50,4.44), (5.50,6.50,6.98)] ]	[(3.21,4.21,5.21), (4.73,5.73,6.73)] ]
C8	[(3.02,4.02,4.88), (5.51,6.51,6.88)] ]	[(1.85,2.54,3.48), (5.41,6.40,6.87)] ]	[(2.26,3.26,4.25), (4.79,5.79,6.49)] ]	...	[(2.50,3.50,4.44), (5.50,6.50,6.98)] ]	[(3.17,4.17,5.15), (5.28,6.28,7.01)] ]
C9	[(5.13,6.13,7.06), (5.88,6.88,7.44)] ]	[(3.21,4.21,5.15), (5.74,6.74,7.23)] ]	[(4.11,5.11,6.10), (5.40,6.40,7.14)] ]	...	[(2.90,3.90,4.89), (5.10,6.10,6.81)] ]	[(2.90,3.90,4.89), (5.10,6.10,6.81)] ]
C10	[(4.74,5.74,6.60), (6.24,7.24,7.60)] ]	[(3.53,4.53,5.51), (5.40,6.40,7.13)] ]	[(4.60,5.60,6.54), (5.89,6.89,7.43)] ]	...	[(3.56,4.56,5.50), (5.84,6.84,7.35)] ]	[(3.81,4.81,5.75), (5.71,6.71,7.21)] ]
C11	[(2.13,2.81,3.80), (5.08,6.06,6.77)] ]	[(2.43,3.11,4.10), (5.24,6.22,6.94)] ]	[(2.91,3.60,4.54), (5.76,6.74,7.26)] ]	...	[(2.77,3.77,4.71), (5.65,6.65,7.15)] ]	[(1.86,2.56,3.56), (3.85,4.84,5.84)] ]
C12	[(1.68,2.37,3.31), (5.18,6.16,6.63)] ]	[(1.86,2.55,3.54), (4.46,5.45,6.14)] ]	[(2.49,3.19,4.19), (4.68,5.66,6.66)] ]	...	[(2.52,3.25,4.18), (5.24,6.22,6.72)] ]	[(1.64,2.34,3.34), (4.11,5.09,6.09)] ]
C13	[(3.56,4.56,5.56), (4.87,5.87,6.87)] ]	[(3.78,4.78,5.78), (4.72,5.72,6.72)] ]	[(3.48,4.48,5.46), (5.06,6.06,6.78)] ]	...	[(3.56,4.56,5.50), (5.84,6.84,7.35)] ]	[(2.29,3.29,4.29), (4.19,5.19,6.19)] ]
C14	[(2.72,3.72,4.70), (4.83,5.83,6.54)] ]	[(2.94,3.94,4.94), (4.52,5.52,6.52)] ]	[(2.50,3.50,4.50), (4.46,5.46,6.46)] ]	...	[(2.26,3.26,4.25), (4.79,5.79,6.49)] ]	[(3.82,4.82,5.43), (6.52,7.52,7.64)] ]

and safety(C9), profits(C10), infrastructure projects(C11), marketing channels(C12), economic performance(C13), social responsibilities (C14). Moreover, eight experts were invited to estimate the strength of each indicator and relationship between them through questionnaire. To ensure the reliability and efficiency of this investigation, these experts have professional knowledge and experience in ASSCM more than ten years, including 2 professors from ASCM department, 2 agricultural consultants, 2 research scholars from agriculture field, and 2 agricultural supply chain managers. The evaluation values of strength and

relationship between fourteen indicators were assessed by experts in Table 3.

4.2. The rough-fuzzy strength-influence matrixes calculated by Rough-fuzzy WINGS

According to the main steps of Rough-fuzzy WINGS method described in 3.4, the group fuzzy initial strength-influence matrix can be transformed from evaluation of eight experts according to the

**Table 5**  
The rough-fuzzy total strength-influence matrix.

	C1	C2	C3	...	C13	C14
C1	[(0.38,0.46,0.50), (0.50,0.57,0.58)]	[(0.28,0.36,0.42), (0.42,0.50,0.53)]	[(0.34,0.41,0.48), (0.43,0.51,0.55)]	...	[(0.33,0.41,0.46), (0.48,0.55,0.57)]	[(0.38,0.46,0.50), (0.50,0.57,0.58)]
C2	[(0.28,0.36,0.42), (0.42,0.50,0.53)]	[(0.45,0.53,0.56), (0.51,0.58,0.59)]	[(0.31,0.38,0.45), (0.43,0.50,0.54)]	...	[(0.33,0.41,0.46), (0.48,0.55,0.57)]	[(0.35,0.43,0.47), (0.49,0.56,0.57)]
C3	[(0.18,0.25,0.33), (0.37,0.45,0.50)]	[(0.20,0.28,0.35), (0.42,0.49,0.53)]	[(0.27,0.35,0.41), (0.46,0.53,0.56)]	...	[(0.24,0.31,0.38), (0.42,0.50,0.53)]	[(0.32,0.39,0.45), (0.46,0.53,0.56)]
C4	[(0.20,0.28,0.35), (0.31,0.38,0.45)]	[(0.18,0.25,0.33), (0.24,0.31,0.38)]	[(0.28,0.35,0.42), (0.39,0.46,0.52)]	...	[(0.27,0.35,0.41), (0.46,0.53,0.56)]	[(0.31,0.38,0.45), (0.46,0.53,0.56)]
C5	[(0.31,0.38,0.45), (0.43,0.50,0.54)]	[(0.24,0.31,0.38), (0.35,0.42,0.50)]	[(0.30,0.38,0.45), (0.40,0.47,0.53)]	...	[(0.17,0.24,0.31), (0.35,0.43,0.48)]	[(0.13,0.21,0.28), (0.27,0.35,0.42)]
C6	[(0.28,0.35,0.42), (0.39,0.46,0.52)]	[(0.30,0.38,0.45), (0.40,0.47,0.53)]	[(0.27,0.35,0.41), (0.43,0.50,0.53)]	...	[(0.18,0.25,0.33), (0.37,0.45,0.50)]	[(0.20,0.27,0.35), (0.36,0.43,0.48)]
C7	[(0.21,0.26,0.34), (0.39,0.46,0.52)]	[(0.18,0.25,0.33), (0.37,0.45,0.50)]	[(0.19,0.27,0.34), (0.17,0.24,0.31)]	...	[(0.18,0.26,0.33), (0.41,0.48,0.52)]	[(0.24,0.31,0.38), (0.35,0.42,0.50)]
C8	[(0.22,0.30,0.36), (0.41,0.48,0.51)]	[(0.14,0.19,0.26), (0.24,0.31,0.38)]	[(0.17,0.24,0.31), (0.30,0.38,0.45)]	...	[(0.18,0.26,0.33), (0.41,0.48,0.52)]	[(0.23,0.31,0.38), (0.39,0.46,0.52)]
C9	[(0.38,0.45,0.52), (0.35,0.42,0.49)]	[(0.24,0.31,0.38), (0.26,0.33,0.41)]	[(0.30,0.38,0.45), (0.40,0.47,0.53)]	...	[(0.21,0.29,0.36), (0.38,0.45,0.50)]	[(0.21,0.29,0.36), (0.38,0.45,0.50)]
C10	[(0.35,0.42,0.49), (0.46,0.53,0.56)]	[(0.26,0.33,0.41), (0.18,0.23,0.30)]	[(0.34,0.41,0.48), (0.43,0.51,0.55)]	...	[(0.26,0.34,0.41), (0.43,0.51,0.54)]	[(0.28,0.36,0.42), (0.42,0.50,0.53)]
C11	[(0.16,0.21,0.28), (0.37,0.45,0.50)]	[(0.18,0.23,0.30), (0.39,0.46,0.51)]	[(0.21,0.27,0.34), (0.43,0.50,0.54)]	...	[(0.20,0.28,0.35), (0.42,0.49,0.53)]	[(0.14,0.19,0.26), (0.28,0.36,0.43)]
C12	[(0.12,0.18,0.24), (0.38,0.46,0.49)]	[(0.14,0.19,0.26), (0.33,0.40,0.45)]	[(0.18,0.24,0.31), (0.35,0.42,0.49)]	...	[(0.19,0.24,0.31), (0.39,0.46,0.50)]	[(0.12,0.17,0.25), (0.30,0.38,0.45)]
C13	[(0.26,0.34,0.41), (0.36,0.43,0.51)]	[(0.28,0.35,0.43), (0.35,0.42,0.50)]	[(0.26,0.33,0.40), (0.37,0.45,0.50)]	...	[(0.26,0.34,0.41), (0.43,0.51,0.54)]	[(0.17,0.24,0.32), (0.31,0.38,0.46)]
C14	[(0.20,0.27,0.35), (0.36,0.43,0.48)]	[(0.22,0.29,0.36), (0.33,0.41,0.48)]	[(0.18,0.26,0.33), (0.33,0.40,0.48)]	...	[(0.17,0.24,0.31), (0.35,0.43,0.48)]	[(0.28,0.36,0.42), (0.48,0.56,0.56)]

corresponding fuzzy number in Table 2. Then the fuzzy numbers can transform into rough numbers by using equations (3)-(6), which could be described as the rough-fuzzy initial direct-relation matrix in Table 4. Equations (7)-(8) are used to normalize and generate the rough-fuzzy total strength-influence matrix (see Table 5).

4.3. Analysis of prominence

As shown in Table 5 and Fig. 1, H depicts the entire effect of indicator i as a cause influence on residual indicators, while L presents the effect of residual indicators influenced by indicator j. The values of (H + L) denote the prominence level of the indicator. The sequence of affecting indicators can be illustrated as C1 > C2 > C4 > C3 > C9 > C5 > C6 > C7 > C10 > C8 > C14 > C13 > C11 > C12. The results demonstrate that environmental legislation (C1) is the most prominent indicator, implying that C1 has the most direct and indirect influence on other indicators in ASSCM. Government supervision(C2), green technology (C4), government subsidies(C3), and agricultural product quality and safety(C9) have significant influence. On the other hand, marketing channels(C12) has the smallest degree of significance, implying that marketing channels have the smallest direct influence on ASSCM. These findings show that the ASSCM is mostly influenced by the government, which provides legal environment and subsidies, enhancing the efficiency and quality. When confronting the major challenges, such as lack of environmental legislation, inadequate government supervision, uncertain agricultural product quality and safety, low green technology,

**Table 6**  
The sums impact among influencing indicators.

	H	L	H + L	H-L
C1	0.1386	0.1200	0.2586	0.0186
C2	0.1404	0.1142	0.2546	0.0262
C3	0.1220	0.1170	0.2390	0.0052
C4	0.1260	0.1178	0.2438	0.0084
C5	0.1096	0.1198	0.2294	-0.0102
C6	0.1172	0.1100	0.2272	0.0072
C7	0.1072	0.1190	0.2262	-0.0116
C8	0.1050	0.1174	0.2224	-0.0124
C9	0.1230	0.1126	0.2356	0.0104
C10	0.1216	0.1026	0.2240	0.0190
C11	0.1014	0.1128	0.2142	-0.0114
C12	0.0930	0.1124	0.2054	-0.0194
C13	0.1028	0.1160	0.2188	-0.0132
C14	0.1024	0.1192	0.2216	-0.0170

and little recompense for the operators, the agricultural supply chain management is difficult to be sustainable.

4.4. Analysis of relation

The fourteen indicators may be classified into two categories by using the values of H-L. The cause group with positive H-L values contains C1, C2, C3, C4, C6, C9, C10, and the sequence is C2 > C10 > C1 > C9 > C4 > C6 > C3, as shown in Table 6 and Fig. 1. Among these



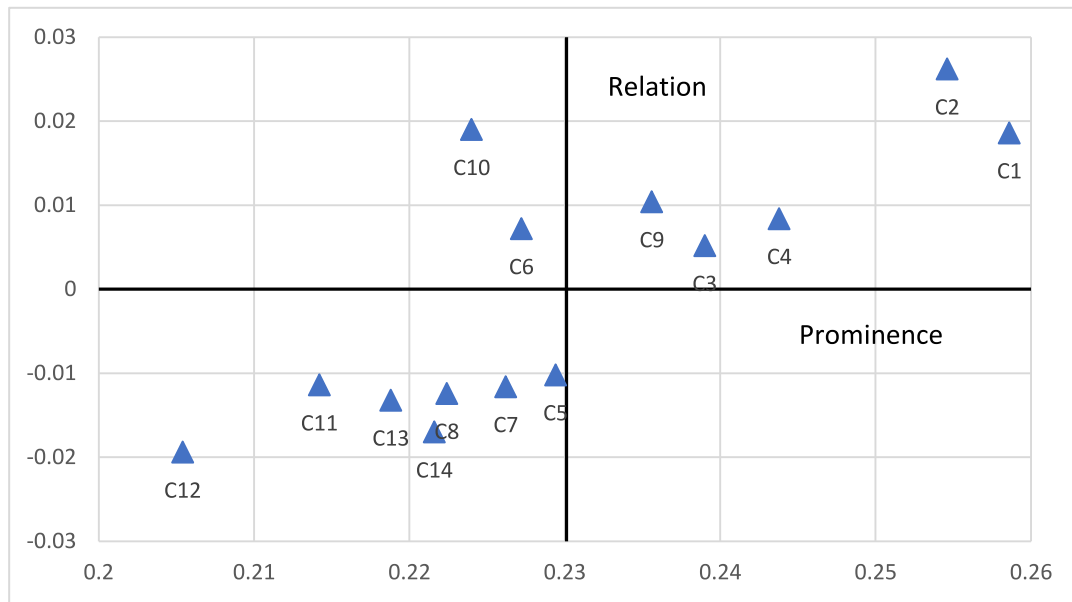


Fig. 2. The interactive influence between the 14 criteria.

components, the government supervision(C2) has the highest H-L value, indicating that the government supervision has a stronger impact on other indicators than other indicators in ASSCM. Profits(C10) has a significant influence on ASSCM with the second highest H-L value. The third highest H-L score is environmental legislation(C1). The agricultural product quality and safety(C9), green technology(C4), and customer demand/requirement(C6) are the economic indicators, which are traditional functions for ASSCM. Government subsidies(C3) is from governments, which is the cash payment given to the farmers or companies to lessen the burden.

C5, C7, C8, C11, C12, C13, and C14 have negative H-L values as effect group, and their sequence is C12 > C14 > C13 > C8 > C11 > C7 > C5. Variables in the effect group are influenced by other indicators. Marketing channels(C12) and social responsibilities(C14) have the lowest H-L score, mainly impacted by other factors. The third and fourth smallest values are economic performance(C13) and sustainable design (C8). Infrastructure projects(C11), sustainability consciousness(C7), and stakeholders' pressures/requirement(C5) are social and economic indicators that are influenced by other indicators. It can be observed that governmental elements might affect the social and economic indicators through environmental legislation, government supervision, and government subsidies.

4.5. Strategy analysis

Using Pan and Chen's(Pan & Chen, 2012) concept of four strategic zones, we further divided all the indicators into four strategic zones as Fig. 2.

- (1) Priority zone—high prominence and high relationship: (a) environmental legislation(C1), government supervision(C2), and government subsidies(C3) are mainly related to government. (b) green technology(C4) and agricultural product quality and safety (C9) are the economic indicators. They are the cause indicators for improving ASSCM, which are the basic indicators influencing other indicators.
- (2) Long-term zone—high prominence and low relation: none items in this area, which means that there are no elements can be influenced by other factors getting better.
- (3) Contingency zone—low prominence and high relationship: customer demand/requirement(C6) and profits(C10) have relatively large influence on other components, but less impacted by other indicators. To improve the development of ASSCM, the farmers, operators, managers, and stakeholders should consider these two indicators.
- (4) No-priority zone—low prominence and low relation: (a) stakeholders' pressures/requirement(C5), sustainable design(C8),

Table 7  
The sums of impact among influencing indicators.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	0.0112	0.0092	0.0094	0.0097	0.0096	0.0084	0.0106	0.0112	0.0092	0.0083	0.0104	0.0097	0.0104	0.0112
C2	0.0092	0.0116	0.0094	0.0097	0.0106	0.0084	0.0104	0.0112	0.0084	0.0088	0.0104	0.0112	0.0104	0.0106
C3	0.0075	0.0082	0.0088	0.0083	0.0097	0.0083	0.0085	0.0097	0.0091	0.0093	0.0083	0.0083	0.0083	0.0097
C4	0.0082	0.0075	0.0092	0.0105	0.0102	0.0077	0.0094	0.0093	0.0092	0.0095	0.0088	0.0083	0.0088	0.0095
C5	0.0093	0.0074	0.0093	0.0091	0.0081	0.0083	0.0091	0.0066	0.0073	0.0056	0.0066	0.0066	0.0068	0.0095
C6	0.0092	0.0093	0.0085	0.0083	0.0093	0.0111	0.0093	0.0083	0.0093	0.0058	0.0075	0.0081	0.0075	0.0057
C7	0.0081	0.0074	0.0073	0.0073	0.0076	0.0073	0.0083	0.0084	0.0073	0.0064	0.0081	0.0083	0.0081	0.0075
C8	0.0083	0.0073	0.0068	0.0078	0.0083	0.0072	0.0074	0.0083	0.0064	0.0072	0.0068	0.0078	0.0081	0.0074
C9	0.0102	0.0083	0.0093	0.0082	0.0092	0.0091	0.0082	0.0083	0.0112	0.0084	0.0075	0.0083	0.0083	0.0084
C10	0.0097	0.0085	0.0093	0.0093	0.0093	0.0083	0.0078	0.0083	0.0076	0.0088	0.0092	0.0085	0.0085	0.0083
C11	0.0068	0.0074	0.0081	0.0074	0.0074	0.0066	0.0074	0.0068	0.0064	0.0054	0.0082	0.0062	0.0081	0.0091
C12	0.0071	0.0064	0.0066	0.0062	0.0061	0.0057	0.0064	0.0062	0.0080	0.0065	0.0067	0.0074	0.0074	0.0062
C13	0.0078	0.0082	0.0078	0.0074	0.0076	0.0071	0.0086	0.0073	0.0066	0.0064	0.0072	0.0064	0.0084	0.0061
C14	0.0074	0.0074	0.0073	0.0083	0.0068	0.0066	0.0074	0.0073	0.0066	0.0062	0.0071	0.0072	0.0068	0.0101

**Table 8**  
The reachability matrix of ASSCM.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C3	0	0	1	1	1	1	1	1	1	1	1	1	1	1
C4	0	0	1	1	1	0	1	1	1	1	1	1	1	1
C5	1	0	1	1	0	1	1	0	0	0	0	0	0	1
C6	1	1	1	1	1	1	1	1	1	0	0	0	0	0
C7	0	0	0	0	0	0	1	1	0	0	0	1	0	0
C8	1	0	0	0	1	0	0	1	0	0	0	0	0	0
C9	1	1	1	0	1	1	0	1	1	1	0	1	1	1
C10	1	1	1	1	1	1	0	1	0	1	1	1	1	1
C11	0	0	0	0	0	0	0	0	0	0	1	0	0	1
C12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C13	0	1	0	0	0	0	1	0	0	0	0	0	1	0
C14	0	0	0	1	0	0	0	0	0	0	0	0	0	1

**Table 9**  
Level partitions of the reachability matrix.

No.	Reachability Set	Antecedent Set	Intersection	Level
1	1,2,3,4,5,6,7,8,9,10,11,12,13,14	1,2,5,6,8,9,10	1,2,5,6,8,9,10	7
2	1,2,3,4,5,6,7,8,9,10,11,12,13,14	1,2,6,9,10,13	1,2,6,9,10,13	6
3	3,4,5,6,7,8,9,10,11,12,13,14	1,2,3,4,5,6,9,10	3,4,5,6,9,10	6
4	3,4,5,7,8,9,10,11,12,13,14	1,2,3,4,5,6,10,14	3,4,5,10,14	5
5	1,3,4,6,7,14	1,2,3,4,6,8,9,10	1,3,4,6	4
6	1,2,3,4,5,6,7,8,9	1,2,3,5,6,9,10	1,2,3,5,6	5
7	7,8,12	1,2,3,4,5,6,7,13	7	2
8	1,5,8	1,2,3,4,6,7,8,9,10,13	1,8	3
9	1,2,3,5,6,8,9,10,12,13,14	1,2,3,4,6,9	1,2,3,6,9	5
10	1,2,3,4,5,6,8,10,11,12,13,14	1,2,3,4,9,10	1,2,3,4,10	5
11	11,14	1,2,3,4,10,11	11	2
12		1,2,3,4,7,9,10		1
13	2,7,13	1,2,3,4,9,10,13	2,13	3
14	4,14	1,2,3,4,5,9,10,11,14	4,14	3

marketing channels(C12), economic performance(C13) are the economic indicators, (b)sustainability consciousness(C7), infrastructure projects(C11), social responsibilities(C14) are within social dimension. Under this situation, these indicators don't have substantively influenced on other indicators, which could be improved in the long term.

4.6. Reachability matrix and interpretive structural model

With the matrix of impact among influencing indicators in Table 7, threshold (0.115), can be obtained by averaging all the items in the entire relation matrix. The reachability matrix created by eliminating items with values that are smaller than threshold as in Table 8.

In the structural model, a component with identical values can be assigned the same hierarchical position. With the similar vein, all the indicators were iterated to reach various levels of estimation. Table 9 shows that all the indicators could be decomposed into seven levels.

The reachability matrix of ASSCM is constructed based on the threshold value. The indicators are illustrated in Fig. 3 by using the ISM approach. Marketing channels(C12), sustainability consciousness(C7), and infrastructure projects(C11) are less significant than the other eleven indicators. Sustainable design(C8), economic performance (C13), social responsibilities(C14) are at level IV. Stakeholders' pressures/requirement(C5) are at level V. Green technology(C4), customer demand/requirement(C6), agricultural product quality and safety(C9), profits(C10) are at level III. There are three issues at the bottom of the hierarchy, government supervision(C2) and government subsidies(C3) are at level VI, and environmental legislation(C1) is the most critical driving indicator, which is at level VII, influencing all other items above.

5. Comparative analysis

It is essential to perform a comparative analysis to show the validity and reliability of this technique. Since WINGS is a structural technique for estimating the interrelationships between complex indicators, which is derived from DEMATEL, so we compare the proposed method with DEMATEL. The results of DEMATEL with rough-fuzzy logic show in Table 10 and 11. The values of H-L show that there is no difference in dividing the indicators into cause and effect group. In accordance with values of H + L, the sequence of the classical DEMATEL method is C12 > C11 > C13 > C14 > C8 > C10 > C7 > C6 > C5 > C9 > C3 > C4 > C2 > C1, and the result of WINGS is C12 > C11 > C14 > C13 > C6 > C8 > C7 > C10 > C9 > C5 > C4 > C3 > C2 > C1. These results show that the sequence of four indicators (C1, C2, C7, C11 and C12) is similar in our approach, but the ranking of the other indicators is divergent in both methods. The reason for this discrepancy is that the WINGS technique takes the strength of the indicators themselves into account, while DEMATEL neglects these components, so the WINGS method is more applicable and precise.

6. Conclusion and implications

6.1. Conclusions

In order to distinguish the interrelationships of the indicators in ASSCM, the current study proposed an integrated rough-fuzzy WINGS-ISM method, which solved the limitations of subjective and the intricate indicators, extended the application of WINGS method. In the rough-fuzzy WINGS-ISM method, the fuzzy logic can deal with the information obtained from experts, which is generally vague, inadequate, unclear, and inaccurate data; the rough set method can aggregate the fuzzy judgements of the group since it can deal with the diversification and

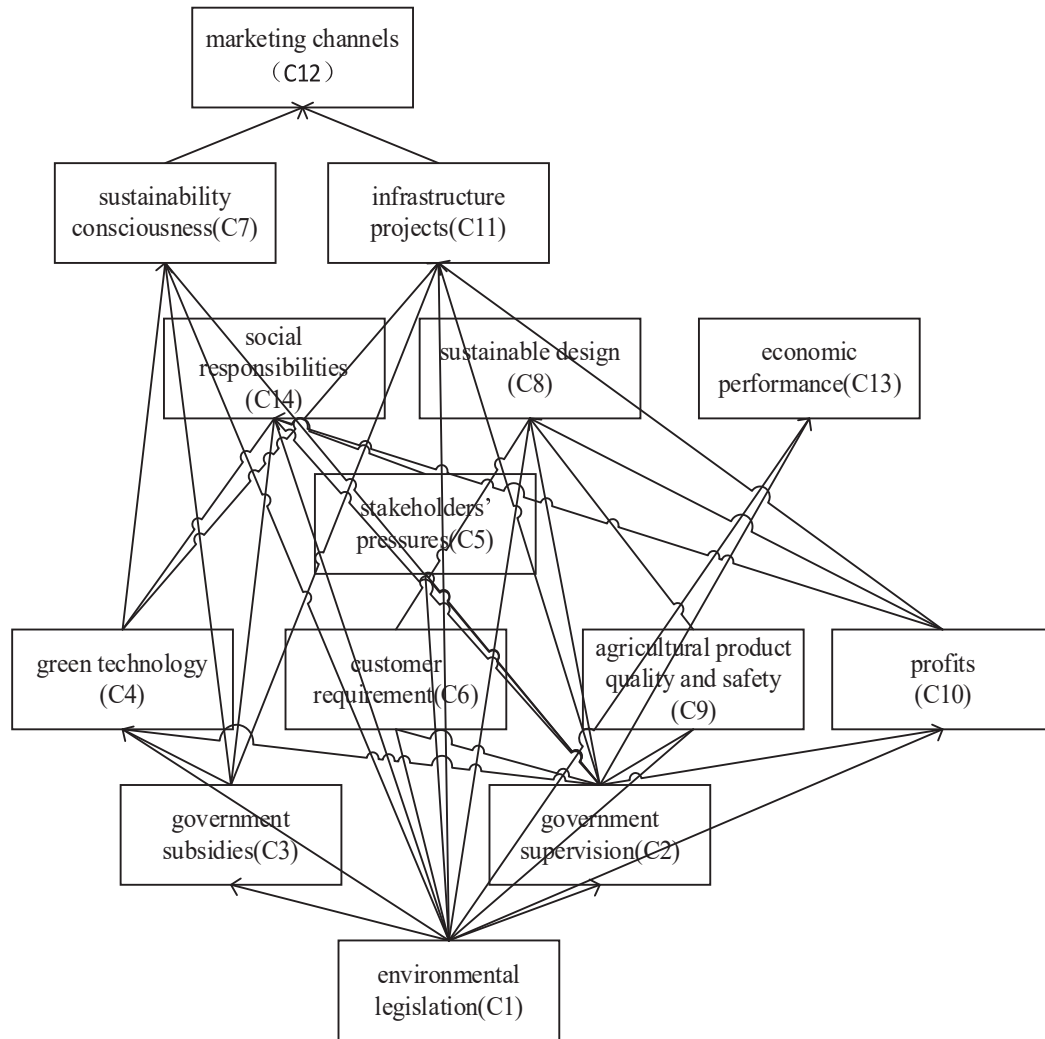


Fig. 3. The structure of indicators in ASSCM.

**Table 10**  
The impact among influencing indicators by DEMATEL.

	H	L	H + L	H-L
C1	0.1374	0.1166	0.2540	0.0207
C2	0.1378	0.1104	0.2481	0.0274
C3	0.1230	0.1177	0.2407	0.0053
C4	0.1249	0.1147	0.2396	0.0102
C5	0.1090	0.1213	0.2303	-0.0123
C6	0.1133	0.1069	0.2202	0.0064
C7	0.1053	0.1187	0.2240	-0.0134
C8	0.1053	0.1175	0.2228	-0.0122
C9	0.1196	0.1085	0.2281	0.0111
C10	0.1230	0.1027	0.2258	0.0203
C11	0.1011	0.1125	0.2135	-0.0114
C12	0.0933	0.1143	0.2076	-0.0210
C13	0.1023	0.1159	0.2182	-0.0136
C14	0.0993	0.1168	0.2161	-0.0175

subjectivity of all types of DMs. WINGS analyzes the cause-effect relationship between the influencing indicators by constructing the strength-influence matrix. ISM method could classify the indicators into hierarchical structure by visualizing the structure graphically.

Furthermore, these processes can scientifically reveal the interrelationships among influencing indicators and identify the significant causal indicators, thus provide a theoretical basis for this study. This paper contributes to ASSCM a complete evaluation method for identifying the relationship structure by employing the proposed integrated method in an ambiguous and uncertain environment. The findings of this technology can provide reference for development of ASSCM.

ASSCM is influenced by circumstances such as environmental variations, economic crisis and social impact for agricultural production or transportations. These relevant indicators have played an important role for strategic and managerial decision making in ASSCM. The proposed model contributes helps to evaluate and analyze the indicators by integrating economic, social, and environmental indicators. The outcomes of this model can be utilized by managers to re-evaluate strength and relationship of various indicators of ASSCM for making appropriate decisions in practice. According to the findings of the empirical analysis, environmental legislation(C1), government supervision(C2) and government subsidies(C3) are concentrated on all indicators, which are the crucial and driving influencing indicators in ASSCM. Complete and effective environmental legislation is necessary for every process in the ASSCM to remain sustainable. Government supervision can eliminate undesirable practices in the current agricultural business environment.

**Table 11**  
The sums of impact among influencing indicators by DEMATEL.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	0.0006	0.0097	0.0105	0.0104	0.0104	0.0096	0.0112	0.0115	0.0100	0.0095	0.0108	0.0108	0.0108	0.0115
C2	0.0097	0.0006	0.0101	0.0108	0.0112	0.0089	0.0108	0.0120	0.0096	0.0099	0.0108	0.0115	0.0108	0.0112
C3	0.0081	0.0088	0.0005	0.0088	0.0104	0.0092	0.0093	0.0108	0.0093	0.0100	0.0088	0.0095	0.0092	0.0104
C4	0.0088	0.0081	0.0093	0.0005	0.0109	0.0085	0.0100	0.0100	0.0093	0.0103	0.0099	0.0091	0.0099	0.0103
C5	0.0100	0.0084	0.0096	0.0096	0.0005	0.0084	0.0092	0.0073	0.0076	0.0060	0.0072	0.0072	0.0077	0.0103
C6	0.0093	0.0096	0.0096	0.0088	0.0101	0.0005	0.0096	0.0084	0.0100	0.0064	0.0081	0.0084	0.0080	0.0065
C7	0.0083	0.0080	0.0077	0.0076	0.0085	0.0076	0.0005	0.0092	0.0076	0.0068	0.0084	0.0088	0.0084	0.0080
C8	0.0088	0.0075	0.0076	0.0088	0.0088	0.0076	0.0081	0.0005	0.0068	0.0076	0.0076	0.0088	0.0084	0.0084
C9	0.0108	0.0092	0.0097	0.0085	0.0097	0.0096	0.0085	0.0095	0.0005	0.0091	0.0081	0.0092	0.0085	0.0088
C10	0.0108	0.0092	0.0104	0.0097	0.0105	0.0092	0.0089	0.0085	0.0085	0.0005	0.0096	0.0093	0.0096	0.0085
C11	0.0075	0.0079	0.0087	0.0079	0.0079	0.0072	0.0080	0.0076	0.0068	0.0060	0.0004	0.0068	0.0087	0.0096
C12	0.0072	0.0068	0.0075	0.0068	0.0065	0.0065	0.0072	0.0069	0.0082	0.0071	0.0079	0.0004	0.0079	0.0064
C13	0.0088	0.0088	0.0088	0.0080	0.0085	0.0072	0.0092	0.0077	0.0072	0.0068	0.0076	0.0068	0.0005	0.0064
C14	0.0080	0.0080	0.0076	0.0084	0.0076	0.0072	0.0080	0.0076	0.0072	0.0068	0.0072	0.0076	0.0076	0.0004

Government subsidies is a key factor driving the development of ASSCM. Through its authority, the government can regulate the business environment and guide the development of ASSCM. For the government, exploring and assessing ways to improve ASSCM is a critical responsibility.

The following are the causes as the basis of the traditional supply chain, including the green technology(C4), customer demand/requirement(C6), agricultural product quality and safety(C9), and profits(C10). The development of technology has not only reduced the cost of agricultural products, but has also improved the quality of the products, which could satisfy customer requirements and generate profits. Over the past decades, the world has made historic achievements in economic and social development, but it has also been affected by the the impact of overconsumption in resources and environment. Economic and social activities must respect and conform the principle of nature, which would promote the world economic and social sustainable progress. In the face of the limited resources and dynamic environment, the ASSCM must be developed with the indicators as stakeholders’ pressures/requirement (C5), sustainable design (C8), economic performance (C13), social responsibilities (C14), and sustainability consciousness (C7), which can ensure the stability and effectiveness of ASSCM to break through the limitations mentioned above. Furthermore, infrastructure projects (C11) and marketing channels (C12) can also provide basic support for the quality and safety of ASSCM. Therefore, some key insights of this paper suggest that decision makers and managers can improve a more accurate MCDM system to focus on evaluating the influencing indicators to ensure the development of ASSCM.

**6.2. Managerial implications**

First of all, improving the system and supervision mechanism is essential for ASSCM. The resent spread of the COVID-19 pandemic and the Russian-Ukrainian conflict have created challenges for the supply chain, especially the agricultural supply chain. Government supervision and licensing are important for the development of ASSCM. Laws and regulations for sustainable development should be improved to meet the various challenges. Depending on the local situation, local governments should implement feasible government supervision mechanisms, such as revising and improving the ASSCM certification system, government departments linkage mechanism, the ASSCM monitoring mechanism etc. Furthermore, governments could raise the subsidies and reduce taxes for farmers and agricultural enterprises to vigorously promote the development of ASSCM.

Secondly, the investment should be concentrated in science and technology for sustainable development of ASSCM. The financial investment is suggested to establish more agricultural research institutes and strengthen the interdisciplinary cooperation with the universities and high-tech companies to optimize agricultural product quality and safety, meet the customer demands, reduce the cost, and increase

profits. Additionally, banks, insurance, and other financial departments should provide financial support for the development of ASSCM.

Finally, the publicity mechanism and communication platform of ASSCM should be optimized by sustainable principles. An advocacy mechanism and communication platform are recommended to motivate stakeholders to support sustainable design. The sustained economic performance, social responsibility, and environmental awareness need more attention to enhance the development of ASSCM.

**7. Limitation and future study**

As environment is changing and the technology is advancing, the indicators and relationships within them may be more and more complicated, the indicators and relevant investigation data may be influenced by these variations, which need further exploration to catch the changing trends. Furthermore, several ways could be extended in the future. Firstly, other applications may be used this technology, such as risk management, waste management, supplier selection, transportation and so on. Secondly, other types of fuzzy extensions could be brought in, containing neutrosophic set, type-2 fuzzy numbers, intuitive fuzzy numbers, D numbers and so on. Thirdly, the WINGS method could be combined with more methods like entropy, TOPSIS, ELECTRE and TODIM for managing the ambiguity, subjectivity, and inaccuracy in the MCDM process.

Data Availability.

The data used to support the conclusions of this study are accessible upon request from the corresponding author.

**CRedit authorship contribution statement**

**Muwen Wang:** Conceptualization, Methodology, Formal analysis, Software. **Yiwen Zhang:** Writing – review & editing. **Yuan Tian:** Data curation, Writing – original draft. **Kecheng Zhang:** Supervision.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Data availability**

Data will be made available on request.

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