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Assessment of the agriculture supply chain risks for investments of agricultural small and medium-sized enterprises (SMEs) using the decision support model

Tao Zhai[a], Daqing Wang[b,c], Qi Zhang[d], Parvaneh Saeidi[e] and Arunodaya Raj Mishra[f]

[a]College of Economics and Management, Northeast Agricultural University, Harbin, Heilongjiang, China; [b]Haikou University of Economics, Haikou, Hainan, China; [c]Heilongjiang Agricultural Reclamation Management Cadre College, Harbin, China; [d]International Cultural and Educational College, Northeast Agricultural University, Harbin, Heilongjiang, China; [e]Facultad de Ciencias Adminsitrativas y Económicas, Universidad Tecnológica Indoamérica, Quito, Ecuador; [f]Department of Mathematics, Government College Raigaon, Satna, Madhya Pradesh, India

ABSTRACT

A key challenge in responding to the emerging challenges in agri-food supply chains is encouraging continued new investment. This is related to the recognition that agricultural production is often a lengthy process requiring ongoing investments that may not produce expected returns for a prolonged period, thereby being highly sensitive to market risks. Agricultural productions are generally susceptible to different serious risks such as crop diseases, weather conditions, and pest infections. Many practitioners in this domain, particularly small and medium-sized enterprises (SMEs), have shifted toward digitalization to address such problems. To help with this situation, the current paper develops an integrated decision-making framework, with the Pythagorean fuzzy sets (PFSs), the method for removal effects of criteria (MEREC), the rank-sum (RS) and the gained and Lost dominance score (GLDS) termed as PF-MEREC-RS-GLDS approach. In this approach, the PF-MEREC-RS method is applied to compute the subjective and objective weights of the main risks to assess the agriculture supply chain for investments of SMEs, and the PF-GLDS model is used to assess the preferences of enterprises over different the main risks to assess of the agriculture supply chain for investments of SMEs. An empirical case study is taken to evaluate the main risks to assess the agriculture supply chain for SME investments. Also, comparison and sensitivity investigation are made to show the superiority of the developed framework.

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1. Introduction

The global demand for food is increasingly growing with the current rate of population growth and increasing consumption; in this regard, the agricultural sector plays

CONTACT Daqing Wang wangdaqing511@163.com

a leading role in satisfying future food requirements (Misra et al., 2022; Pawlak & Kołodziejczak, 2020; Yazdani et al., 2021). Through historical time frames, considerable intensification in agricultural production has occurred. As statistics indicate, from 1961 to 2011, the transformation of raw ingredients into food products and global agricultural production has almost tripled (Alexandratos & Bruinsma, 2012). Sustainable agriculture refers to producing long-term crops and livestock while generating minimum environmental emissions by maintaining an acceptable proportion between food generation and ecological conservation (Siebrecht, 2020; Umesha et al., 2018). Natural resources have been used as the basis for producing food and a variety of services (Esposito et al., 2018; Lopez-Morales et al., 2020). In a basic definition, environmental sustainability refers to the potential and perceived influence the agricultural sector exerts upon the environment. In addition, economic and social sustainability are two inherent parts of this context.

The agricultural sector significantly affects both human capacity and animal welfare (Al-Dakhil et al., 2021; Ito et al., 2021; Nouman et al., 2021; Streimikis & Saraji, 2022; Zdeněk et al., 2022; Zhou et al., 2022). This covers working conditions and also the agricultural participants' psycho-physical health status. A sustainable economy is capable of continuing its operations to be profitable (El Amrani et al., 2021; Rai et al., 2021). Accordingly, supply chain management in the agriculture sector needs to maintain materials flow, i.e., activities such as processing the units for the delivery of completed products to consumers. Agricultural supply chain management comprises some organizations that are responsible for producing and distributing the products (Gardas et al., 2019; Li, 2011). In addition to the labour market problems, horticultural production, which contributes considerably to the fresh food supply chains, is suffering from serious problems. All over the globe, numerous major ports are congested with reefer containers that cannot be shipped because of trade restrictions. As a result, the authorities have to divert the shipments to minor ports, which leads to a significant loss of the revenues of logistics providers (Hey, 2020).

The agricultural products supply chain is the process of acquisition, processing, transportation, distribution of agricultural products, and delivery to ultimate consumers in a supply-demand network that is made up of farmer households, manufacturers, wholesalers, and retailers and ultimate consumers based on the management of the flow of goods, funds, and information by the core company (Fu et al., 2010). On the other side, the majority of the third-world and developing countries have a serious dependency on the import of agricultural products' consequently, the agricultural supply chains (ASCs) in such countries are subjected to different risks (Sharma et al., 2020). As a matter of fact, food demand/supply has a direct connection with the food security aspects; for that reason, worldwide food security is at a global-scale risk (Siche, 2020). Restricting people in regard to their work and socialization has rigorously impaired economic activities, particularly in the services and the agricultural sectors (Barichello, 2020). It is obvious that ASCs are labour-intensive for meat products, fisheries, and high-value crops; the COVID-19-induced restrictions and lockdown cases are harshly affecting the labour market. The great shock in the labour market, arising from the movement restrictions on migrant labourers, seriously influences their capability of harvesting and processing the agricultural products.

Many researchers have considered these changes and focused on risk management in the context of ASC. Yan et al. (2015) investigated how to sustainably develop a fresh agricultural product (FAP) supply chain. They made use of the radio frequency identification (RFID) technology in the revenue-sharing contract. On the other hand, the study of Rohmah et al. (2015) was concentrated on the organic rice product; they applied the fuzzy failure mode and effects analysis (FMEA) method to the determination of the risks that exist in ASC, for example, the risk of damage or lost quality and product contamination. Huh and Lall (2013) examined random variables such as water and weather; they concentrated on the consequences of the decisions made by farmers regarding the previous risks. Hovelaque et al. (2009) made some analyses on various economic consequences of the controlled supply process in agricultural cooperation and attempted to understand how to best address the risks of price uncertainty.

No one in this domain can ignore the risks that may arise in ASCs. There is a need for the optimization of the market systems of agricultural products. The firms working in this realm have started to understand the serious impacts of supply chain (SC) risks, and many of them have taken into action some measures to address them effectively. Researchers and practitioners have implemented various techniques/methods to investigate the SC risks from various viewpoints to propose more effective measures against such risks. As a result, there is a need for the development of proper methods applicable to the problems that may arise in ASCs. A number of researchers, such as Hardaker et al. (2015) and (Backus et al., 1997), have started some initial research into how to manage risks in the agriculture sector at the farm level. Within a general setting of supply chain management (SCM), Tang (2006) categorized four aspects (supply, demand, product, and information management) of SCM in order to address the risks effectively and examine the qualitative/quantitative approaches proposed in the literature in this regard. The ASC domain consists of many risk sources, some of which are attributed to logistics, demand, weather, infrastructure, political issues, policies, financial issues, as well as biological and environmental problems (Reytar et al., 2014).

The most important factors influencing the sustainability and safety of the SCs operations are the internal and external risks of the SC system. These two factors influence the ability to respond effectively to customers and satisfy their requirements. This has directed the attention of several researchers towards the issues related to the risk control of SC. The SC risk is, in fact, the instability or breakdown of the whole SC system induced by different negative factors that can influence the operation processes of these systems. In addition, these risks could be attributed to the changes that may occur in the external environment of SC, for instance, the changes to the natural, political, economic, and legal environment. These risks can also be induced due to the susceptibility of cooperative management amongst the different nodes that exist within an SC system (e.g., information processing, mode of cooperation, and management level). Closer the links between firms in SC, the greater the impact of the problems in any link of SC on the whole SC. Any interruptions in the supply or demand could result in the failure of SC in most cases. As a result, it is of high importance to carry out further research on SC risk control. Accordingly, the current study aims to address the complexities of ASC risks. This article proposes a methodology for the assessment of the ASC risks, which could be taken into account when making the decision about the investment in any small and medium-sized enterprises (SMEs) in the agriculture sector.

Atanassov (1986) proposed the theory of intuitionistic fuzzy sets (IFSs) that was characterized by the belongingness degree (BD) and non-belongingness degree (ND); it fulfils the constraint that the sum of the BD and ND is less than or equal to 1. On the other hand, some conditions in the decision-making problems may appear where decision experts (DEs) allocate the value of 0.8 when an alternative satisfies the attribute and the value of 0.5 in cases where the alternative dissatisfies it. In this condition, $0.8 + 0.5 > 1$, and IFS cannot well address this situation (Mishra et al., 2022; Yager, 2014). To cope with this challenge, the idea of Pythagorean fuzzy sets (PFSs) was suggested by (Yager, 2014). PFSs satisfy the constraint that the square sum of BD and ND is less than or equal to 1. As a result, compared to IFSs, PFSs have more robustness when describing the nature of ambiguity. Because of the exclusive advantages of PFSs, Zhang and Xu (2014) suggested the basic operations of Pythagorean fuzzy numbers (PFNs) with the aim of solving the problems associated with group decision-making processes. Today's environment is overwhelmed by the ever-increasing complexity and many wide-ranging challenges. Different scholars have attempted to develop several multi-criteria decision-making (MCDM) approaches to address such a situation. For instance, Wu and Liao (2019) developed the gained and lost dominance score (GLDS) method for the solution of the MCDM problems. Their proposed method chooses the best alternative(s) through the computation of the dominance flow between any two alternatives concerning the attributes. Note that the alternative with a higher gained dominance score and lower lost dominance score is considered the best. Liao et al. (2019) employed the GLDS integrated method in order to propose a model for evaluating the life satisfaction of people living in an earthquake-hit region.

Traditional MCDM methods have been developed for decision-makers to make the right decision. However, in most decision-making processes, the judgment and experience of decision-makers should also be taken into account. Fuzzy sets theory can be employed to allow this matter. The methodology proposed in this study is related to neutrosophic sets that are an extension of fuzzy sets. Thus, it is aimed to make more flexible and realistic decisions (Ecer & Pamucar, 2021). In the proposed MCDM methodology, the 'method based on the removal effects of criteria (MEREC)' method is used to determine the objective weighting coefficients. The MEREC methodology proposed by Keshavarz-Ghorabaee et al. (2021) is used the variations in different alternatives' performances concerning each criterion by removal effects of each criterion on the aggregate performance of alternatives to determine the weights. Rani et al. (2022) presented a Fermatean fuzzy information-MEREC-additive ratio assessment (ARAS) method with the application in a food waste treatment technology selection problem. The rank sum (RS) method developed by Stillwell et al. (1981) is used the ranking values of selected criteria with the help of the decision maker opinions. Hezam et al. (2022) introduced a hybrid MCDM methodology by combining the 'MEREC-rank sum (RS)-DNMA (double normalization based multiple aggregation)' approach with IFSs and applied to evaluate the 'alternative fuel vehicles (AFVs)' problem.

To take the flexibility and efficacy of PFSs, the paper aims to introduce an innovative discrimination measure and discuss its elegant properties. Accordingly, the GLDS framework was developed in order to evaluate the MCDM problem on PFSs. Because PFSs are both flexible and efficient, the current paper is focused on the PFSs environment. On the other hand, the new methodology of the PF-MEREC-RS weight finding technique to compute the weights or significance degrees of main risks to assess the agriculture supply chain for investments of SMEs. Then, the GLDS method is a new elegant approach to handling the MCDM problems. Thus, in this study, we have developed a new approach to the MCDM method using the PF-MEREC-RS and PF-GLDS methods and further implemented it for the evaluation of the risks to assess the agriculture supply chain for investments of SMEs. The primary outcomes of the developed work are given by

- To identify the main risks to assess the agriculture supply chain for investments of SMEs using current literature review and experts' opinions.
- To present a comprehensive framework to assess the risks in the agriculture supply chain for SME investments using a new Pythagorean fuzzy-MEREC-RS decision-making approach to rank the enterprises.
- The PF-MEREC-RS approach is utilized to evaluate and rank the main risks to assess the agriculture supply chain for investments of SMEs.
- To present the sensitivity and comparison analyses to validate the integrated PF-MEREC-RS-GLDS approach.

The remainder of this paper is provided based on the following sections. Section 2 presents the literature review and related works on the main risks to assess the agriculture supply chain for investments of SMEs. Section 3 provides the proposed PF-MEREC-RS-GLDS approach and the basic concept of PFSs. Section 4 presents the study's results, the case study, sensitivity investigation, and comparative study. Finally, section 5 discusses the conclusion of the study.

2. Agricultural supply chains risks

Agriculture widely refers to the numerous ways through which crop plants and domestic animals sustain the human population on a global scale through the provision of food, bio-energy, industrial material products, etc. Agriculture covers wide-ranging activities, e.g., cultivation, horticulture, domestication, vegeculture, and arboriculture in addition to forms of livestock management such as mixed crop-livestock farming, transhumance, and pastoralism (Harris & Fuller, 2014). With the wide development of SCM on a global scale, several disruptions are continually occurring to the agri-food supply chain (AFSC) (Hosseini et al., 2019; Kamalahmadi & Parast, 2016). The risks to AFSC are complicated and could be categorized generally into two types: functional and disrupting (Choi et al., 2019; Xu et al., 2020). The former is related to the disorders that may occur in the AFSC functions on a daily basis, for instance, processing and demand's fluctuating, lead time of Agri products production, and the disrupting risks associated with low-frequency highly impacting actions (Ivanov, 2020; Kinra et al., 2020). As a result, the inadequate agri-food products and delaying of services propagated towards AFSC downstream result in the rippling effects and competitive disadvantages that may appear in the shape of performance degradation (Dolgui et al., 2020).

By definition, ASCs are 'the set of activities included in a 'farm to fork' progression, including activities such as farming (i.e., cultivation of land for crop production), processing/production, testing, packaging, warehousing, transportation, distribution, and marketing' (Tsolakis et al., 2014). ASCs generally have several stakeholders, e.g., food procurement, processing, and manufacturing companies, distribution and commercial companies, agents, food-service companies, hotels and restaurants, and grocers and retail companies (Sgarbossa & Russo, 2017). Several researchers have employed the term ASC based on the contexts of their research, for instance, post-harvest SC (Mvumi et al., 2016), food SC (Zirham & Palomba, 2016), agri-business SC (Bhagat & Dhar, 2011), agricultural value chains (Ho et al., 2018, 2019), and agriculture value chain (D. G. Brewin, 2016).

Nowadays, the vibrancy and unpredictability of the agricultural environment considerably increase the difficulty of making decisions about achieving economic survival (Lowe & Preckel, 2004). Both scholars and practitioners have made attempts in the domain of supply chain risk management (SCRM) to reduce the adverse impacts of such risks. Despite the fact that managing the risks has become even more important for ASCs because of many existing challenges that are accompanied by issues such as seasonality, supply spikes, perishability, and long supply lead times, the literature still lacks quantitative models applicable to agricultural products (Behzadi et al., 2018).

In the agriculture sector, one of the major challenges is how to make the most effective decisions under uncertainty. When performing upstream operations, the managers of agricultural companies face several qualitative and quantitative issues such as weather conditions, interregional disparities in climate, capital availability, soil quality, and seasonal factors (Weintraub & Romero, 2006). Further down the production chain, this market suffers from volatility, heterogeneity, and extreme sensitivity to financial/economic instabilities. Some of the above-noted factors could be measured based on accessible historical information, producers' experiences, or agricultural managers' predictions. The use of existing information could provide helpful suggestions and support the adaptation to the worldwide competitive pressures that are typically exerted by globalization, stringent regulations, climate change, variations in market demands, the unpredictability of prices, etc. Therefore, the literature indicates that by integrating the uncertain aspects, the managerial decision-making in the agriculture sector could constantly gain relevance at tactical, operational, and strategical levels of planning. Previous to the consumption of final products, ASC involves a number of operations; among them, the most important ones are activities such as producing, storing, processing, and distributing the products.

ASCs have experienced dramatic evolution in recent decades, and each partner in this system has been exposed to substantial changes. A number of researchers have discussed research contributions at the farm level. For instance, an operations research-oriented survey was conducted by Glen (1987) on the challenges and difficulties that generally arise in agricultural planning, particularly at the farm level. Considering the demands for logistics restructuring in agricultural supermarket docking, Ji et al. (2012) analysed agricultural supermarket docking from the perspective of enterprises. Regarding the particular background of the global agricultural production network, Mei and Shao (2011) examined how supermarkets affect the Chinese agricultural market. They also attempted to explore the changing trends of agricultural development and transformation in the context of China. Xie et al. (2013) investigated the key modes of Agricultural-Super Partnership, which included supermarket (as the core), cooperation mode, and mixed-mode. In addition, they provided a full discussion of the internal problems that exist in this domain. Long and Xu (2012) examined four commonly-implemented SC modes and the elements of farmers' perceived value in the docking of agricultural supermarkets. Then, they made a comparison among the modes from the perspective of modes. Wu and Zhang (2012) attempted to explore the factors affecting the willingness of vegetable growers to participate in 'super agriculture docking'.

Currently, we witness an increasing trend in the risks involved in ASCs, which is mainly due to the continual changes that occur to the agricultural market and also to the agricultural product characteristics (Leat & Revoredo-Giha, 2013; Sharma et al., 2020). There is a great need for risk assessment methods applicable to ASCs due to the fact that risks in this context are highly complex and diverse (Yan et al., 2017). The implementation of novel technologies in ASCs also causes the introduction of some new risks to these chains (Du et al., 2016; Feng et al., 2021). As a result, risk assessment methods should be selected considering the capacity of the methods in accurately assessing the indefinite risks and those causing substantial losses or fluctuations. Supply chain (SC) managers need to have a certain idea about the right time for restructuring and optimizing SC in a way to lower the SC maintenance costs as much as possible and also the right time for improving its value.

The SCs of various agricultural commodities in various countries (Newton et al., 2013) have faced many challenges that mostly stem from the inherent problems of this particular sector. The ASC system of a country is determined by various sartorial issues such as fragmented supply chains, the dominance of marginal farmers, lack of marketing infrastructure, the nonexistence of scale economies, and low processing/value addition (Mudda et al., 2017). It is clear that the agricultural sector has a significant contribution to the world economy (Anshari et al., 2019; Pawlak & Kołodziejczak, 2020); nevertheless, many external factors affect the generation of most products in this sector, e.g., seed quality, weather changes, and culture methods. These factors cannot be completely controlled by the SC members. The above-explained situation worsens by the fact that the production of agricultural products comprises a long lead time. Therefore, the production plan cannot be adjusted to changes that occur in the environment. Producers in this sector typically do not have enough market information and cannot be certain about the final output when they start the production procedures. They cannot decide exactly what and how much to produce, particularly in an environment of high uncertainty. In addition, the shortage and oversupply of agricultural products are ordinary issues in the agricultural market, which can decrease the profit of SC and negatively influence the SC members' enthusiasm for working in such context. Therefore, an important question in the ASC domain is: How to moderate the impacts of the fluctuations and share the risks in the ASC domain?

Ahumada and Villalobos (2009) evaluated the modern production and distribution planning models concerning various commodities of agri-food supply chains. They suggested a classification considering the features of highest relevance, for example, the type of agri-food commodity addressed, the optimization approach adopted (linear and stochastic programming), and the research objectives. Hayashi (2000) also re-examined the existing agriculture-oriented planning models and performed another critical survey by taking into account the MCDM. According to de Paulo Farias and Dos Santos Gomes (2020), COVID-19 has caused the health status of those involved in the ASCs to be at risk; as a result, the final links in the ASCs need to be more careful when handling food processing in a way avoid ASC contamination and spread of the disease. Derek Gerald Brewin (2020) discussed the risks to oilseed processors, which occurred because of potential labour shortages, resulting in several potential bottlenecks between crushers and millers, which obstructed the retail and distribution phase in ASCs. Zirham and Palomba (2016) identified and discussed different risks that hinder the sustainable generation and consumption of food during COVID-19. In another research, Torero (2020) attempted to specify the ASC disruptions and the way they affect food security. Stephens et al. (2020) discussed the abruptness of the virus spread and rigorousness of the contamination measures, e.g., lockdown and social distancing, which have left minuscule scope for the identification of ideal domestic substitutes in the short term but might spur a lesser amount of reliance upon the global agri-food value chains in the future because of the problems such as transparency and trust.

Hailu (2020) investigated the shocks in the supply and demand in the food production sector, which originated from a dramatic drop in the demand for processed foods because of the border closures and trade limits. Hobbs (2020) examined the different demand-side risks (changes to consumption patterns and consumers' panic buying behaviour) and supply-side risks (transport disruptions and labour shortages) in the food SCs in the course of the COVID-19 pandemic. Stockford (2020) discussed the influences of COVID-19 on the two phases of storing and transporting food, which could raise the costs of procurement and, consequently, potential delays in ASCs. Haley et al. (2020) studied different risks encountered by the migrant workers engaged in the ASCs and attempted to determine some preventive measures to make sure of the occupational health and safety of workers in this domain. Ker (2020) investigated the potential financial risks ASCs may encounter during the COVID-19 pandemic that has obstructed the agricultural trade and damaged the farmers' financial status. The study of Gray (2020) was focused on different COVID-19-induced transportation risks (for instance, limited movements of marine containers, labour issues, and regulatory closures of transportation services).

In recent years, a comprehensive literature review was carried out by Behzadi et al. (2018) on the mathematical models applied to the risks in agribusiness SC management and recommended some helpful directions for future studies. Their findings showed that amongst the risk modelling approaches applied to agricultural SC, stochastic programming is of the highest popularity; on the other hand, the most commonly adopted approach was the minimization of the total absolute deviation, particularly in crop and farm planning (Hazell, 1971; Scott & Baker, 1972). Regarding the supply-side risks, Schmitt and Snyder (2012) classified the risks into disruptions, capacity uncertainty, lead-time uncertainty, yield uncertainty, and input cost parameter uncertainty. In another study, Blanco et al. (2005) discussed uncertainty in yield and crop quality. Remember that most of the research carried out in the ASC is on the supply-side risks originating from weather conditions. In addition, mixed-integer linear programming, stochastic programming, multi-objective optimization, stochastic dynamic programming, and simulation are quantitative techniques that are applied to different types of ASC risk problems (Behzadi et al., 2018). On the other hand, based on our review of the existing literature, it lacks research evaluating the risks of flooding in crop areas considering multiple factors. Flooding affection, as considered in a global SC, could be reflected in manufacturing processes, transportation networks, and information centres more than damaging buildings in rural and urban regions (Deasy et al., 2014). Haraguchi and Lall (2015) maintained that with the increase of the impacts of natural disasters on the global SC, a variation occurs in the organizing, preparing, and preventing strategies of companies. Considering the Thailand floods that occurred in 2011, they investigated how the floods affected various firms and attempted to determine the factors in the top-level decision making, which can influence the members and the whole SC resilience (Chopra & Sodhi, 2014).

Our review of the ASC-related literature revealed that the ASC risks are exposed to different variations across the ASC phases. Such risks obstacle the ASCs' productivity and decrease their performance quality. The COVID-19 pandemic has severely affected food security and deteriorated community health and income (Deaton & Deaton, 2020). Except for a few risks, all other risk factors could be optimized in a way to improve the performance of ASCs. The current pandemic has caused substantial supply and demand issues for SCM and distribution systems (Gray, 2020). Some other significant risks, rather than the pandemic, have been induced by transportation challenges in the course of nationwide lockdowns, border closures, migrant labour-management challenges, and farm-financial instabilities (Ker, 2020). In addition, stakeholders that work on the processing, retail, and distribution sides of ASCs have been beaten by demand-side shocks (panic buying and stocking), transportation challenges, and supply shortages (Zirham & Palomba, 2016). During the current COVID-19 pandemic, ASCs need to adopt alternative strategies to improve their resilience capacities (Hobbs, 2020; Ker & Cardwell, 2020). Based on the above-presented discussions, the present paper determined the number of significant risks that should be taken into account when evaluating ASC in SMEs. Information security risk (r_1), Technical risk (r_2), Market environment risk (r_3), Distribution of risk (r_4), Supply fluctuation risk (r_5), Policy risk (r_6) Quality of supply chain risk (r_7), Risk in choosing suppliers and dealers (r_8), Information transfer risk (r_9), Structure of the supply chain risk (r_{10}), Natural risk (r_{11}), Transportation risk (r_{12}), Quality risk of the fresh agricultural products (r_{13}), Risk of deterioration for the fresh agricultural products (r_{14}), Risk management decision (r_{15}), Legislation risks (r_{16}), Credit risks (r_{17}), Inventory risk (r_{18}), Demand fluctuation risk (r_{19}), Political instability (r_{20}) and political instability (r_{20}).

3. Proposed PF-MEREC-RS-GLDS approach

First, we present basic notions to the PFSs.

Let V be a fixed set. A Pythagorean fuzzy set F on V is characterized by a belongingness grade $b_F : V \longrightarrow [0,1]$ and a non-belongingness grade$n_F : V \longrightarrow [0,1]$, satisfying a constraint $0 \leq (b_F(x_i))^2 + (n_F(x_i))^2 \leq 1$. It can be defined as

$$F = \{\langle x_i, (b_F(x_i), n_F(x_i))\rangle x_i \in V\}, \tag{1}$$

For each $x_i \in V$, $\pi_F(x_i) = \sqrt{1 - b_F^2(x_i) - n_F^2(x_i)}$ is known as a hesitancy degree. Additionally, Zhang and Xu (2014) discussed the Pythagorean fuzzy number (PFN), denoted by $\wp = (b_\wp, n_\wp)$, such that $b_\wp, n_\wp \in [0,1]$ and $0 \leq b_\wp^2 + n_\wp^2 \leq 1$. To compare the PFNs, the score and accuracy functions of $\wp$ are described by

$$\mathsf{S}(\wp) = \frac{1}{2}\left(\left((b_\wp)^2 - (n_\wp)^2\right) + 1\right) \quad \text{and} \quad h(\wp) = (b_\wp)^2 + (n_\wp)^2, \tag{2}$$

Next, this section develops a PF-MEREC-RS-GLDS method under the PFSs setting for solving decision-making applications. The calculation procedure of the proposed method is given by (see Figure 1)

Step 1: Generate a 'linguistic decision matrix (LDM)'.

A set of l decision experts (DEs) $A = \{A_1, A_2, \ldots, A_\mathsf{l}\}$ determine the sets of m options$E = \{e_1, e_2, \ldots, e_m\}$ and n criteria $R = \{r_1, r_2, \ldots, r_n\}$, respectively. Owing to the vagueness of the human mind, lack of data, and imprecise knowledge about the options, the DEs allocate PFNs to evaluate his/her decision on option e_i concerning a criterion r_j. Assume that $\mathsf{Z}^{(k)} = (\xi_{ij}^{(k)})_{m\times n}$, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$ is the LDM by DEs, where $\xi_{ij}^{(k)}$refer to the evaluation of an option e_i over a criterion r_j in the form of PFN given by kth expert.

Step 2: Compute the weights of DEs

To determine the DEs' weights, firstly, the importance degrees of the DEs are assumed as linguistic value (LVs) and then expressed by PFNs. To compute the kth DE, let $A_k = (b_k, n_k)$ be the PFN. Now, the expert weight is obtained by

$$\varpi_k = \frac{\left((b_k^2 - n_k^2) + 1\right)}{\sum_{k=1}^{\mathsf{l}}\left((b_k^2 - n_k^2) + 1\right)}, \quad k = 1(1)\mathsf{l}, \quad \varpi_k \geq 0 \quad \text{and} \quad \sum_{k=1}^{\mathsf{l}} \varpi_k = 1. \tag{3}$$

Step 3: Aggregate all 'Pythagorean fuzzy-decision matrix (PF-DMs)'

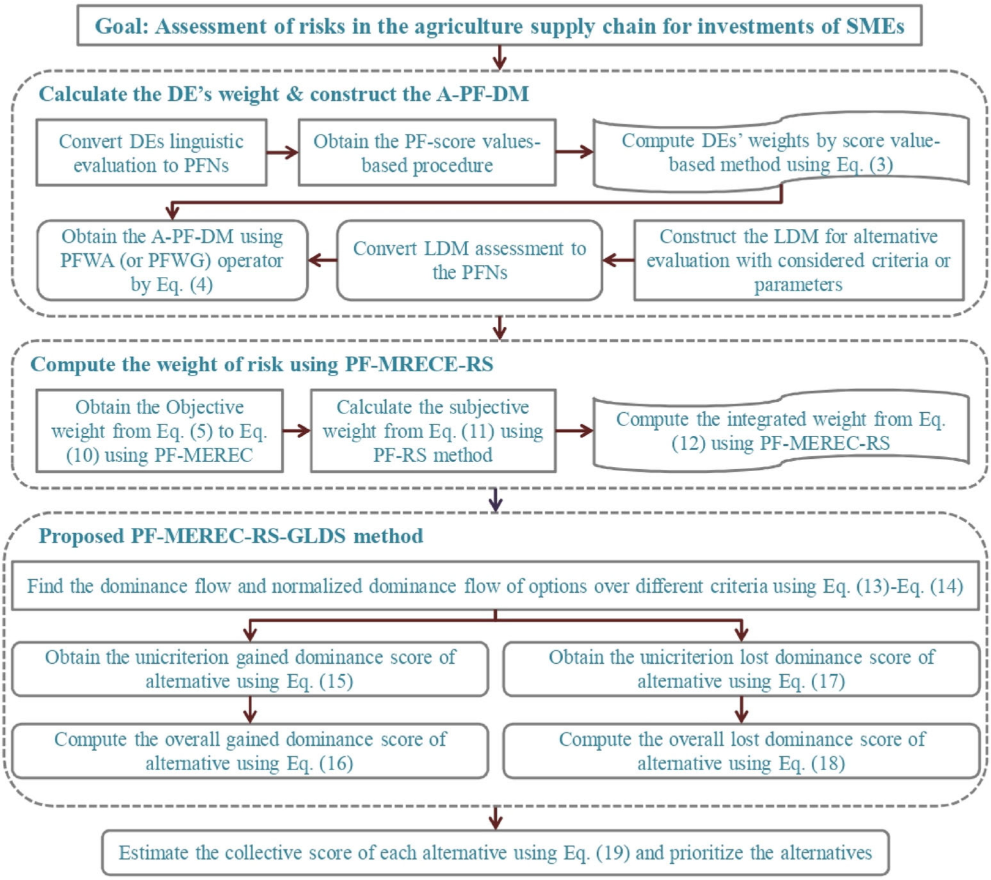

Figure 1. Flowchart of developed PF-MEREC-RS-GLDS model.
Source: Authors.

To create the aggregated PF-DM (A-PF-DM), the 'Pythagorean fuzzy weighted averaging (PFWA)' operator is used, and then $Z = (\xi_{ij})_{m\times n}$, where

$$\xi_{ij} = (b_{ij}, n_{ij}) = PFWA_{\varpi}\left(\xi_{ij}^{(1)}, \xi_{ij}^{(2)}, \ldots, \xi_{ij}^{(l)}\right) = \left(\sqrt{1-\prod_{k=1}^{l}\left(1-b_k^2\right)^{\varpi_k}}, \prod_{k=1}^{l}(n_k)^{\varpi_k}\right). \tag{4}$$

Step 4: Proposed PF-subjective and objective weighting approach

Case I: Determination of objective weights by the method of PF-MEREC

All the criteria are not presumed to be of equal importance. Suppose $w = (w_1, w_2, \ldots, w_n)^T$ is the weight of the criterion set with $\sum_{j=1}^{n} w_j = 1$ and $w_j \in [0,\ 1]$. Now, to find the criteria weights, the classical MEREC (Keshavarz-Ghorabaee et al., 2021; Rani et al., 2022) model is extended under the PFSs environment. In the following, the procedure of the MEREC is presented by

Step 4a: Normalize the A-PF-DM.

In this step, a simple linear normalization is used to scale the elements of the A-PF-DM $Z = (\xi_{ij})_{m\times n}$ and generate the normalized A-PF-DM $\bar{R} = (\bar{y}_{ij})_{m\times n}$. If r_b shows the benefit-type criteria set and r_n represents the cost-type criteria set, then we utilize the following equation for normalization:

$$\bar{y}_{ij} = \left(\bar{b}_{ij}, \bar{n}_{ij}\right) = \begin{cases} \xi_{ij} = \left(b_{ij}, n_{ij}\right), & j \in r_b, \\ \left(\xi_{ij}\right)^c = \left(n_{ij}, b_{ij}\right), & j \in r_n. \end{cases} \tag{5}$$

Step 4b: Find the score matrix.

With the use of the following formula, the score matrix $\Omega = (\eta_{ij})_{m\times n}$ of each PFN ς_{ij} is calculated:

$$\eta_{ij} = \frac{1}{2}\left(\left(\bar{b}_{ij}\right)^2 - \left(\bar{n}_{ij}\right)^2 + 1\right). \tag{6}$$

Step 4c: Compute the overall performance of the alternatives.

This step involves the use of a logarithmic measure with equal criteria weights for the achievement of the overall performance of the alternatives at this step. Based on the normalized values achieved in step 4 b, it can be ensured that the smaller values of η_{ij} result in greater performance values. For this computation, Eq. (7) is employed as follows:

$$S_i = ln\left(1 + \left(\frac{1}{n}\sum_j \left|ln\left(\eta_{ij}\right)\right|\right)\right). \tag{7}$$

Step 4d: Calculate the performance of the alternatives by removing each criterion.

This step involves the implementation of the logarithmic measure in a similar way to the former step. The difference between this step and Step 4c is that the alternatives' performances are calculated based on the removal of each criterion separately. As a result, there will be n sets of performances accompanied with n criteria. Let us signify by S_i' the overall performance of the ith alternative considering the removal of jth criterion. The following equation is used for the calculations of this step:

$$S'_{ij} = ln\left(1 + \left(\frac{1}{n}\sum_{k,\, k\neq j} \left|ln\left(\eta_{ik}\right)\right|\right)\right). \tag{8}$$

Step 4e: Compute the summation of absolute deviations.

This step computes the jth criterion's removal effect considering the values achieved from Steps 4c and 4d. Here, V_j stands for the effect of removing the jth criterion. Equation (9) can be used to compute the values of V_j :

$$V_j = \sum_i \left| S'_{ij} - S_i \right|. \tag{9}$$

Step 4f: Specify the weights of the final criteria.

Here, the objective weight of each criterion is computed using the removal effects (V_j) of step 4e. In The following equation, w_j^o. Equation (10) is used to calculate w_j^o (which denotes the weight of jth criterion):

$$w_j^o = \frac{V_j}{\sum_{j=1}^{n} V_j}. \tag{10}$$

Case II: Determine the subjective weights by the PF-RS method

The subjective weighting system helps reflect the decision makers' thoughts and core values. It is hoped that these procedures could help not only to consider the alternatives taken but also to show the significance of the prevailing criteria. When the best choice of a given problem is to be selected, the opinions of the decision-makers regarding each alternative with dependent criteria are of high importance. Decision-makers in such important situations typically give their subjective weight. Here, the procedure of the rank-sum weight method helps the decision-makers to reveal their ranking values for selected criteria (Hezam et al., 2022; Stillwell et al., 1981). In the following, the formula of this method is presented:

$$w_j^s = \frac{n - r_j + 1}{\sum_{j=1}^{n} (n - r_j + 1)}, \tag{11}$$

where w_j^s represents the weights for each criteria j and n represents the number of criteria, r_j denotes the rank of each criterion, $j = 1,2,3, \ldots ,n$.

Case III: Integrated weights using the objective and subjective weights:

In A-PF-DM, the decision-maker wants to utilize both subjective and objective weights, for the following integrated weighted equation is given.

$$w_j = \gamma w_j^o + (1 - \gamma) w_j^s \tag{12}$$

where $\gamma \in [0, 1]$ is an strategic factor.

Step 5: Construct the dominance flows

Let $\bar{y}_{ij} = (b_{ij}, n_{ij})$and $\bar{y}_{vj} = (b_{vj}, n_{vj})$ be two PFNs for two alternatives e_i and e_v under the criterion r_j, respectively.

The dominance flow of the alternative e_i over e_v with respect to the criterion r_j is defined as:

$$DF_j(e_i, e_v) = \begin{cases} \mathsf{S}(\bar{y}_{ij}) - \mathsf{S}(\bar{y}_{vj}), & \text{if } \mathsf{S}(\bar{y}_{ij}) \geq \mathsf{S}(\bar{y}_{vj}) \\ 0, & \text{if } \mathsf{S}(\bar{y}_{ij}) < \mathsf{S}(\bar{y}_{vj}) \end{cases} \tag{13}$$

where $\mathsf{S}(y_{ij})$ is the improved score function for PFNs.

We normalize the dominance flow by vector normalization, shown as

$$DF_j^N(e_i, e_v) = \frac{DF_j(e_i, e_v)}{\sqrt{\sum_{v=1}^{m} \sum_{i=1}^{m} \left[DF_j(e_i, e_v)\right]^2}} \tag{14}$$

Step 6: Calculate the gained dominance score (GDS) of e_i on all criteria

The uni-criterion gained dominance score (UGDS) of alternative e_i outranking all the other alternatives e_v $(v = 1, 2, \ldots, m$ and $v \neq i)$ under criterion r_j is calculated by

$$UGDS_j(e_i) = \sum_{v=1}^{m} DF_j^N(e_i, e_v) \tag{15}$$

The overall gained dominance score (OGDS) of alternative e_i is computed as:

$$OGDS_j(e_i) = \sum_{v=1}^{m} w_j \cdot UGDS_j(e_i) \tag{16}$$

Then, a subordinate rank set $\rho_1 = \{p_1(e_1), p_1(e_2), \ldots, p_1(e_m)\}$ is obtained in descending order of the values of $OGDS_j(e_i)$ $(i = 1, 2, \ldots, m)$.

Step 7: Calculate the lost dominance score (LDS) of e_i on all criteria

To depict the feature that alternative e_i does not always dominate e_v, the unicriterion lost dominance score (ULDS) of

Alternative e_i is adopted by employing the maximizing operator as:

$$ULDS_j(e_i) = \max_{v} \left(DF_j^N(e_v, e_i)\right) \tag{17}$$

Similarly, the overall lost dominance score (OLDS) of alternative e_i is determined by

$$OLDS_j(e_i) = \max_j \left(w_j \cdot DF_j^N(e_v, e_i) \right) \tag{18}$$

Then, another subordinate rank set $\rho_2 = \{p_2(e_1), p_2(e_2), \ldots, p_2(e_m)\}$ is obtained in ascending order of the values of $OLDS_j(e_i)$ $(i = 1, 2, \ldots, m)$.

Step 8: Compute the collective score (CS)

Normalizing the overall gained and lost dominance scores of alternatives by vector normalization, we obtain $OGDS^N(e_i)$ and $OLDS^N(e_i)$. The final rank set $\rho = \{p(e_1), p(e_2), \ldots, p(e_m)\}$ is derived in descending order of CS_i, where CS_i indicates the collective score of alternative s_i :

$$CS_i = OGDS^N(e_i) \cdot \frac{m - p_1(e_i) + 1}{(m(m+1)/2)} - OLDS^N(e_i) \cdot \frac{p_2(e_i)}{(m(m+1)/2)}; \quad i = 1(1)m. \tag{19}$$

4. Results and discussion

4.1. Case study

A key challenge in responding to the emerging challenges in agri-food supply chains is encouraging continued new investment. This is related to the recognition that agricultural production is often a lengthy process requiring ongoing investments that may not produce expected returns for a prolonged period, thereby being highly sensitive to market risks. One of the biggest agricultural producers in the world is China (Hopewell, 2019). During the past decade, China's agri-food SMEs and the vegetable sector have recorded fast growth rates (Lu et al., 2012). As indicated by statistics released by the National Bureau of Statistics of China, in 2009, China generated over 600 million tons of vegetables; one-fourth of this quantity was processed, and agri-food SMEs exported 1.5 percent. This study uses a comprehensive survey approach based on the interview with experts and current literature review to identify the main risks associated with the agriculture supply chain for investments in agricultural SMEs. In the first round of survey approach using literature review, 40 important risks related to supply chain in agricultural are identified. In the second round of this survey, the selected risks are presented in the format of the questionnaires and sent to more than 25 experts in academia. Results of this round of survey indicated that, in total, 25 of main agriculture supply chain risks are important for investments in agricultural SMEs. In the next round of study, we have invited ten DEs from academics and industry in the areas of agricultural SMEs and supply chain to evaluate these 25 selected risks. We have performed this stage of the study in the firms. The interviewees selected for this study were mostly chief executive officers (CEOs), general managers, and marketing managers. All the interviews held for the purpose of this paper were digitally recorded. The required data were collected in 2019 and 2020. Finally, we succeeded in holding with six SMEs located in China, and the collected

Table 1. Performance ratings of alternatives over criteria and DEs regarding the LVs.

LVs	PFNs
Absolutely high (AH)/ Extremely significant (ES)	(0.95, 0.20, 0.240)
Very very high (VVH)/ Very very significant (VVS)	(0.85, 0.30, 0.433)
Very high (VH)/ Very significant (VS)	(0.80, 0.35, 0.487)
High (H)/ Significant (S)	(0.70, 0.45, 0.554)
Moderate high (MH)/ Moderate significant (MS)	(0.60, 0.55, 0.581)
Moderate (M)/Average (A)	(0.50, 0.60, 0.624)
Moderate low (ML)/ Moderate insignificant (MI)	(0.40, 0.70, 0.592)
Low (L) / Very insignificant (VI)	(0.30, 0.75, 0.589)
Very low (VL) /Very very insignificant (VVI)	(0.20, 0.85, 0.487)
Absolutely low (AL)/ Extremely insignificant (EI)	(0.10, 0.95, 0.296)

Source: Authors.

Table 2. Weight of DEs to the risks to assess the agriculture supply chain for investments of SMEs.

DEs	LVs	PFNs	Score	Weights
A_1	S	(0.70, 0.45, 0.554)	0.6437	0.2343
A_2	VVS	(0.85, 0.30, 0.433)	0.8162	0.2971
A_3	VS	(0.80, 0.35, 0.487)	0.7588	0.2762
A_4	MS	(0.60, 0.55, 0.581)	0.5287	0.1924

Source: Authors.

data were exposed to empirical analyses. The following steps taken into action to use the PF-MEREC-RS-GLDS method are described.

Steps 1–3: Table 1 depicts the significance of the DEs and criteria in the form of 'linguistic values (LVs)' and then converted into PFNs. Table 2 presents the DEs weight based on Table 1 and Eq. (3). Table 3 describes the importance of DEs to evaluate the options and the assessments of options concerning each criterion.

The judgment provided by five DEs have been aggregated utilizing Eq. (4) into a A-PF-DM $Z = (\xi_{ij})_{m\times n}$, taking into effect the importance of individual DEs and is provided in Table 4.

Step 4: Since all the criteria are the same type, the A-PF-DM presented in Table 4 must be normalized. For the determination of the criteria weights using MEREC, the overall performances of the alternatives values were computed using Eq. (6); the results were as follow: $S_1 = 0.547$, $S_2 = 0.560$, $S_3 = 0.530$, $S_4 = 0.530$, $S_5 = 0.567$, and $S_6 = 0.572$. With the use of Eq. (7), the alternatives' overall performances (S'_{ij}) were determined through the removal of each criterion; they are presented in Table 5. Afterward, the removal effect of each criterion on the overall performance of the alternatives was calculated using the deviation-based formula of Eq. (8). The weight of each criterion was calculated considering the impact of their removal upon the performance V_j of the alternatives, using Eq. (9). With the help of Eq. (10) and the V_j values, the weights of the main risks were calculated to assess of the agriculture supply chain for investments of SMEs and are given in the last column of Table 5. The resultant values are in Figure 2.

Table 3. LVs by DEs to the risks to assess the agriculture supply chain for investments of SMEs.

	e_1	e_2	e_3	e_4	e_5	e_6
r_1	(MH,H,ML,VL)	(MH,H,ML,L)	(MH,H,M,M)	(MH,MH,M,H)	(M,VH,VH,H)	(L,H,L,M)
r_2	(ML,ML,M,M)	(M,M,VL,VL)	(ML,H,M,MH)	(ML,M,MH,M)	(L,M,MH,ML)	(MH,H,L,ML)
r_3	(M,H,MH,H,M)	(ML,H,H,VH)	(M,L,ML,H)	(M,M,VH,MH)	(MH,H,M,VH)	(MH,M,VL,M)
r_4	(M,M,MH,H)	(H,VH,M,H)	(L,L,ML,MH)	(H,L,MH,M)	(H,MH,L,VL)	(MH,L,L,H)
r_5	(H,M,MH,H)	(MH,M,H,H)	(MH,MH,L,M)	(VL,L,M,VH)	(M,VVH,H,H)	(ML,M,VL,MH)
r_6	(MH,H,MH,M)	(L,MH,VL,ML)	(H,VH,H,M)	(H,M,M,MH)	(L,M,M,ML)	(ML,MH,M,L)
r_7	(M,ML,MH,L)	(H,ML,ML,L)	(ML,L,MH,M)	(M,H,M,ML)	(M,M,VL,ML)	(H,VL,M,ML)
r_8	(MH,H,VH,VH)	(H,M,VVH,VH)	(MH,L,M,MH)	(L,M,H,ML)	(MH,H,L,VL)	(H,H,ML,VH)
r_9	(ML,MH,MH,H)	(ML,M,VH,H)	(M,M,ML,H)	(MH,L,VH,MH)	(M,VVH,H,M)	(ML,H,VH,M)
r_{10}	(ML,L,VH,H)	(ML,ML,MH,H)	(H,M,MH,ML)	(M,MH,ML,MH)	(MH,H,M,VL)	(ML,M,L,VL)
r_{11}	(H,M,ML, L)	(M,MH,ML,L)	(L,H,VH,M)	(VH,H,M,MH)	(M,MH,H,M)	(MH,M,L,VL)
r_{12}	(MH,ML,L,ML)	(M,L,MH,ML)	(H,H,VH,M)	(L,H,M,MH)	(M,MH,M,MH)	(H,H,ML,VL)
r_{13}	(MH,H,M,H)	(MH,M,H,H)	(M,M,MH,ML)	(ML,M,ML,M)	(ML,H,M,VL)	(VH,H,ML,L)
r_{14}	(ML,MH,M,H)	(ML,M,H,MH)	(H,L,MH,MH)	(VL,H,MH,M)	(H,VVH,H,M,H)	(ML,MH,VH,VL)
r_{15}	(M,VH,MH,M)	(M,L,VVH,H)	(H,M,ML,VVH)	(ML,L,H,MH)	(MH,L,M,M,ML)	(MH,H,MH,M)
r_{16}	(H,ML,ML,L)	(M,M,ML,VL)	(MH,MH,H,VH)	(ML,M,H,H)	(M,M,ML,L,L)	(MH,M,L,MH)
r_{17}	(M,ML,ML,M)	(H,ML,L,ML)	(VL,M,ML,M)	(L,ML,M,MH)	(M,L,M,VL,VL)	(M,H,MH,VL)
r_{18}	(MH,M,H,MH)	(M,H,MH,M)	(L,MH,MH,M)	(H,MH,M,H)	(VVH,H,M,H)	(MH,VH,VL,L)
r_{19}	(VH,MH,M,M)	(L,VVH,H,MH)	(M,ML,VVH,H)	(L,H,MH,MH)	(L,M,M,ML)	(H,MH,M,MH)
r_{20}	(ML,ML,L,ML)	(M,ML,VL,M)	(MH,H,VH,M)	(M,H,H,MH)	(M,ML,L,L)	(M,L,MH,L)
r_{21}	(ML,ML,M,MH)	(ML,L,ML,ML)	(M,ML,M,H)	(ML,M,MH,H)	(L,M,VL,VL)	(H,MH,VL,L)

Source: Authors.

From Eq. (11), we have calculated the subjective weights using the PF-rank sum (RS) weight procedure of each risk to assess the agriculture supply chain for investments of SMEs. The resultant values are given in Table 6 and shown in Figure 2.

From the algorithm of proposed PF-MEREC-RS method, we have to combining the PF-MEREC for objective weighting and PF-RS weight for subjective weighting by using Eq. (12). The integrated weight for $\tau = 0.5$ is shown in the Figure 1 and given as follows:w_j = (0.0581, 0.0625, 0.0447, 0.0420, 0.0289, 0.0635, 0.0589, 0.0457, 0.0514, 0.0532, 0.0275, 0.0347, 0.0381, 0.0427, 0.0618, 0.0689, 0.0755, 0.0393, 0.0331, 0.0370, 0.0325).

Here, Figure 2 shows the significant degree or weights of different risks to assess the agriculture supply chain for investments of SMEs with respect to the goal. Credit risks (r_{17}) with a weight value of 0.0755 have become the most important risk to assess the agriculture supply chain for investments of SMEs. Legislation risks (r_{16}) with a weight value of 0.0689 are the second most important risk to assess in the agriculture supply chain for investments of SMEs. Policy risk (r_6) has third with a significance value of 0.0635, technical risk (r_2) has fourth with a weight value of 0.0625, risk management decision (r_{15}) with a significance value of 0.0618 has the fifth most important risk to assess of the agriculture supply chain for investments of SMEs and others are considered crucial risk to assess of the agriculture supply chain for investments of SMEs.

Step 5: By using the score function Eqs. (13) and (14), the decision matrix is transformed into the score-valued decision matrix given in Table 7.

Steps 6–7: Based on the score-valued decision matrix, the overall gained dominance scores $OGDS$ (e_i) is calculated by Eqs. (15) and (16), while the overall lost

Table 4. A-PF-DM to the risks to assess the agriculture supply chain for investments of SMEs.

	e_1	e_2	e_3	e_4	e_5	e_6
r_1	(0.550, 0.602, 0.578)	(0.557, 0.588, 0.587)	(0.596, 0.540, 0.594)	(0.600, 0.542, 0.588)	(0.737, 0.417, 0.532)	(0.512, 0.617, 0.598)
r_2	(0.451, 0.651, 0.610)	(0.398, 0.706, 0.586)	(0.578, 0.562, 0.592)	(0.513, 0.607, 0.607)	(0.482, 0.636, 0.603)	(0.552, 0.591, 0.587)
r_3	(0.637, 0.509, 0.579)	(0.681, 0.476, 0.557)	(0.489, 0.633, 0.600)	(0.637, 0.508, 0.579)	(0.664, 0.487, 0.568)	(0.476, 0.647, 0.596)
r_4	(0.577, 0.554, 0.599)	(0.699, 0.452, 0.554)	(0.410, 0.693, 0.593)	(0.553, 0.585, 0.594)	(0.526, 0.622, 0.580)	(0.500, 0.632, 0.592)
r_5	(0.625, 0.518, 0.584)	(0.630, 0.514, 0.582)	(0.522, 0.609, 0.597)	(0.519, 0.627, 0.581)	(0.731, 0.427, 0.533)	(0.447, 0.674, 0.588)
r_6	(0.619, 0.527, 0.582)	(0.425, 0.699, 0.575)	(0.710, 0.441, 0.548)	(0.579, 0.552, 0.600)	(0.445, 0.651, 0.615)	(0.487, 0.633, 0.602)
r_7	(0.479, 0.640, 0.601)	(0.491, 0.640, 0.591)	(0.468, 0.649, 0.600)	(0.563, 0.567, 0.601)	(0.424, 0.680, 0.598)	(0.496, 0.641, 0.586)
r_8	(0.737, 0.419, 0.530)	(0.740, 0.418, 0.527)	(0.508, 0.618, 0.601)	(0.528, 0.601, 0.599)	(0.536, 0.614, 0.580)	(0.673, 0.484, 0.559)
r_9	(0.589, 0.560, 0.583)	(0.645, 0.507, 0.572)	(0.531, 0.592, 0.606)	(0.628, 0.532, 0.568)	(0.706, 0.451, 0.546)	(0.663, 0.492, 0.564)
r_{10}	(0.618, 0.542, 0.570)	(0.540, 0.602, 0.588)	(0.574, 0.564, 0.593)	(0.533, 0.600, 0.597)	(0.569, 0.577, 0.585)	(0.385, 0.707, 0.593)
r_{11}	(0.516, 0.611, 0.600)	(0.484, 0.637, 0.600)	(0.655, 0.500, 0.567)	(0.674, 0.477, 0.564)	(0.597, 0.540, 0.593)	(0.448, 0.669, 0.594)
r_{12}	(0.441, 0.674, 0.593)	(0.472, 0.645, 0.601)	(0.708, 0.444, 0.550)	(0.567, 0.571, 0.594)	(0.553, 0.575, 0.603)	(0.582, 0.575, 0.575)
r_{13}	(0.634, 0.511, 0.581)	(0.630, 0.514, 0.582)	(0.516, 0.603, 0.608)	(0.453, 0.649, 0.611)	(0.529, 0.611, 0.589)	(0.630, 0.529, 0.569)
r_{14}	(0.564, 0.574, 0.594)	(0.534, 0.597, 0.599)	(0.571, 0.575, 0.585)	(0.567, 0.583, 0.581)	(0.736, 0.422, 0.530)	(0.609, 0.559, 0.563)
r_{15}	(0.650, 0.499, 0.573)	(0.663, 0.501, 0.556)	(0.645, 0.512, 0.567)	(0.537, 0.604, 0.589)	(0.484, 0.628, 0.609)	(0.619, 0.527, 0.582)
r_{16}	(0.491, 0.640, 0.591)	(0.434, 0.669, 0.603)	(0.680, 0.477, 0.557)	(0.598, 0.544, 0.589)	(0.444, 0.654, 0.613)	(0.511, 0.615, 0.601)
r_{17}	(0.447, 0.655, 0.609)	(0.486, 0.643, 0.592)	(0.424, 0.679, 0.599)	(0.461, 0.651, 0.603)	(0.409, 0.686, 0.602)	(0.573, 0.575, 0.584)
r_{18}	(0.608, 0.534, 0.587)	(0.600, 0.538, 0.592)	(0.532, 0.601, 0.596)	(0.627, 0.517, 0.583)	(0.713, 0.443, 0.544)	(0.595, 0.576, 0.561)
r_{19}	(0.631, 0.515, 0.580)	(0.701, 0.467, 0.539)	(0.673, 0.491, 0.554)	(0.592, 0.557, 0.582)	(0.445, 0.651, 0.615)	(0.605, 0.538, 0.587)
r_{20}	(0.376, 0.713, 0.591)	(0.412, 0.692, 0.593)	(0.688, 0.465, 0.557)	(0.646, 0.500, 0.577)	(0.388, 0.697, 0.602)	(0.459, 0.653, 0.602)
r_{21}	(0.477, 0.640, 0.602)	(0.374, 0.714, 0.591)	(0.529, 0.594, 0.606)	(0.562, 0.575, 0.595)	(0.345, 0.744, 0.572)	(0.523, 0.628, 0.576)

Source: Authors.

Table 5. The implementation of the MEREC weighting approach for computing the criteria weights.

	(S'_{ij}) values							
Criteria	e_1	e_2	e_3	e_4	e_5	e_6	V_j	w_j^M
r_1	0.526	0.540	0.512	0.513	0.556	0.550	0.109	0.0425
r_2	0.521	0.530	0.511	0.508	0.542	0.552	0.143	0.0557
r_3	0.532	0.547	0.505	0.515	0.553	0.548	0.107	0.0418
r_4	0.528	0.548	0.499	0.510	0.544	0.549	0.127	0.0495
r_5	0.531	0.545	0.507	0.507	0.556	0.545	0.115	0.0448
r_6	0.531	0.531	0.518	0.512	0.541	0.549	0.126	0.0491
r_7	0.522	0.536	0.504	0.511	0.538	0.549	0.147	0.0571
r_8	0.537	0.550	0.506	0.508	0.545	0.559	0.101	0.0394
r_9	0.529	0.545	0.508	0.514	0.555	0.558	0.097	0.0379
r_{10}	0.530	0.539	0.510	0.509	0.547	0.542	0.129	0.0502
r_{11}	0.525	0.536	0.515	0.517	0.549	0.546	0.119	0.0464
r_{12}	0.519	0.535	0.518	0.511	0.547	0.554	0.123	0.0478
r_{13}	0.531	0.545	0.507	0.504	0.545	0.557	0.118	0.0458
r_{14}	0.527	0.539	0.510	0.510	0.556	0.555	0.108	0.0421
r_{15}	0.532	0.546	0.514	0.509	0.543	0.556	0.106	0.0413
r_{16}	0.523	0.533	0.516	0.513	0.540	0.550	0.132	0.0513
r_{17}	0.520	0.536	0.501	0.504	0.538	0.553	0.154	0.0601
r_{18}	0.530	0.543	0.508	0.514	0.555	0.554	0.102	0.0397
r_{19}	0.531	0.548	0.516	0.512	0.541	0.556	0.104	0.0403
r_{20}	0.515	0.531	0.517	0.515	0.536	0.547	0.146	0.0567
r_{21}	0.522	0.528	0.508	0.510	0.532	0.550	0.156	0.0606

Source: Authors.

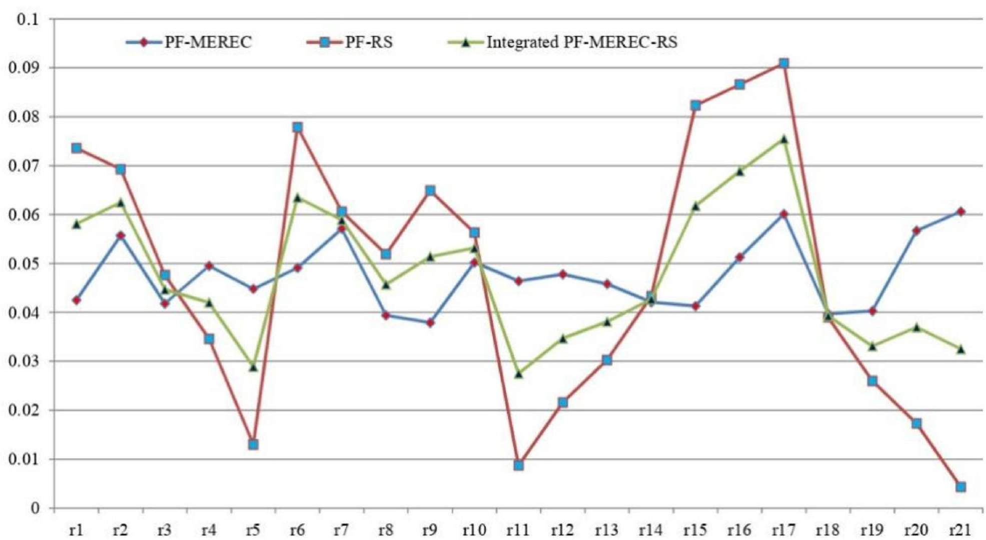

Figure 2. Weight of the main risks to assess the agriculture supply chain for investments of SMEs. Source: Authors.

dominance scores $OLDS\ (e_i)$ is computed by Eqs. (17) and (18), which are shown in Tables 8 and 9, respectively.

Step 8: By Eq. (19), the collective scores of the enterprises for the main risks to assess the agriculture supply chain for investments of SMEs are derived and depicted in Table 10. Therefore, desired preferences as $e_3 \succ e_5 \succ e_1 \succ e_4 \succ e_2 \succ e_6$. That is to say; the firm enterprise e_2 is the optimal one for the main risks to assess the agriculture supply chain for investments of SMEs.

Table 6. Weights of the risks to assess the agriculture supply chain for investments of SMEs using the RS method.

Criteria	A_1	A_2	A_3	A_4	Aggregated PFNs	Crisp values $S(\tilde{\xi}_{kj})$	Rank of challenges	Weight w_j^s
r_1	ML	H	M	M	(0.560, 0.571, 0.601)	0.494	5	0.0736
r_2	MH	MH	M	M	(0.557, 0.573, 0.601)	0.491	6	0.0693
r_3	MH	M	MH	L	(0.531, 0.599, 0.599)	0.462	11	0.0476
r_4	H	M	L	ML	(0.511, 0.615, 0.601)	0.442	14	0.0346
r_5	MH	ML	ML	L	(0.447, 0.670, 0.592)	0.375	19	0.0130
r_6	ML	M	H	MH	(0.573, 0.565, 0.594)	0.505	4	0.0779
r_7	MH	ML	M	H	(0.553, 0.582, 0.596)	0.483	8	0.0606
r_8	MH	MH	M	L	(0.533, 0.598, 0.598)	0.463	10	0.0519
r_9	H	ML	M	MH	(0.559, 0.577, 0.595)	0.490	7	0.0649
r_{10}	L	H	M	ML	(0.534, 0.598, 0.598)	0.464	9	0.0563
r_{11}	MH	L	VL	MH	(0.453, 0.680, 0.576)	0.371	20	0.0087
r_{12}	M	ML	M	MH	(0.498, 0.618, 0.609)	0.433	17	0.0216
r_{13}	ML	H	ML	L	(0.514, 0.622, 0.590)	0.439	15	0.0303
r_{14}	M	H	L	ML	(0.528, 0.604, 0.597)	0.457	12	0.0433
r_{15}	M	MH	H	L	(0.577, 0.564, 0.591)	0.507	3	0.0823
r_{16}	MH	M	H	M	(0.592, 0.543, 0.596)	0.528	2	0.0866
r_{17}	H	ML	H	M	(0.602, 0.542, 0.586)	0.534	1	0.0909
r_{18}	MH	ML	MH	ML	(0.519, 0.619, 0.590)	0.443	13	0.0390
r_{19}	L	MH	M	M	(0.501, 0.616, 0.608)	0.436	16	0.0260
r_{20}	M	ML	M	L	(0.441, 0.656, 0.613)	0.383	18	0.0173
r_{21}	M	L	L	MH	(0.433, 0.671, 0.603)	0.369	21	0.0043

Source: Authors.

Table 7. Score values of normalized A-PF-DM.

	e_1	e_2	e_3	e_4	e_5	e_6
r_1	0.470	0.482	0.532	0.533	0.685	0.440
r_2	0.390	0.330	0.509	0.447	0.414	0.478
r_3	0.573	0.619	0.419	0.574	0.602	0.404
r_4	0.513	0.642	0.344	0.482	0.445	0.425
r_5	0.561	0.566	0.451	0.438	0.676	0.373
r_6	0.553	0.346	0.655	0.516	0.387	0.419
r_7	0.410	0.416	0.399	0.497	0.358	0.418
r_8	0.684	0.687	0.438	0.459	0.455	0.609
r_9	0.517	0.579	0.465	0.555	0.647	0.599
r_{10}	0.544	0.465	0.506	0.462	0.496	0.324
r_{11}	0.446	0.414	0.589	0.613	0.533	0.377
r_{12}	0.370	0.404	0.652	0.498	0.488	0.504
r_{13}	0.570	0.566	0.451	0.392	0.453	0.559
r_{14}	0.494	0.464	0.498	0.491	0.682	0.529
r_{15}	0.587	0.594	0.577	0.462	0.420	0.553
r_{16}	0.416	0.370	0.617	0.531	0.385	0.441
r_{17}	0.385	0.411	0.359	0.395	0.349	0.499
r_{18}	0.542	0.535	0.461	0.563	0.656	0.511
r_{19}	0.566	0.636	0.606	0.520	0.387	0.539
r_{20}	0.316	0.346	0.629	0.583	0.332	0.392
r_{21}	0.409	0.315	0.463	0.493	0.283	0.440

Source: Authors.

4.2. Sensitivity investigation

This subsection shows a sensitivity investigation associated with the parameter γ. The variation of γ is a useful issue helping to evaluate the sensitivity level of the approach, changing from objective weighting to subjective weighting procedures. In addition, changing the values γ is applied to the investigation of the sensitivity of the proposed method to the eminence of attribute weights.

Table 11 and Figure 3 represent the sensitivity analysis of the alternatives for diverse values of the utility parameter γ. Based on the assessments; we obtain the

Table 8. The gained dominance scores of each alternative.

	e_1	e_2	e_3	e_4	e_5	e_6
r_1	0.062	0.113	0.429	0.437	2.032	0.000
r_2	0.170	0.000	1.381	0.588	0.308	0.937
r_3	0.623	1.005	0.030	0.625	0.841	0.000
r_4	0.652	1.828	0.000	0.420	0.222	0.149
r_5	0.699	0.733	0.150	0.107	1.640	0.000
r_6	0.855	0.000	1.657	0.621	0.064	0.163
r_7	0.252	0.326	0.165	1.954	0.000	0.357
r_8	1.196	1.220	0.000	0.037	0.027	0.734
r_9	0.147	0.575	0.000	0.367	1.493	0.793
r_{10}	1.125	0.348	0.666	0.333	0.568	0.000
r_{11}	0.192	0.070	1.105	1.327	0.678	0.000
r_{12}	0.000	0.063	1.851	0.431	0.375	0.480
r_{13}	1.032	0.984	0.142	0.000	0.153	0.909
r_{14}	0.079	0.000	0.101	0.061	2.157	0.395
r_{15}	0.838	0.931	0.738	0.105	0.000	0.558
r_{16}	0.147	0.000	1.800	0.976	0.028	0.292
r_{17}	0.211	0.532	0.037	0.308	0.000	2.024
r_{18}	0.337	0.278	0.000	0.568	1.882	0.143
r_{19}	0.529	1.179	0.863	0.278	0.000	0.356
r_{20}	0.000	0.057	1.564	1.261	0.021	0.242
r_{21}	0.420	0.061	0.779	1.059	0.000	0.597

Source: Authors.

Table 9. The lost dominance scores of each alternative.

	e_1	e_2	e_3	e_4	e_5	e_6
r_1	0.062	0.088	0.193	0.195	0.514	0.000
r_2	0.170	0.000	0.509	0.333	0.239	0.420
r_3	0.326	0.414	0.030	0.327	0.381	0.000
r_4	0.309	0.545	0.000	0.252	0.185	0.149
r_5	0.311	0.320	0.128	0.107	0.501	0.000
r_6	0.324	0.000	0.485	0.266	0.064	0.113
r_7	0.208	0.233	0.165	0.560	0.000	0.241
r_8	0.380	0.384	0.000	0.032	0.027	0.264
r_9	0.147	0.327	0.000	0.257	0.521	0.381
r_{10}	0.530	0.340	0.438	0.333	0.413	0.000
r_{11}	0.131	0.070	0.400	0.444	0.293	0.000
r_{12}	0.000	0.063	0.524	0.237	0.219	0.250
r_{13}	0.428	0.418	0.142	0.000	0.147	0.399
r_{14}	0.070	0.000	0.077	0.061	0.503	0.151
r_{15}	0.416	0.435	0.391	0.105	0.000	0.331
r_{16}	0.088	0.000	0.472	0.307	0.028	0.136
r_{17}	0.124	0.212	0.037	0.156	0.000	0.510
r_{18}	0.230	0.210	0.000	0.288	0.551	0.143
r_{19}	0.375	0.521	0.458	0.278	0.000	0.317
r_{20}	0.000	0.039	0.416	0.356	0.021	0.101
r_{21}	0.241	0.061	0.345	0.401	0.000	0.300

Source: Authors.

preferences of enterprises for the main risks to assess the agriculture supply chain for investments of SMEs as $e_4 \succ e_3 \succ e_5 \succ e_1 \succ e_2 \succ e_6$ when $\gamma = 0.0$ using the PF-RS weighting procedure, $e_3 \succ e_4 \succ e_5 \succ e_1 \succ e_2 \succ e_6$ when $\gamma = 0.5$ using the integrated PF-MEREC-RS weighting procedure and $e_3 \succ e_5 \succ e_4 \succ e_1 \succ e_2 \succ e_6$ when $\gamma = 1.0$using the PF-MEREC weighting procedure, which implies e_3 is at the top of the ranking for each value of γ, while the e_6 has the last rank for $\gamma = 0.0$ to $\gamma = 1.0$.Therefore, it is observable that the developed method possesses adequate stability with numerous parameter values. As shown clearly in Table 11, the developed

Table 10. The collective scores of the enterprises for the main risks to assess the agriculture supply chain for investments of SMEs.

	OGDS	ρ_1	$OGDS^N$	OLDS	ρ_2	$OLDS^N$	CS_i	Final ranking
e_1	0.4510	5	0.3481	0.0282	2	0.3631	0.0159	3
e_2	0.4235	6	0.3269	0.0269	1	0.3459	−0.0009	5
e_3	0.6558	1	0.5061	0.0325	4	0.4183	0.0649	1
e_4	0.5673	2	0.4378	0.0330	5	0.4243	0.0032	4
e_5	0.5501	3	0.4245	0.0299	3	0.3842	0.0260	2
e_6	0.4917	4	0.3795	0.0385	6	0.4959	−0.0875	6

Source: Authors.

Table 11. Ranking results of the PF-MEREC-RS-GLDS method with different values of γ.

γ	e_1	e_2	e_3	e_4	e_5	e_6	Ranking order
0.0	−0.0180	−0.0389	0.0378	0.0610	0.0272	−0.0827	$e_4 \succ e_3 \succ e_5 \succ e_1 \succ e_2 \succ e_6$
0.5	0.0159	−0.0009	0.0649	0.0032	0.0260	−0.0875	$e_3 \succ e_4 \succ e_5 \succ e_1 \succ e_2 \succ e_6$
1.0	−0.0231	−0.0405	0.0691	−0.0228	0.0630	−0.0563	$e_3 \succ e_5 \succ e_4 \succ e_1 \succ e_2 \succ e_6$

Source: Authors.

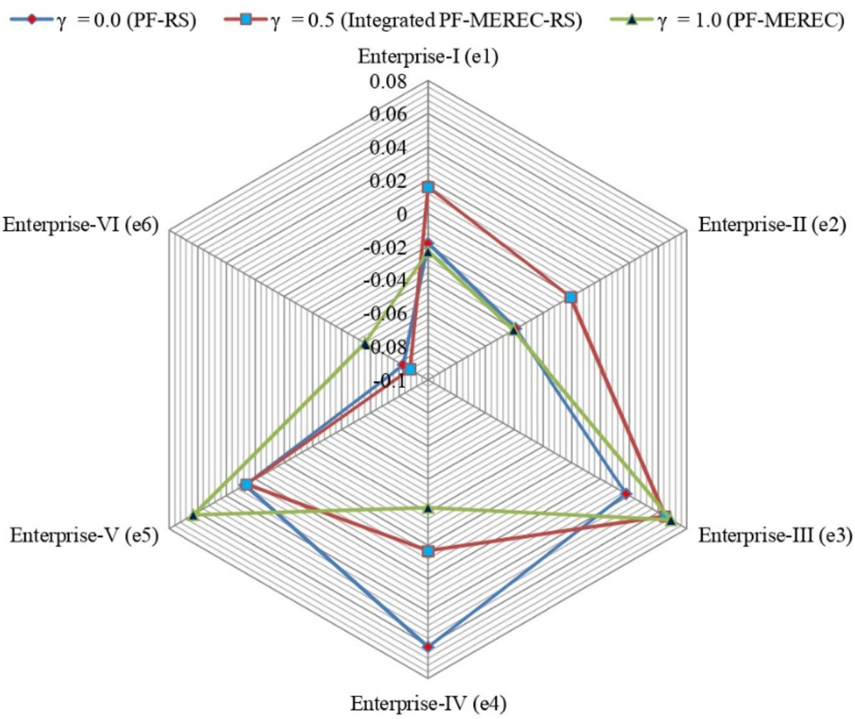

Figure 3. Sensitivity outcomes of the CS_i values over the utility parameter γ.
Source: Authors.

PF-MEREC-RS-GLDS methodology is capable of generating stable and, at the same time, flexible preference results in a variety of utility parameters. This property is of high importance for MCDM procedures and decision-making reality.

4.3. Comparison with existing methods

In the current part of the study, we present a comparative study between the proposed and existing PF-TOPSIS (Technique for order preference by similarity to ideal solution) (Zhang & Xu, 2014) model and PF-WASPAS (Weighted aggregated sum product assessment) (Rani et al., 2020) for solving MCDM problems under the PFSs context as follows:

4.3.1. PF-TOPSIS model

Steps 1–4: Follow the steps of the PF-TOPSIS method
Step 5: Calculate the discriminations of each alternative from 'PF-positive ideal solution (PIS)' and 'PF-negative-ideal solution (NIS)'.

In this method, calculating the PF-PIS and PF-NIS values of each criterion is a key concern for DMs. Let ϕ^+ and ϕ^-be the PF-PIS and PF-NIS, respectively, which are computed with the use of Eqs. (20) and (21) as follows:

$$\phi^+ = \begin{cases} \max\limits_i b_{ij}, & \text{for benefit criterion } r_b \\ \min\limits_i n_{ij}, & \text{for cost criterion } r_n \end{cases} \quad \text{for } j = 1(1)n \tag{22}$$

$$\phi^- = \begin{cases} \min\limits_i b_{ij}, & \text{for benefit criterion } r_b \\ \max\limits_i n_{ij}, & \text{for cost criterion } r_n \end{cases} \quad \text{for } j = 1(1)n. \tag{23}$$

Step 6: Derive the degrees of distances of options from PF-PIS and PF-NIS.

We estimate the degree of distance $D(e_i, \phi^+)$ among the option e_i and the PF-PIS ϕ^+.

$$D(e_i, \phi^+) = \frac{1}{2}\sum_{j=1}^{n}\left[w_j\left(\left|b^2_{\xi_{ij}} - b^2_{\phi^+_j}\right| + \left|n^2_{\xi_{ij}} - n^2_{\phi^+_j}\right| + \left|\pi^2_{\xi_{ij}} - \pi^2_{\phi^+_j}\right|\right)\right]. \tag{24}$$

and the degree of distance $D(e_i, \phi^-)$ among the options e_i and the PF-NIS ϕ^- is given as follows:

$$D(e_i, \phi^-) = \frac{1}{2}\sum_{j=1}^{n}\left[w_j\left(\left|b^2_{\xi_{ij}} - b^2_{\phi^-_j}\right| + \left|n^2_{\xi_{ij}} - n^2_{\phi^-_j}\right| + \left|\pi^2_{\xi_{ij}} - \pi^2_{\phi^-_j}\right|\right)\right]. \tag{25}$$

Step 7: Compute the relative closeness index (CI)

$$\mathsf{C}(e_i) = \frac{D(e_i, \phi^-)}{D(e_i, \phi^+) + D(e_i, \phi^-)}, \quad i = 1(1)m. \tag{26}$$

Based on the values of CI, the most suitable candidate and the prioritization order of all alternatives are determined. The maximum value of $\mathsf{C}(e_k)$ determines the most appropriate choice.

Table 12. Ranking results of the PF-TOPSIS model.

Options	$D(e_i, \phi^+)$	$D(e_i, \phi^-)$	$\mathbb{C}(e_i)$	Ranking
e_1	0.131	0.119	0.4761	3
e_2	0.139	0.109	0.4396	4
e_3	0.114	0.135	0.5429	1
e_4	0.126	0.125	0.4981	2
e_5	0.145	0.109	0.4284	5
e_6	0.151	0.101	0.4012	6

Source: Authors.

Next, we implement the PF-TOPSIS on the abovementioned case study. For this, firstly we have computed the PF-PIS and PF-NIS by means of Eqs. (22) and (23), and then we have

ϕ^+ ={(0.737, 0.417, 0.532), (0.578, 0.562, 0.592), (0.681, 0.476, 0.557), (0.699, 0.452, 0.554), (0.731, 0.427, 0.533), (0.710, 0.441, 0.548), (0.563, 0.567, 0.601), (0.740, 0.418, 0.527), (0.706, 0.451, 0.546), (0.618, 0.542, 0.570), (0.674, 0.477, 0.564), (0.708, 0.444, 0.550), (0.634, 0.511, 0.581), (0.736, 0.422, 0.530), (0.663, 0.501, 0.556), (0.680, 0.477, 0.557), (0.573, 0.575, 0.584), (0.713, 0.443, 0.544), (0.701, 0.467, 0.539), (0.688, 0.465, 0.557), (0.562, 0.575, 0.595)}.

ϕ^- ={(0.512, 0.617, 0.598), (0.398, 0.706, 0.586), (0.476, 0.647, 0.596), (0.410, 0.693, 0.593), (0.447, 0.674, 0.588), (0.425, 0.699, 0.575), (0.424, 0.680, 0.598), (0.508, 0.618, 0.601), (0.531, 0.592, 0.606), (0.385, 0.707, 0.593), (0.448, 0.669, 0.594), (0.441, 0.674, 0.593), (0.453, 0.649, 0.611), (0.534, 0.597, 0.599), (0.484, 0.628, 0.609), (0.434, 0.669, 0.603), (0.409, 0.686, 0.602), (0.532, 0.601, 0.596), (0.445, 0.651, 0.615), (0.376, 0.713, 0.591), (0.345, 0.744, 0.572)}.

Using Eqs. (24)–(26), the overall computational results and preference order of the options to main risks to assess the agriculture supply chain for investments of SMEs are presented in Table 12. Hence, the desirable enterprise option is e_3 to the main risks to assess the agriculture supply chain for investments of SMEs. The priority order of options is $e_3 \succ e_4 \succ e_1 \succ e_2 \succ e_5 \succ e_6$ to the evaluation of the main risks to assess the agriculture supply chain for investments of SMEs.

4.3.2. PF-WASPAS model

The PF-WASPAS method is implemented to handle the decision-making problem. The description of the PF-WASPAS method is given as follows:

Steps 1–4: As the aforementioned model

Step 5: Utilize the weighted sum model (WSM) $C_i^{(1)}$ in the following expression

$$C_i^{(1)} = \bigoplus_{j=1}^{n} w_j \, \eta_{ij}^{(1)}. \tag{27}$$

Step 6: Apply the weighted product model (WPM)$C_i^{(2)}$ in the following expression

$$C_i^{(2)} = \bigotimes_{j=1}^{n} \left(\eta_{ij}^{(1)}\right)^{w_j}. \tag{28}$$

Table 13. The *UD* of option to the evaluation of risks to assess the agriculture supply chain for investments of SMEs.

	WSM		WPM			
Options	$C_i^{(1)}$	$S(C_i^{(1)})$	$C_i^{(2)}$	$S(C_i^{(2)})$	*UD*	Ranking
e_1	(0.568, 0.574, 0.590)	0.4967	(0.548, 0.587, 0.596)	0.4777	0.4872	3
e_2	(0.566, 0.581, 0.585)	0.4911	(0.534, 0.602, 0.593)	0.4613	0.4762	4
e_3	(0.584, 0.560, 0.587)	0.5138	(0.562, 0.575, 0.594)	0.4929	0.5033	1
e_4	(0.569, 0.571, 0.592)	0.4988	(0.561, 0.576, 0.595)	0.4914	0.4951	2
e_5	(0.564, 0.579, 0.589)	0.4911	(0.524, 0.604, 0.601)	0.4552	0.4731	5
e_6	(0.551, 0.594, 0.587)	0.4757	(0.536, 0.602, 0.591)	0.4624	0.4690	6

Source: Authors.

Step 7: Obtain the *UD* of each option in the following expression

$$C_i = \lambda\, C_i^{(1)} + (1-\lambda)\, C_i^{(2)}, \tag{29}$$

where ‘λ’ means the decision strategy parameter, where $\lambda \in [0,\ 1]$.

Step 8: Based on $UD\ (C_i)$, prioritize the options.

Using Eqs. (27) and (28), the WSM and WPM values are estimated. Then, the *UD* of WASPAS for each organization to evaluate the main risks to assess the agriculture supply chain for investments of SMEs is obtained with the use of Eq. (29) and mentioned in Table 13.

The priority order of options is $e_3 \succ e_4 \succ e_1 \succ e_2 \succ e_5 \succ e_6$. Thus, the enterprise-III (e_3) option is the best one to the evaluating of the main risks to assess the agriculture supply chain for investments of SMEs.

As a whole, the benefits of the PF-MEREC-RS-GLDS method over the extant method are given as follows (see Figure 4):

- In the developed method, the subjective weights of attributes are obtained by the PF-RS method, and the objective weights of criteria are computed by MEREC, whereas in PF-WASPAS, only objective weights of criteria are obtained by entropy and divergence measure-based weighting procedure, and in PF-TOPSIS, the criteria weights are chosen arbitrarily.
- The normalization process is conducted in the PF-MEREC-RS-GLDS method before calculating the ‘gained’ and lost dominance scores over different criteria. However, such a process is ignored in the TOPSIS and WASPAS methods.
- The introduced PF-MEREC-RS-GLDS methodology could provide a more precise explanation under uncertain conditions because of computing the criteria and DEs’ weights and applying them in the procedure of the developed framework. Besides, two other considered central features in the process of the developed framework lead the computational results to a dependable solution. The features include the last aggregation method to prevent data loss and modify the proposed approach based on PFSs information.

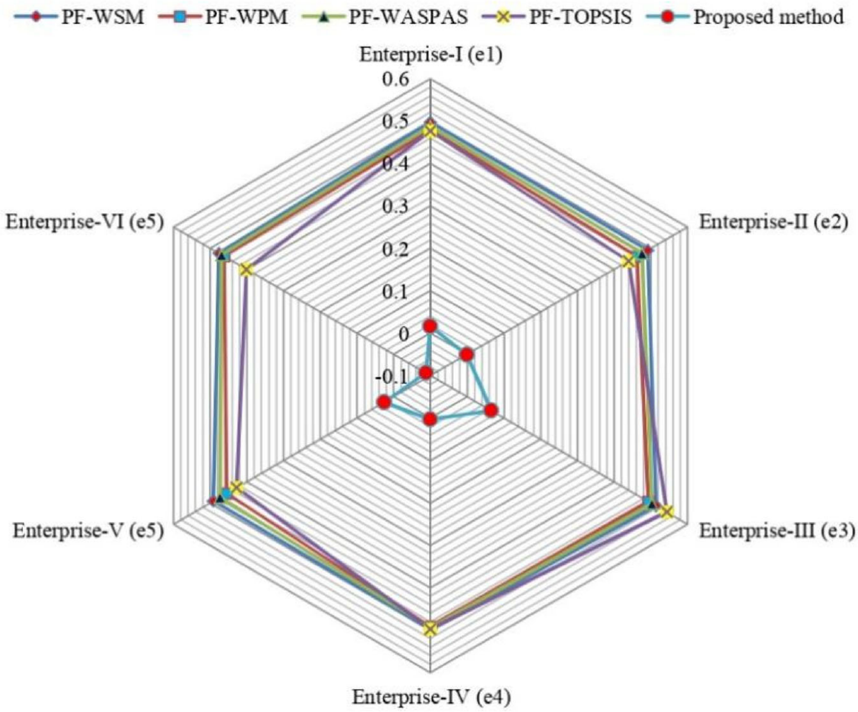

Figure 4. Comparison of utility degree of each industry with various methods.
Source: Authors.

5. Conclusions

Research on investment in agri-food businesses shows extensive impacts as a consequence of uncertainties in investment decisions. Investment in the food supply chain, from farmers to food-providing services, can also be dampened and discouraged by volatile prices. There is a paucity of literature on risk management in agri-food environments, and efforts so far have mainly concerned strategies and solutions such as hedging and insurance against adverse circumstances, particularly weather-related circumstances. Limited studies have looked at commodity price-related aspects of the agri-food sector. A key challenge in responding to the emerging challenges in agri-food supply chains is encouraging continued new investment. This is related to the recognition that agricultural production is often a lengthy process requiring ongoing investments that may not produce expected returns for a prolonged period, thereby being highly sensitive to market risks.

This study uses a survey study based on the interview with experts and a current literature review to identify the main risks associated with the agriculture supply chain for investments in agricultural SMEs. In the first round of the survey approach using literature review, 40 important risks related to the supply chain in agriculture are identified. Results of this round of survey indicated that, in total, 25 of the main agriculture supply chain risks are important for investments in agricultural SMEs. In the next study round, we invited ten DEs from academics and industry in the areas of agricultural SMEs and supply chain for evaluations of 25 selected risks. This study is an attempt to introduce a new framework to assess the agriculture supply chain for investments of SMEs. To analyse, rank and evaluate the main risks to assess of the agriculture supply chain for investments of SMEs, this study introduced an integrated decision-making method using PFSs. In this regard, a novel decision-making approach using PF-MEREC-RS and PF-GLDS methods called the PF-MEREC-RS-GLDS method is introduced to evaluate the main risks to assess the agriculture supply chain for investments of SMEs. To rank the main risks to assess the agriculture supply chain for investments of SMEs, the PF-MEREC-RS method is utilized, and to compute the preference order of different enterprises to the evaluation of the main risks to assess the agriculture supply chain for investments of SMEs, the PF-GLDS method is used. Finally, to validation of the results of this study, a comparison using the various extant methods such as PF-TOPSIS, PF-WSM, PF-WPM, and PF-WASPAS is conducted. Here, we discuss the presented PF-MEREC-RS-GLDS method and illustrate how to apply it for realistic applications. Since the PF-MEREC-RS and PF-DNMA are powerful and straightforward, thus, various further research concerns are well worth exploring on the setting the PF-MEREC-RS-GLDS method as authors can expand the study by using diverse MCDM models such as the combined compromise solution (CoCoSo), measurement alternatives and ranking based on compromise solution (MARCOS), or WASPAS to evaluate the main risks to assess the agriculture supply chain for investments of SMEs. Also, the developed PF-MEREC-RS-GLDS approach can also be utilized to solve the MCDM problems encountered in various disciplines, namely low carbon supplier selection, and green supply chain management, barriers of intelligent transportation system, and different branches of engineering.

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