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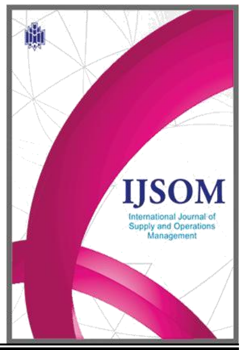


# Evaluation on Risks of Sustainable Supply Chain Based on Integrated Rough DEMATEL in Tunisian Dairy Industry

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**Abstract**

Recently, sustainable supply chain management (SSCM) has grown considerably at agro-food supply chain (AFSC). Due to their complex nature, these supply chains are exposed to a variety of interrelated risks from natural disasters and man-made. Hence, one of the fundamental concerns in the AFSC is identifying and prioritizing risks to achieve sustainability. However, in analyzing sustainability concerns, most previous studies have paid less attention to interrelationship between sustainability and risk assessment. The objective of this work is to propose a methodology to supply chain sustainability risk assessment by evaluating environmental, economic, social and operational risks. The proposed approach is an integrated rough decision- making and trial evaluation laboratory (DEMATEL) method for solving this problem, which takes into account the interrelationship between different risks and the group preference variety. The proposed methodology integrates the strength of DEMATEL approach in exploring both internal strength and external influence of risks as well as the advantage of rough number in manipulating the vagueness of information. A real-world case study of a Tunisian dairy company is presented to test the applicability of the proposed framework. It can be observed from results that the most important risks are “Large number of intermediaries”, “Lack of proper storage facilities” and “Transport disruption”. The results and findings can help the dairy sector decision-makers in a variety of ways to successfully identify and prioritize supply chain risks in order to attain sustainability.

**Keywords:** Sustainability; Risk assessment; Interval rough numbers; DEMATEL; Dairy supply chain.

## 1. Introduction

Agro-food supply chain (AFSC) is a network of diverse operations including farming, processing, transportation and distribution that meet the needs of customers (Allaoui et al., 2018). The AFSC presents several important indicators that distinguish it from others supply chain (SC) such as food quality, weather variability and limited shelf life (Jouzdani et al., 2021). According to Mangla et al., (2018), the notion of sustainability is becoming increasingly relevant in the agro-food sector as a result of rising concerns about food safety and quality. Sustainability is defined by the UN World Commission on Environment and Development as a balance between social, economic and environmental objectives that meets the current world demands without compromising future generations ‘ability to satisfy their own needs.

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These SCs have recently become more vulnerable to various risks caused by both man-made and natural disasters (Ali et al., 2019). These risks could have a significant impact on the supply chain's short and long-term performance (Moktadir et al., 2021). According to Ivanov et al., (2020), supply chain risks are divided into two main groups: (i) *Operational risks*, which are concerned to the high frequency events in the SC operations such as demand fluctuations and uncertainty in the lead-time, cost and supply and (ii) *Disruption risks* refer to low frequency-high-impact events such as natural disasters, epidemic, man-made catastrophes and so one. They are characterized by a strong and immediate impact on the SC structure since some suppliers, manufacturers and transportation links become temporarily unavailable. In order to prevent harm, it is necessary to build an effective risk management in the industry in addition to investing in enhancing sustainable strategies (Moktadir et al., 2021). In particular, supply chain sustainability risk assessment expands the scope of sustainable supply chain management (SSCM) by incorporating SC risks associated with social, economic and environmental aspects. However, there is a research lack in studying the connections of supply chain risks and the sustainable supply chain management (Rostamzadeh et al., 2018).

Several multi-criteria decisions making (MCDM) approaches have been proposed in literature for assessing the risks of various industries that satisfy decision-makers (Yazdani et al., 2020; Diabat et al., 2012; Chand et al., 2017; Abdel-Basset et al., 2019). The proposed MCDM approaches evaluated different risks by taking into account the data nature (crisp, fuzzy, interval, rough or others). Most of the existing literature explores the Analytic Hierarchy Process (AHP) approaches to compare and rank risks. Fuzzy AHP is utilized to manipulate vagueness in risk ranking (Mangla et al., 2015; Giannakis et al., 2016; Yazdani et al., 2019; Paksoy et al., 2019; Sharma et al., 2021). As a matter of fact, most of the risks associated to SSCM such as economic, environmental and social risks are interconnected in practice (Song et al., 2017). For example, Economic issues such as price volatility or inflation problems can damage the demand and supply, which in return will most increase product waste. Such interrelation between different SSCM risks may affect decision priorities (Song et al., 2017). Nevertheless, the majority of previous studies consider less about the interrelationship between risks. To solve this problem, some researchers used the decision-making and trial evaluation laboratory (DEMATEL) as a comprehensive graphs-based tool, for capturing the complex relation between risks (Du et al., 2021). The DEMATEL method is one of the most effective approaches to visualize the cause-effect relationship between risks and evaluate the influence of each risk on others (Song et al., 2017; Liu et al., 2021). Li et al., (2021) proposed a method combining the DEMATEL with the technique for order preference by similarity to an ideal solution (TOPSIS) for the ranking risks of accidents factors. Li et al., (2020) combined DEMATEL with TOPSIS method to analyze operational risks of hydrogen SC. However, the classical DEMATEL ignores the vagueness and uncertainties of human judgment which widely exist in the real world (Liu et al., 2021).

The risk assessment decision-making process involves huge amount of data and expert knowledge that is often imprecise. Therefore, uncertainties should be taken into consideration when the risks are evaluated. To deal with these uncertainties which are related to real-world problems, the majority of studies uses fuzzy sets or various extensions of fuzzy sets, such as intuitionistic fuzzy sets, or hesitant fuzzy sets. Fuzzy sets are commonly used for dealing with vagueness. However, the subjectivity related to selecting an adequate membership function for fuzzy sets can affect the final decision. Besides, rough set theory, which has been introduced by Pawlak et al., (1982), is another applied tool to help decision makers to deal with imprecision. Unlike the fuzzy set theory, grey theory and other theories, the rough set theory is a powerful technique to treat the uncertainty without considering the subjectivity of judgement (yazdani et al., 2019; Pamučar et al., 2017). Moreover, unlike the fuzzy set theory, the degree of uncertainty in the rough set theory is defined based on approximation areas which is the main concept of rough numbers (yazdani et al., 2019; Pamučar et al., 2017). With regard to this, the rough set theory can effectively handle the uncertainties related to human subjective evaluation, and it can also give acceptable results. Inspired by the above findings, the rough DEMATEL method is proposed in this study for evaluating the SSCM risks and interrelationship between them in an uncertain environment, aiming to improve the successful implementation of risk management in the field of SSCM.

Agriculture is a major economic sector in Tunisia. It contributes about 11.5% of Gross Domestic Product (GDP), employs about 22% of the Tunisian workforce and presents 14% of the balance of payments (ZEF, FARA, INRAT, 2017). In addition, this sector is the largest user of the natural resources, about 80% of water resources, and 90% of fertile land. About 10 million ha of area are agricultural and shared in 5 Million ha of Arable Land; 4 Million of rangelands and 1 Million ha of Forest. The majority of farmers are smallholders with limited resources and operate under constraints such as weakness of infrastructure and access to market. The average farms size is within 0.5 and 2 Hectares. In addition, 40% of farmers are elderly and have more than 60 years old (ZEF, FARA, INRAT, 2017). The most relevant value chains in Tunisia include mainly meat and dairy, and vegetable and fruits. The dairy sector plays an important role in Tunisian agricultural sector. In fact, it presents about 11% of the value agricultural production. Since 1960s, several public programs were proposed to enhance milk production at farm level and improve collection and trade network. Combined with these public programs, private investments in dairy processing plants have remarkably enhanced the infrastructure of dairy value chain. However, the Tunisian dairy sector surfaces many difficulties in developing SSCM practices due to strong problems such as feed and milk quality, dominance of informal circuit, low productivity, climate conditions, high cost of production and transportation (Msaddek et al., 2017) (Soethoudt et al., 2018). Sustainable risk management in the context of the dairy supply chain is a newly research domain. In this context, the examination and the prioritization of risks will contribute to dairy industry's SSCM performance improvement. The contribution of this study includes (1) The supply chain sustainability risk comprises simultaneously all aspects of sustainability, including economic, environmental, social and operational risks. (2) Using rough numbers to manipulate the subjectivity and vagueness of information. (3) Considering the strength and influence of risks simultaneously in the DEMATEL method. (4) This study uses a dairy industry in emerging country (Tunisia) to demonstrate the effectiveness of our framework and help managers to focus on the emerging issues of sustainable supply chain risk management.

The main objective of this study is to develop a framework for the sustainable supply chain risk assessment in the Tunisian dairy industry. The three phases' framework is presented as follows: In phase 1, a literature is conducted and the potential risks are identified. Then, risks are filtered through an expert panel. In phase 2, rough set theory and DEMATEL approach are combined for assessing risks and identifying complex cause-effect relationship between them when uncertainty is occurred. In phase 3, a sensitivity analysis is realised to evaluate the robustness of the proposed model and check the results stability and robustness.

The remainder of this paper is structured as follows. Section 2 gives an overview of related literature. Section 3 describes the proposed methodology. Section 4 details how this methodology is applied in Tunisian dairy industry. Section 5 presents the results and a sensitivity analysis of the applied methodology. Section 6 concludes this paper.

## 2. Literature Review

### 2.1. Related works

Recently, the concept of sustainable supply chain (SSCM) is becoming popular. Abdel-Basset et al., (2020) defined the sustainability supply chain as the integration of economic, environmental and social triple bottom line across the supply chain and proved that SSCM is not enough to evaluate the performance without considering sustainability risks. Khan et al., (2020) represents a systematic literature review of drivers and barriers in the field of SSCM.

Supply chain risk management (SCRM) has emerged as an important research field (Behzadi et al., 2018). It was recently characterized as a systematic strategy for detecting and managing risks by presenting proactive and reactive strategies to make the supply chain less vulnerable (Kara et al., 2020). Based on the ISO 31000: 2009 certificate, developed by the International Organization for Standardization, De Oliveira et al., (2017) proposed a four steps process for risk management:

- Step1: Identify all risks that can assist to the possible disruption of the SC by using various techniques like risk mapping and risk checklist (Behzadi et al., 2018; Moktadir et al., 2021);
- Step2: Rank by priority the identified risks qualitatively and/or quantitively (El Baz., 2021; Moktadir et al., 2021);
- Step3: Implement risk management strategies with appropriate measures. These strategies include mitigation strategies to minimize the effect of disruption before occurrence and contingency strategies after the identification of the risks (El Baz., 2021; Moktadir et al., 2021);
- Step4: Perform risk monitoring to evaluate the performance of SCRM practices. Some researchers highlighted the important role of this step.

Recent studies presented various supply chain risk management strategies to detect and manage risks arising from various source of uncertainty. To investigate internal and external risks, Abdel-Basset et al., (2018) developed mitigation strategies like supply chain protection and response to unexpected incidents. Yazdani et al., (2019) suggested a new methodology for assessing flood risk drivers on different agricultural zones in the food supply chain in the context of the circular economy. Ge et al., (2016) identified and tested various cost-efficient solutions to preserve food safety in Canadian wheat supply chain. Tse et al., (2019) employed supplier development and proactive product recall as two risk management strategies for dealing with quality risks. Deng et al., (2019) found various risks in the perishable SC, including environmental, organizational, inventory and equipment risk. In addition, risk propagations are constructed due to the transmission of these risks along the supply chain due to nodes dependencies. El Baz et al., (2021) investigated the role of SCRM in mitigating the effect of disruption impact on SC in the context of epidemic COVID-16 that constitute a special case of SC risks.

Even though supply chain risk management has been deemed the most interesting research in the recent studies, sustainable supply chain risk management which combines sustainability with supply chain risks, has received little attention (Rostamzadeh et al., 2018; De Oliveira et al., 2017). The supply chain sustainability risks are focused on social and environmental areas may disrupt the competitiveness and profitability of the supply chain if they are not considered by the organizations (Valinejad et al., 2018). However, due to the complexity of SSCM, several risks may arise when considering the triple bottom line of sustainability (Giannakis et al., 2016). For instance, waste product and packaging, environmental damages such as pollution and greenhouse gas emissions during the production, and logistics operations are sustainability related for many industries (Rostamzadeh et al., 2018).

Sustainable supply chain risk management (SSCRM) is defined by Valinejad et al., (2018) as the identification and management process of the supply chain risks sustainability that leads to effective allocation of resources across the chain, protection of sustainability and treatment of threats. In recent years, several studies related to SSCRM are developed. For instance, in their study, Rostamzadeh et al., (2018) identified various sustainability related risks in oil industry including environmental risks, organizational risks, sustainable supplier risks, sustainable production risks, sustainable distribution risks, sustainable recycling risks and information technology risks. Song et al., (2017) considered twenty SSCM linked risks classified into four categories (operational, economic, environmental and social) to determine the most relevant risk variables in telecommunications supply chain. More recently, Ali et al., (2019) coupled supply chain risks with food waste to develop sustainability in Bangladesh food companies. The most significant risks are shortage of qualified personnel, capacity, disruption from man-made and natural disasters, failures in information technology and regulatory issues, which are classified into cause categories for the purpose of developing mitigation strategies. Various sustainability risks were defined by Xu et al., (2019) related to global automotive supply chain including operational, social and environmental risks.

The recent literature performed in the domain of risk assessment highlights several multi-criteria decisions making (MCDM) methods to assess supply chain risks. Giannakis et al., (2016) used a failure mode and effect analysis (FMEA) method to identify and evaluate the cause effect relation between thirty risks in two textile companies in UK and France. Also, Chand et al., (2017) used ANP and MOORA methods to assess risks for selecting best supply chain in Indian industry. Rostamzadeh et al., (2018) investigate the SC risks using fuzzy TOPSIS-CRITIC in the domain of petrochemical industry in Iran. More recently, Yazdani et al., (2019) employed fuzzy AHP to quantify risks to evaluate flood risks drivers in the agricultural SC. Furtheremore, Ali et al., (2019) obtained the cause-effect relation between risks in the food SC in Bangladech by using Grey system theory based DEMATEL. Further, Song et al., (2017) proposed rough DEMATEL method to identify the critical risks in the telecommunications industry.

Abdel-Basset et al., (2020) used a combined multi-criteria decision-making approach based on TOPSIS and CRITIC methods with Plithogeny, to evaluate risks in telecommunication industry. Paksoy et al., (2020) evaluated risks in green SC in the context of automobile SC in Turkey by investigating fuzzy AHP. More recently, Sharma et al., (2021) used Fuzzy AHP to assess the risks in sustainable food SC in India. Further, Wu et al., (2019) performed a fuzzy multi-criteria risk assessment in the electric vehicle supply chain. Ozturkoglu et al., (2019) focused on risks of ship recycling activities using a fuzzy DEMATEL approach.

Thereby, different previous MCDM approaches have been used to evaluate risks under imprecise environment. The previous studies provide valuable insights into the risk management. However, most of the previous approaches need auxiliary information in describing the degree of uncertainty which can directly affect the ranking results (e.g. rough numbers). Moreover, the impact of strength and direct influence among risks is ignored in most of the risk assessment methods. Furthermore, the previous studies lack a systematic way to consider simultaneously the four dimensions of sustainability in the field of risk assessment.

### 2.2. Four-dimensional sustainability approaches

Some authors proposed a conventional sustainability approach covering three dimensions: social, environmental, and economic. However, this model unable to deal with the entire supply chain (Moktadir et al., 2021; Abdel-Basset et al., 2020). For instance, the recent coronavirus is one of specific cases of SC risks that highly disrupted the supply, demand and logistic infrastructure (Ivanov et al., 2020). Da Silva et al., (2020) invented four dimensions of sustainability risk factors including operational risks caused by bankruptcy, equipment failure and so ones. Therefore, this study proposes a four-dimensional sustainability risks including social, economic, environmental and social dimensions (see figure 1).

The four-dimension sustainability risks are explained in detail in the following subsections:

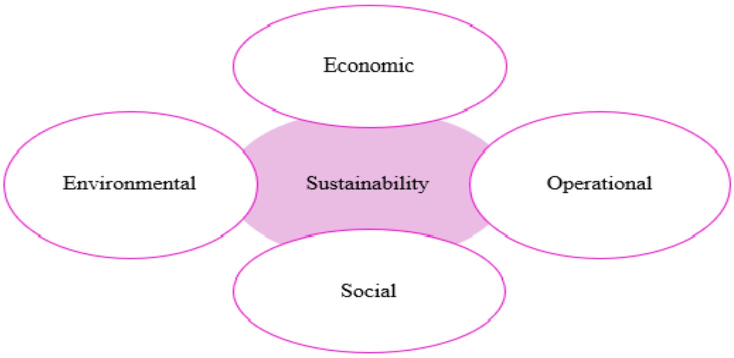


**Figure 1.** Four dimensions of sustainability risks

**a.** *Environmental risks*
De Oliveira et al., (2017) defined environmental risks as ecological risks that have detrimental influence on the SC's performance and sustainability, as well as the environment, due to emissions waste and resource depletion from supply chain activities. These risks were divided classified these risks into two categories by Giannakis et al., (2016): endogenous risks caused by companies' activities along the supply chain, such as resource scarcity (water, energy, land), and exogenous risks happened by the interactions of supply chain with the environment, such as natural disasters and man-made disasters.

**b.** *Social risks*
Social risks are defined by Cuncha et al., (2019) as the threats to human rights such as discrimination and forced or child labor, as well as labor practices, which includes working conditions (poor or unfair earnings; overtime work (Cunha et al., 2021). It also refers to lack of government and institution support of effective communication (Gardas et al., 2018). These types of risks can impact very badly the company reputation.

**c.** *Economic risks*
According to Moktader et al., (2021), economic risks imply the possibility that the economic conditions would have an impact on the SC's investment and expectations. In the present study, corruption, price and cost volatility, inflation and current exchange rate are considered under the economic dimension as in Xu et al., (2019).

**d.** *Operational risks*
Operational risks, according to Xu et al., (2019), are the multifaceted risks associated with supply chain activities at each stage from upstream supply to internal production to distribution to downstream (demand). Recently, the supply chains are becoming increasingly exposed to risks, making it hardly to meet the demand on the impact of specific risk cases such as COVID-19 (Karwasra et al., 2021).

## 3. Research Gaps and Contributions

A study of recent literature revealed that the most studies focused on the conventional risk management, with little emphasis paid to the assessment of risks in the context of SSCM. In practice, the major of risks is interrelated and the importance of each risk can affect the importance of others risks. However, the majority of studies in the research literature ignored this interaction. To the best of our knowledge, only a few research have looked at the cause-effect relationship among various risks such as the work of Song et al., (2017) and more recently Abdel-Basset et al., (2019). Both studies proposed a DEMATEL method for treating the relationship between risks. In addition, the major of studies that considered the sustainability risks assessment considered only three aspects of sustainability: environmental, economic and social dimensions. Thus, the whole supply chain sustainability risks are still not covered and some of these risks are completely ignored, notably operational risks.

The risk assessment decision-making process involves vast amount of data and expert knowledge that is often imprecise and ambiguous. To deal with different experts' subjective assessments, grey theory, fuzzy set theory and rough set theory are widely combined with MCDM techniques. In fact, rough numbers are flexible to deal with the high degree of vagueness and subjectivity in group-decision making without any records whereas fuzzy methods need a data distribution and robust membership functions. Moreover, despite the great importance of sustainability risk assessment of agro-food supply chain (Abdel-Basset et al., (2019), there are few comprehensive studies that consider the risks of the supply chain with different dimensions of sustainability. In the best of the authors 'knowledge, a very little attention is accorded to building a risk evaluation framework for the SSCM of the dairy industry. In fact, this research gaps encourages us to address the following questions:

Q1-What are the risks in SSCM of the dairy industry?
Q2- How these risks can be assessed and categorized into cause-and-effect groups?
Q3- How the risk assessment process can provide with practical and managerial insight to the industrial managers?

To this purpose, our study combines the rough sets with DEMATEL approach to evaluate fourteen risks across four dimensions (social, economic, environmental and operational). The suggested method combines the advantages of rough sets in controlling the uncertainty associated with subjective experts' judgments DEMATEL in capturing the cause-effect relationship between different risks. As a result, a number of contributions and novelties are given in this paper:

1. Dealing with a new risk category by introducing risks sustainability as a fourth dimension of sustainability;
2. Decision theory contribution by proposing a rough DEMATEL approach that captures simultaneously the interrelationship between different risks and the decisions makers' diversity;
3. Tunisian case study in dairy industry: a study that can be conducted in emerging country to support managers in identifying critical supply chain sustainability risks using the proposed approach.

## 4. Methodology

In this section, a literature review of rough set theory and DEMATEL method is presented:

### 4.1. Rough numbers and its basic operations

Uncertainty can be presented by roughness, vagueness, fuzziness in MCDM (Yazdani et al., 2020). Rough set theory (RST), was firstly introduced by Pawlak (1982). Then, it was recently presented as a new approach methodology to deal with the vagueness in decision making (Pamučar et al., 2017). It is considered as a new alternative to fuzzy set theory (Pelissari et al., 2021). RST is based on rough numbers, within boundary intervals, and it aims to analyse the vagueness of information (Roy et al., 2018). According to its effectiveness, RST has been widely combined with various MCDM techniques and applied in many fields. Yazdani et al., (2020) used rough BWM method integrated with Dombi-Bonferroni to manage waste in private hospital in Madrid. Zhu et al., (2020) adopted an integrated fuzzy-rough number with Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to evaluate the design concept of product. Song et al., (2017) proposed a rough DEMATEL method for sustainable supply chain risk management in telecommunication industry in China. A rough AHP combined with multi-attribute border approximation area comparison (MABAC) is used by Roy et al., (2018) to evaluate the medical tourism sites in India. Pamucar et al., (2017) proposed hybrid rough DEMATEL-ANP-MAICRA for selecting process in public procurement procedure.

In group decision making problems, the subjective evaluation of multi-experts is specified and aggregated by rough numbers consisting of upper, lower and boundary interval respectively. According to Chen et al., (2019) and Roy et al., (2018b), the definition of rough number is shown as follow. Assume $U$ is a universe containing all objects and $X$ is a random object from $U$. Then, consider that there exists a set of $k$ classes representing decision makers' preferences:

$$J = \{r_{ij}^1, r_{ij}^2, \dots, r_{ij}^k\}$$

The lower approximation $\underline{Apr}\left(r_{ij}^k\right)$ of $r_{ij}^k$ and the upper approximation $\overline{Apr}\left(r_{ij}^k\right)$of $r_{ij}^k$ are determined respectively (1)and (2) as:

$$\underline{Apr}\left(r_{ij}^k\right) = \cup \left\{X \in U/R(X) \le r_{ij}^k\right\} \tag{1}$$

$$\overline{Apr}\left(r_{ij}^k\right) = \cup \left\{X \in U/R(X) \ge r_{ij}^k\right\} \tag{2}$$

The judgment $r_{ij}^k$ can be described by a rough number (RN), which is given by its lower limit $\underline{Lim}\left(r_{ij}^k\right)$and its upper limit $\overline{Lim}\left(r_{ij}^k\right)$ respectively (3)and (4)as follows:

$$\underline{Lim}\left(r_{ij}^k\right) = \left(\prod_{m=1}^{N_i^L} x_i\right)^{1/N_i^L} \tag{3}$$

$$\overline{Lim}\left(r_{ij}^{k}\right) = \left(\prod_{m=1}^{N_i^U} y_i\right)^{1/N_i^U} \quad (4)$$

Where $x_i$ and $y_i$ are the elements of lower and upper approximation for $r_{ij}^{k}$ respectively, and $N_i^L$ and $N_i^U$ are the sum of objects contained in lower and upper approximation of $r_{ij}^{k}$ respectively. All the elements between the lower limit $r_{ij}^{Lk}$ and upper limit $r_{ij}^{Uk}$ are represented by the rough number $\left(r_{ij}^{k}\right)$ , which is expressed as follows:

$$RN\left(r_{ij}^{k}\right) = \left[\underline{Lim}\left(r_{ij}^{k}\right), \overline{Lim}\left(r_{ij}^{k}\right)\right] = \left[r_{ij}^{Lk}, r_{ij}^{Uk}\right] \quad (5)$$

The rough boundary interval presents interval between lower and upper limits as $\left(r_{ij}^{Uk} - r_{ij}^{Lk}\right)$ and it indicates the degree of uncertainty.

### 4.2. Rough DEMATEL

This section presents the main concepts of DEMATEL and describes its steps. The DEMATEL (Decision-Making Trial and Evaluating Laboratory) method is first introduced by the Geneva Research Centre of the Battelle Memorial Institute at 1976 (Fontela et al., 1976). It is a suitable method for exploring the causal relationship between criteria, visualizing the overall influence of criteria, and analyzing the dependent criteria in multi-criteria decision problems (Ali et al., 2019; Du et al., 2020). Based on three mentioned advantages, it is not difficult to find that the DEMATEL method is widely used in different areas to help in solving complex problems by determining the most important criteria and build a causal-effect relation diagram. However, DEMATEL approach is still limited in dealing the uncertainties and subjectivity related to human judgement.

The fuzzy sets theory was combined with DEMATEL to deal with uncertain information (Samvedi et al., 2013; Tadić et al., 2014; Zhang et al., 2019; Mohammadfam et al., 2019; Khalilzadeh et al., 2021). On the other hand, other studies suggested rough numbers combined with DEMATEL to describe the vagueness and ambiguity (Song et al., 2020; Pamucar et al., 2017; Liu et al., 2019; Mao et al., 2019). As for the third one, A new improved rough -fuzzy DEMATEL was proposed in some papers for involving judgement ambiguousness and group decision diversity (Chen et al., 2019; Chen et al., 2020). Since the DEMATEL approach can analyze the relationship between criteria, it is always combined with others MCDM approaches. For instance, Chen at al., (2019) applied an integrated rough-fuzzy DEMATEL with ANP method for evaluating sustainable values of product and service system. To manipulate the uncertainty in decision making, Tadić et al., (2014) used Fuzzy DEMATEL coupled with fuzzy ANP and fuzzy VIKOR for selecting city logistics according to conflicting and uncertain objectives. Baykasoğlu et al., (2017) integrated DEMATEL with TOPSIS method to solve the strategic planning in industrial engineering department. Ortiz-Barrios et al., (2020) proposed a hybrid approach integrating AHP, TOPSIS and DEMATEL to evaluate the performance of suppliers in pork supply chain. Li et al., (2020) combined fuzzy DEMATEL with TOPSIS to assess the operational risks of hydrogen generation. Chen et al., (2021) integrated DEMATEL with MULTIMOORA method under fuzzy environment for improving QFD (Quality Function Deployment). From the above literatures, it is easy to find that DEMATEL has been successfully improved and combined with others MCDM to solve many complex problems in different fields. The improvement has been proposed to overcome this main disadvantage It's has also been improved to overcome the combination with other MCDM to extend its main advantages.

In order to attain the research objective, the present study applied DEMATEL method improved with rough numbers to deal with vagueness and uncertainty (Ali et al., 2019; Song et al., 2017). The rough DEMATEL has several steps described as follows:

***Step1: Determining the internal strength of risks***

Suppose a set of risks $R = \{R_1;\ R_2, \ldots, R_i, \ldots, R_n\}$ where $R_i$ denotes the $ith$ risk, $i = \{1,2, \ldots, n\}$is the total number of risks and $E = \{E_1;\ E_2, \ldots, E_j, \ldots, E_m\}$ a set of experts where $E_j$ denote the $jth$ expert, $j = \{1,2, \ldots, m\}$, is the number of experts. Each expert can evaluate the internal strength of each risk by using a 5-point verbal scale adapted from linguistic scale in table 1. For instance, if the expert $j$considers that the strength of risk $i$ is high, the internal strength of risk is assigned by "High". After acquiring the internal strength of risks in linguistic terms, the crisp judgment of $m$ experts are obtained as:$IS_i = \{IS_1^1, IS_2^2, \ldots, IS_i^j, \ldots, IS_n^m\}$, where $IS_i^j$ is the $jth$ expert opinion on the internal strength of risk $i$. Then, the crisp group judgement of experts is converted into rough interval form using equations (1)-(5) as:

$$\widetilde{IS}_i = \{\widetilde{IS}_i^1, \widetilde{IS}_i^2, \cdots, \widetilde{IS}_i^j, \cdots, \widetilde{IS}_i^m\} \text{ where: } \widetilde{IS}_i^j = \left[\widetilde{IS}_i^{jL}, \widetilde{IS}_i^{jU}\right] \quad (6)$$

With $\widetilde{IS}_i^{jL}$ and $\widetilde{IS}_i^{jU}$ represent the lower limit and upper limit of rough number $\widetilde{IS}_i^j$ respectively.

Finally, the aggregated expert judgement in this step is calculated with the help of following equation where the decision makers are assigned the same weights:

$$\overline{IS}_i = \sum_{j=1}^{m} \widetilde{IS}_i^j = \left[\sum_{j=1}^{m} \widetilde{IS}_i^{jL}, \sum_{j=1}^{m} \widetilde{IS}_i^{jU}\right] \tag{7}$$

Where $\sum_{j=1}^{m} \widetilde{IS}_i^{jL}$ $and$ $\sum_{j=1}^{m} \widetilde{IS}_i^{jU}$ represent the lower limit and upper limit of the rough aggregated internal strength $\overline{IS}_i$ respectively.

**Table 1.** Linguistic terms of internal strength adapted from song et al, (2017)

| Linguistic term | Corresponding score |
|---|---|
| Very high strength (VHS) | 4 |
| High strength (HS) | 3 |
| Medium strength (MS) | 2 |
| Low strength (LS) | 1 |
| No strength (NS) | 0 |

***Step 2: Design of the direct-relation matrix***

Each expert $j$ is invited to indicate the level of impact between risks $R = \{R_1;\ R_2, \dots, R_i, \dots, R_n\}$ according to the linguistic scale in table 2. The influence of risk $i$ on risk $j$ indicates how an increase or decrease of risk $i$ can increase or decrease the risk . The $n \times n$ direct relation matrix $\mathrm{DR_j}$ is given as follows:

$$DR_j = \begin{bmatrix} 0 & r_{12}^j & \cdots & r_{1n}^j \\ r_{21}^j & 0 & \cdots & r_{2n}^j \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1}^j & r_{n2}^j & \cdots & 0 \end{bmatrix} \quad j = \{1,2, \dots, j, \dots, m\} \tag{8}$$

Where $r_{ik}^j$ denoted by the $jth$ expert judgement for the influence of $ith$ risk to $kth$ risk where $r_{ik}^j = 0$ for $i = k$ indicate that the risk cannot exert an influence on itself.

**Table 2.** Linguistic terms of direct relation adapted from song et al, (2017)

| Linguistic term | Corresponding score |
|---|---|
| Very high impact (VHI) | 4 |
| High impact (HI) | 3 |
| Medium impact (MI) | 2 |
| Low impact (LI) | 1 |
| No impact (NI) | 0 |

Then, the $j$ matrices obtained are converted into rough interval form and the group direct relation matrix $\widetilde{DR}$ can be obtained as follows:

$$\widetilde{DR} = \begin{bmatrix} 0 & \tilde{r}_{12} & \cdots & \tilde{r}_{1n} \\ \tilde{r}_{21} & 0 & \cdots & \tilde{r}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{r}_{n1} & \tilde{r}_{n2} & \cdots & 0 \end{bmatrix} \tag{9}$$

Where $\tilde{r}_{ik} = \{r_{ik}^1; r_{ik}^2; \cdots; r_{ik}^j; \cdots; r_{ik}^m\}_{1\times m}$ and $\tilde{0} = \{0,0, \cdots ,0\}_{1\times m}$ .

According to equation $(1) - (5)$, the kth rough direct-relation matrix $\widetilde{DR}_J$ can be acquired as follows:

$$\widetilde{DR}_j = \begin{bmatrix} [0,0] & [r_{12}^{Lj}, r_{12}^{Uj}] & \cdots & [r_{1n}^{Lj}, r_{1n}^{Uj}] \\ [r_{21}^{Lj}, r_{21}^{Uj}] & [0,0] & \cdots & [r_{2n}^{Lj}, r_{2n}^{Uj}] \\ \vdots & \vdots & \ddots & \vdots \\ [r_{n1}^{Lj}, r_{n1}^{Uj}] & [r_{2n}^{Lj}, r_{2n}^{Uj}] & \cdots & [0,0] \end{bmatrix} j = \{1,2, \dots, m\} \tag{10}$$

Finally, the individual rough direct relation matrices are aggregated to produce a group rough direct-relation matrix $\overline{DR}$ as seen below:

$$\overline{DR} = \sum_{j=1}^{m} \widetilde{DR}_j = \begin{bmatrix} [0,0] & [r_{12}^L, r_{12}^U] & \dots & [r_{1n}^L, r_{1n}^U] \\ [r_{21}^L, r_{21}^U] & [0,0] & \dots & [r_{2n}^L, r_{2n}^U] \\ \vdots & \vdots & \ddots & \vdots \\ [r_{n1}^L, r_{n1}^U] & [r_{n2}^L, r_{n2}^U] & \dots & [0,0] \end{bmatrix} \tag{11}$$

Where

$$r_{ik}^L = \sum_{j=1}^{m} r_{ik}^{jL};\ r_{ij}^U = \sum_{j=1}^{m} r_{ik}^{jU}$$

With $r_{ik}^L$ and $r_{ij}^U$ are the lower limit and the upper limit of rough number $[r_{ik}^L;\ r_{ik}^U]$, respectively, $j$ is the number of experts.

***Step 3: Determination of the total strength-relation matrix***

The internal strength of risks presented by the rough numbers acquired in step 1 $\widetilde{IS}$ are entered into the principal diagonal of the group-relation matrix $\widetilde{DR}$ created in step 2. The obtained group direct strength-relation matrix $D$ is obtained in equation (12) and presented by $d_{ii}$ =Internal strength of risk $R_i$ for $i \neq k$; $d_{ik}$ = impact of the risk $R_i$ on the risk $R_k$.

$$D = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \dots & d_{nn} \end{bmatrix} \tag{12}$$

Where

$$d_{ik} = [d_{ik}^L, d_{ik}^U] = \begin{cases} \sum_{j=1}^{m} \widetilde{IS}_i^{jL}; \sum_{j=1}^{m} \widetilde{IS}_i^{jU}, i = k \\ \sum_{j=1}^{m} r_{ik}^{jL}; \sum_{j=1}^{m} r_{ik}^{jU}, \quad i \neq k \end{cases},$$

The normalized matrix $C$ is computed after getting the group direct-relation matrix $D$ (Song et al, 2017):

$$C = \begin{bmatrix} u_{11} & u_{12} & \dots & u_{1n} \\ u_{21} & u_{22} & \dots & u_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{n1} & u_{n2} & \dots & u_{nn} \end{bmatrix} \tag{13}$$

Where

$$u_{ik} = [u_{ik}^L, u_{ik}^U] = \left[\frac{d_{ik}^L}{\gamma}, \frac{d_{ik}^U}{\gamma}\right] \text{ and } \qquad \gamma = max\left[\sum_{i=1}^{n}\sum_{k=1}^{n} d_{ik}^L, \sum_{i=1}^{n}\sum_{k=1}^{n} d_{ik}^U\right]$$

$u_{ik}^L$ and $u_{ik}^U$ are the lower limit and upper limit of the rough number $\tilde{u}_{ik}$ respectively

After obtaining the normalized group direct relation matrix $C$, the rough numbers are segmented into two sub matrices presented by $C^L$ and $C^U$:

$$C^L = \begin{bmatrix} u_{11}^L & u_{12}^L & \dots & u_{12}^L \\ u_{21}^L & u_{22}^L & \dots & u_{2n}^L \\ \vdots & \vdots & \ddots & \vdots \\ u_{n1}^L & u_{n2}^L & \dots & u_{nn}^L \end{bmatrix} \text{ and } C^U = \begin{bmatrix} u_{11}^U & u_{12}^U & \dots & u_{12}^U \\ u_{21}^L & u_{22}^L & \dots & u_{2n}^L \\ \vdots & \vdots & \ddots & \vdots \\ u_{n1}^L & u_{n2}^L & \dots & u_{nn}^L \end{bmatrix} \tag{14}$$

According to Song et al (2017), the total strength-relation matrix $T^S$ $(S = L, U)$ can be obtained using the following equalities :

$$T^L = [t_{ik}^L]_{n \times n} = C^L(I - C^L)^{-1} \tag{15}$$

$$T^U = [t_{ik}^U]_{n \times n} = C^U(I - C^U)^{-1} \tag{16}$$

Where $I$ represents the identity matrix.

The total strength relation matrix $T$ can be obtained as:

$$T = [\tilde{t}_{ik}]_{n\times n} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \cdots & \tilde{t}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \tilde{t}_{nn} \end{bmatrix} \tag{17}$$

Where $\tilde{t}_{ik} = [t_{ik}^L; t_{ik}^U]$ denotes the overall influence rating for the risk $R_i$ against the risk $R_k$ taking into consideration the internal strength of risk. The lower limit and the upper limit of the rough interval $t_{ik}$ in the rough total strength-relation matrix $T$ are $t_{ik}^L$ and $t_{ik}^U$ respectively. The obtained rough number is separated into exerted and exerting influence of risks as described in table 3.

**Table 3.** The total influence exerted and exerting between risks

| Overall impact of risk $\boldsymbol{i}$ on all other risks | Overall impact exerted by all the risks on risk $\boldsymbol{i}$ |
|---|---|
| $\tilde{\boldsymbol{x}}_{\boldsymbol{i}} = \sum_{\boldsymbol{k}=\boldsymbol{1}}^{\boldsymbol{n}} \tilde{\boldsymbol{t}}_{\boldsymbol{ik}} \quad \boldsymbol{i} = \boldsymbol{1}, \boldsymbol{2}, \dots, \boldsymbol{n} \qquad (\boldsymbol{18})$ | $\tilde{y}_i = \sum_{i=1}^{n} \tilde{t}_{ik} \quad k = 1,2, \dots, n \qquad (19)$ |

The rough numbers $\tilde{x}_i$ and $\tilde{y}_i$ are converted into crisp forms $\tilde{x}_i^{der}$ and $\tilde{y}_i^{der}$ to determine the “Prominence” and the “Relation” as follows:

- Normalization

$$X_i^L = (x_i^L - minx_i^L)/\Delta_{min}^{max}$$
$$X_i^U = (x_i^U - minx_i^L)/\Delta_{min}^{max} \tag{20}$$

Where $\Delta_{min}^{max} = max\ x_i^U - minx_i^L$ , $X_i^L$ and $X_i^U$ present the lower and the upper limits of the rough number $\tilde{x}_i$ respectively, and $\tilde{x}_i^L$ and $\tilde{x}_i^U$ are the normalized parameters of $X_i^L$ and $X_i^U$, respectively.

- Calculate a total normalized crisp value

$$\propto_i = \frac{x_i^L(1 - x_i^L) + x_i^U \times x_i^L}{1 - x_i^L + x_i^U} \tag{21}$$

- The final crisp form $\tilde{x}_i^{der}$ for $\tilde{x}_i$ is computed as :

$$x_i^{der} = minx_i^L + \propto_i \Delta_{min}^{max} \tag{22}$$

The final $\tilde{y}_i^{der}$ for $\tilde{y}_i$ can be obtained similarly.

***Step 4 :Identification of critical risks***

To rank the SSCM risks and analyse the cause-effect relations between them, equations (23) and (24) are used to calculate the “Prominence” ($\boldsymbol{P_i}$) and the “Relation” ($\boldsymbol{R_i}$). Both $\boldsymbol{P_i}$ and $\boldsymbol{R_i}$ are provided in table 4.

**Table 4.** Prominence and Relation description

| $P_{i=} x_i^{der} + y_i^{der} \qquad (23)$ | $R_{i=} x_i^{der} - y_i^{der} \qquad (24)$ |
|---|---|
| $P_i$ determines the horizontally exerted and the vertically received influence of the risk $R_i$ and is visualized as an overall influence intensity of each sustainability risk. When the value of $P_i$ is high, the overall prominence of $R_i$, in terms of overall relationships with other risks, is important. The risks can be ranked based on the $P_i$ | The vector $R_i$ is interpreted by the difference between the exerted and received influence and it is used for risks classification. if the value of $R_i$ is positive, the risk $R_i$ belongs to the cause group. If the value $R_i$ is negative, the risk $R_i$ belongs to the effect group. |

## 5. Application

To demonstrate the effectiveness and the feasibility of the proposed methodology for assessing risks in sustainable supply chain, the elaborated method is applied to the milk collection center “El Rahma” whose main mission is to collect and refrigerate fresh milk (see description in figure2).

### 5.1. Case background

The dairy supply chain (DSC), as important perishable food supply chain especially in Tunisia, is a network of activities including milk production, collection activity and storage, processing and distribution as presented in figure 2. In today's uncertain, volatile and ambiguous world for supply chain actors, the DSC in Tunisia are becoming more vulnerable due to to risks associated to climate change, lack of natural resources particularly water, food wastage, price instability, insufficient use of modern farm technologies increased demand (Souissi et al., 2019). Thus, these hot challenges should be investigated in sustainable risk assessment.

A milk collection center “El Rahma” is selected as a case study to validate the feasibility of the proposed methodology. This center is one of the biggest milk collection centers in the region of Sfax (in the South of Tunisia) where the milk is collected from many farmers, cooled and stocked before to be transported to factories for processing and bottling. This center which is cooperating with upstream (farmers) and downstream (processors) partners, provides consumers with high quality of dairy product. However, many risks occur when implementing SSCM practices. The center “El Rahma”, who acts as the leader of milk collection activity, attempts to explore the critical risks in the field of SSCM, and to determine the interrelationship between them by applying the proposed methodology.

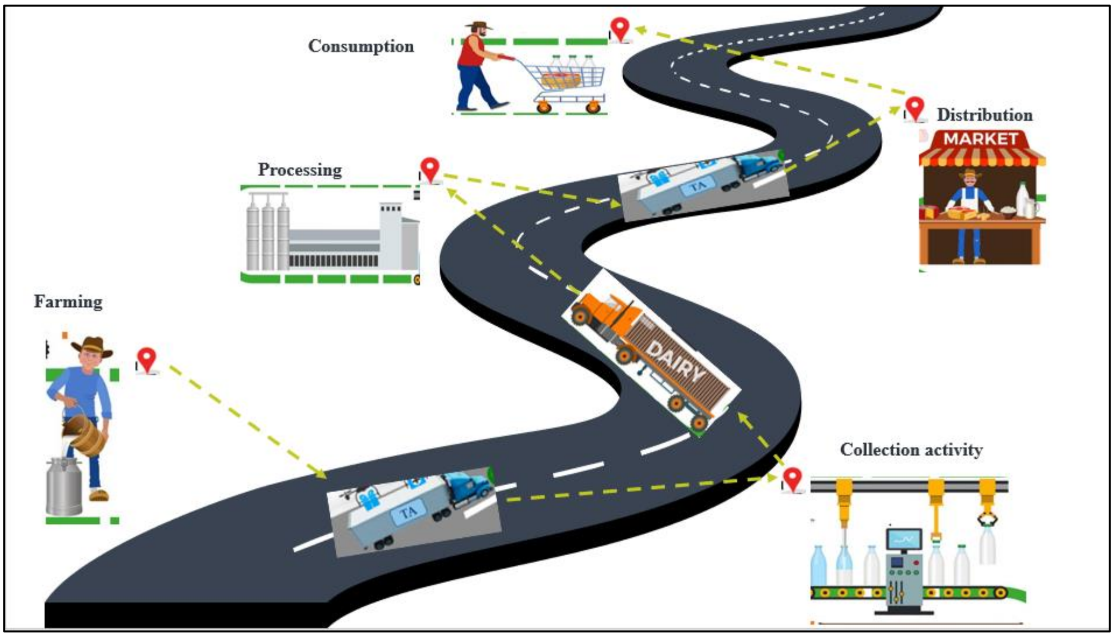


**Figure 2.** The dairy supply chain

**5.2. Implementation**

Figure 3 illustrates the procedure of our proposed approach.

**Phase** 1 → *Identification of risks under four dimensions of sustainability though literature*

**Phase** 2 → *Expert invitation for validation of different risks*

**Phase** 3 → ***Start***

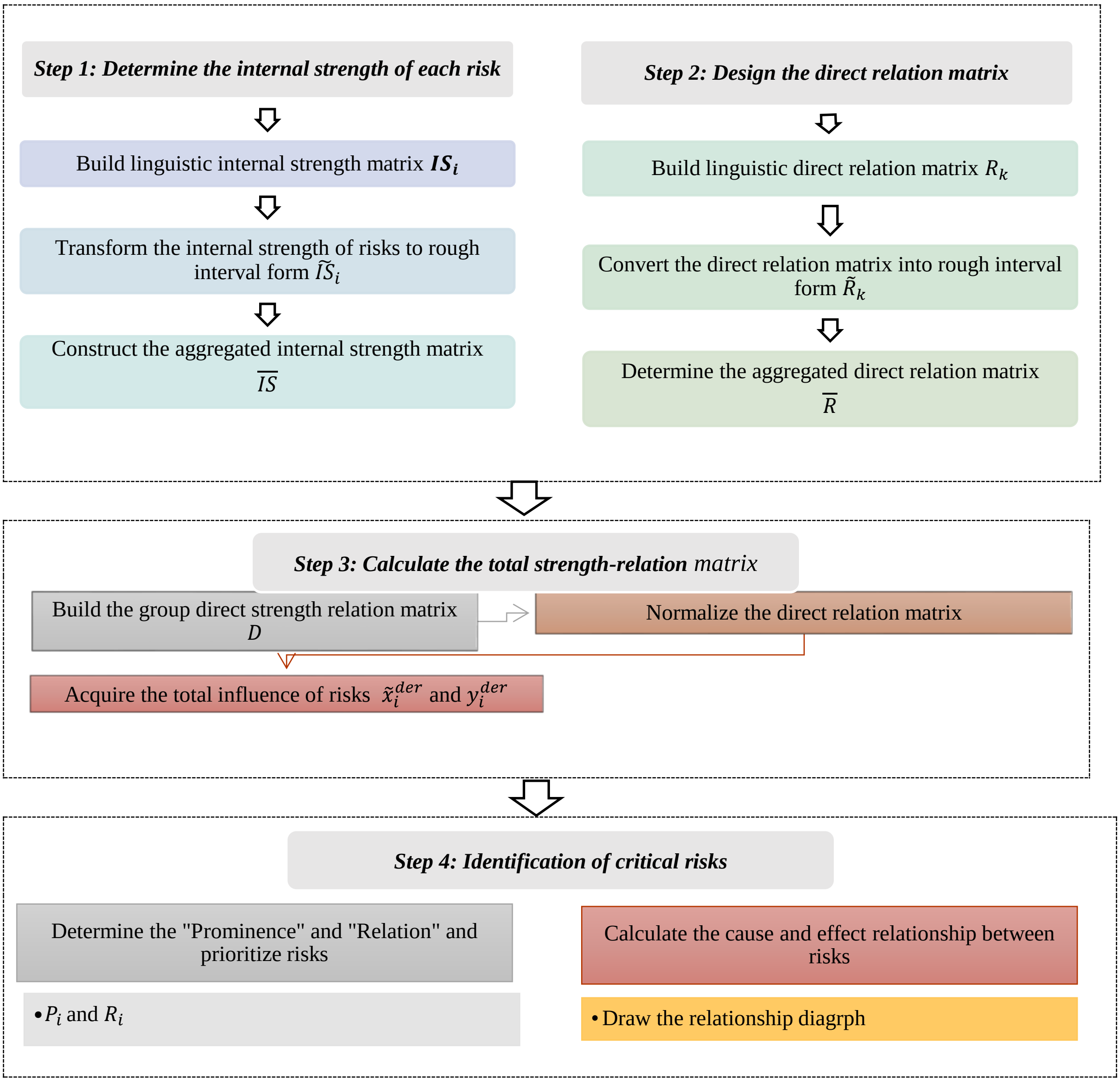


**Figure 3.** Proposed methodology

- ***Phase 1: Identification of risks under four dimension of sustainability through literature***

In this phase, the SSCM risks essential for dairy supply chain are identified through a literature survey. To this end, several keywords are used such as “sustainability risk assessment”, “supply chain for dairy industry”, “risk and dairy supply chain”, in different databases like Science direct, web of science and Google scholar. Table 5 presents the identified risks under four dimensions of sustainability for the dairy industry.

**Table 5.** Identification of risks under four elements of sustainability through literature

| Elements of sustainability | Risks | Reference |
|---|---|---|
| Environmental dimension | R1: Weather variability | (De Olivia et al, 2017) |
| | R2: Water scarcity | (Ginnakis et al, 2016) |
| | R3: Waste | (De Olivia et al, 2017) |
| | R4: Pollution | (De Olivia et al, 2017) |
| Social dimension | R5: Lack of linkage between institution, industry and government | (Cuncha et al, 2019) |
| | R6: Unhealthy and dangerous working environment | (Ginnakis et al, 2016) |
| | R7: Large number of intermediaries | (Ginnakis et al, 2016); |
| Economic risks | R8: Corruption | (Ginnakis et al, 2016) |
| | R9: Volatility of price and cost | (Song et al, 2017) |
| | R10: Inflation and currency exchange rates | (Song et al, 2017) |
| | R11: Financial crisis | (Ginnakis et al, 2016) |
| Operational risks | R12: Demand disruption | Sharma et al, 2020 |
| | R13: Transport Disruptions | Ivanov et al, 2020 |
| | R14: Lack of proper storage facilities | Karwasra et al, 2021 |

- ***Phase 2: Validation of risks under four dimension of sustainability by experts***

In this phase, the identified risks from literature survey are validated by experts. For this end, three experts working in milk collection center as showed in figure 4 are invited to identify the potential risks. The three experts validated all the risks under four dimensions filtered by the literature in phase 1.

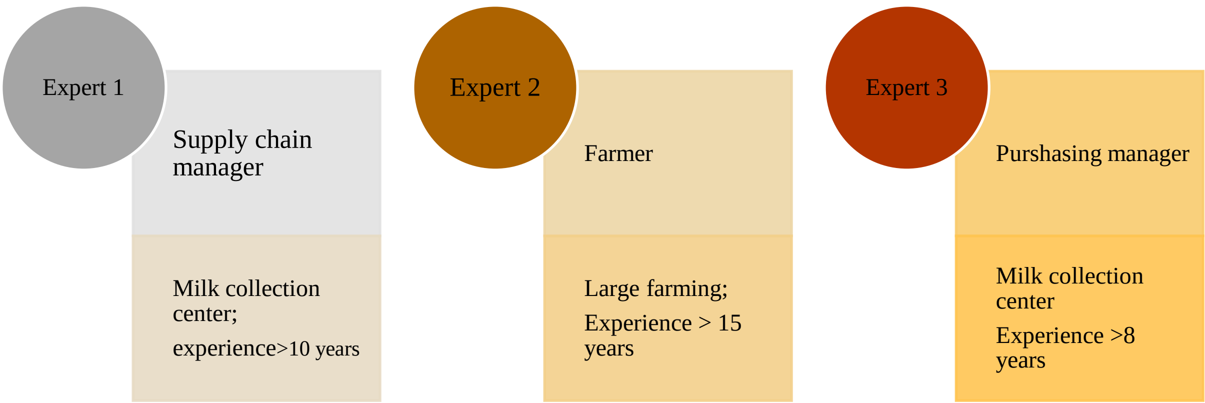


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**Figure 4.** Description of experts

- ***Phase 3: Prioritization of risks using rough DEMATEL method***

***1) Calculating the internal strength of risks***

In this step, the three decision makers are invited to evaluate the internal strength of different risks by linguistic terms according to table 1. All the internal strength of risks are provided in form of verbal scales are presented in table 6.

**Table 6.** The linguistic value of internal strength of sustainability risks with

| | **DM1** | **DM2** | **DM3** |
|---|---|---|---|
| **R1** | VHS | VHS | HS |
| **R2** | HS | VHS | MS |
| **R3** | HS | HS | VHS |
| **R4** | HS | HS | MS |
| **R5** | HS | MS | LS |
| **R6** | HS | HS | LS |
| **R7** | HS | MS | LS |
| **R8** | VHS | VHS | HS |
| **R9** | VHS | MS | VHS |
| **R10** | VHS | HS | HS |
| **R11** | HS | MS | HS |
| **R12** | VHS | MS | VHS |
| **R13** | VHS | MS | MS |
| **R14** | LS | HS | HS |

According to table 1, all the linguistic judgements in table 6 can be acquired by the crisp scores 0-4 according to table 1. The evaluation set of the first risk $R_1$by three experts can be presented as $IS_1 = \{VHS, VHS, HS\} = \{4,4,3\}$. $IS_1$ is converted into the rough interval form according to equations (1)-(5) as follows:

$$\overline{Lim}(4) = \frac{4+4}{2} = 4; \qquad \underline{Lim}(4) = \frac{4+4+3}{3} = 3.66$$

$$\overline{Lim}(3) = \frac{4+4+3}{3} = 3.66; \qquad \underline{Lim}(3) = \frac{3}{1} = 3$$

Then, $IS_1$ can be transformed into rough interval set as $\widetilde{IS}_1 = \{[3.66; 4]; [3.66; 4]; [3; 3.66]\}$. The others rough internal strength of risks can be calculated similarly.

Based on equation (7), the rough aggregated internal strength of risks under four dimensions of sustainability can be obtained in table 7.

**Table 7.** The rough interval strength of risks under four dimensions of sustainability

| **Risk** | **Internal strength of risk** | **Risk** | **Internal strength of risk** |
|---|---|---|---|
| **R1** | [3.44; 3.88] | R8 | [3.44; 3.88] |
| **R2** | [2.5; 3.5] | R9 | [2.88; 3.77] |
| **R3** | [2.5; 3.5] | R10 | [3.11; 3.55] |
| **R4** | [2.44; 2.88] | R11 | [2.44; 2.88] |
| **R5** | [1.5; 2.5] | R12 | [2.88; 3.77] |
| **R6** | [1.88; 2.77] | R13 | [2.22; 3.11] |
| **R7** | [1.83; 2.5] | R14 | [1.88; 2.77] |

### *2) Build the direct-relation matrix*

In this phase, the three experts evaluated the influence between risks by using the linguistic terms in the light of table 2 (see table 8). Then, the verbal score presented in table 8 is transformed into crisp number from 0 to 4 using table 3.

According to equation (8), three direct relation matrices $DR_j$ $j = (1,2,3)$ of sustainability risks are obtained. For example, table 9 shows the direct relation matrix of expert 1. The other matrices of $DR_1$ and $DR_2$ can be obtained similarly. The rough matrix $\widetilde{DR}_{kj}$ is calculated by using equations (1)-(5). According to equation (9) and (10), the three matrices are synchronized to obtain rough direct relation matrix $\widetilde{DR}$. According to equation (11), the aggregated rough direct relation matrix is reported in table 10.

**Table 8.** The verbal scores of direct relation matrix between risks

| | R1 | R2 | R3 | ... | R11 | R12 | R13 | R14 |
|---|---|---|---|---|---|---|---|---|
| R1 | NI, NI, NI | VHI, HI, HI | NI, NI, MI | ... | MI, MI, LI | VHI, HI, HI | MI, LI, NI | LI, MI, HI |
| R2 | NI, MI, MI | NI, NI, NI | LI, HI, MI | ... | VHI,VHI,HI | MI, MI, LI | HI, HI, VHI | HI, MI, MI |
| R3 | VHI,VHI, HI | VHI, HI, HI | NI, NI, NI | ... | MI, MI, LI | MI, MI, LI | HI, VHI, HI | MI, MI, LI |
| R5 | VHI, HI, HI | MI, MI, LI | MI, MI, LI | ... | MI, MI, LI | VHI,VHI, HI | MI, MI, LI | HI, HI, VHI |
| R5 | MI, LI, NI | HI, HI, VHI | MI, MI, LI | ... | VHI,VHI,HI | MI, MI, LI | MI, MI, LI | MI, MI, LI |
| R6 | NI, MI, NI | VHI, HI, HI | HI, HI, VHI | ... | MI, MI, LI | VHI,VHI,HI | VHI,VHI,HI | MI, MI, LI |
| R7 | MI, MI, LI | HI, HI, VHI | MI, MI, LI | ... | VHI,VHI,HI | MI, MI, LI | MI, MI, LI | NI, MI, NI |
| R8 | HI, VHI, HI | MI, MI, LI | HI, HI, VHI | ... | MI, MI, LI | HI, HI, VHI | HI, HI, VHI | MI, MI, LI |
| R9 | MI, MI, LI | VHI, HI, HI | NI, MI, NI | ... | HI, HI, VHI | MI, MI, LI | MI, MI, LI | HI, HI, VHI |
| R10 | MI, MI, LI | HI, HI, VHI | VHI, HI, HI | ... | MI, MI, LI | MI, MI, LI | MI, MI, LI | HI, VHI, HI |
| R11 | VHI, HI, HI | HI, HI, VHI | MI, MI, LI | ... | VHI, HI, HI | LI, HI, MI | MI, MI, LI | LI, HI, MI |
| R12 | HI, HI, VHI | VHI, HI, HI | MI, MI, LI | ... | HI, HI, VHI | MI, MI, LI | HI, HI, VHI | MI, MI, LI |
| R13 | HI, VHI, HI | LI, HI, MI | HI, HI, VHI | ... | MI, MI, LI | LI, HI, MI | NI, NI, NI | MI, MI, LI |
| R14 | LI, HI, MI | HI, VHI, HI | MI, MI, LI | ... | LI, HI, MI | MI, MI, LI | HI, HI, VHI | NI, NI, NI |

**Table 9.** The direct relation matrix $DR_1$

| | **R1** | **R2** | **R3** | ... | **R11** | **R12** | **R13** | **R14** |
|---|---|---|---|---|---|---|---|---|
| **R1** | 0 | 4 | 0 | ... | 2 | 4 | 2 | 1 |
| **R2** | 0 | 0 | 1 | ... | 4 | 2 | 3 | 3 |
| **R3** | 4 | 4 | 0 | ... | 2 | 2 | 3 | 2 |
| **R5** | 4 | 2 | 2 | ... | 2 | 4 | 2 | 3 |
| **R5** | 2 | 3 | 2 | ... | 4 | 2 | 2 | 2 |
| **R6** | 0 | 4 | 3 | ... | 2 | 4 | 4 | 2 |
| **R7** | 2 | 3 | 2 | ... | 4 | 2 | 2 | 0 |
| **R8** | 3 | 2 | 3 | ... | 2 | 3 | 3 | 2 |
| **R9** | 2 | 4 | 0 | ... | 3 | 2 | 2 | 3 |
| **R10** | 2 | 3 | 4 | ... | 2 | 2 | 2 | 3 |
| **R11** | 4 | 3 | 2 | ... | 4 | 1 | 2 | 1 |
| **R12** | 3 | 4 | 2 | ... | 3 | 2 | 3 | 2 |
| **R13** | 3 | 1 | 3 | ... | 2 | 1 | 0 | 2 |
| **R14** | 1 | 3 | 2 | ... | 1 | 2 | 3 | 0 |

**Table 10.** The aggregated direct-relation matrix (due to lack of space, only a portion of data is displayed)

| | R1 | R2 | R3 | … | R14 |
|---|---|---|---|---|---|
| R1 | [0; 0] | [2.22;3.1] | [2.33; 3.66] | … | [1.88; 2.77] |
| R2 | [0.11;0.55] | [0; 0] | [2.33; 3.66] | … | [3;3] |
| R3 | [1;1] | [2.22;3.1] | [0; 0] | … | [2;2] |
| … | … | … | … | … | … |
| R14 | [1;1] | [2.22;3.1] | [3.11;3.55] | … | [0; 0] |

***3) Determination of the total strength-relation matrix***

First, the internal strength of each risk is integrated into the diagonal of the matrix, which define the direct-relation matrix, to obtain the matrix using the equation (12). Afterward, the above matrix D is normalized and segmented into two sub-matrices using equations (13) and (14). According to equations (15), (16) and (17), we can obtain the total strength relation matrix T. Then, using equations (18) and (19), $\tilde{x}_i$ and $\tilde{y}_i$ are obtained. They indicated the overall influence of each risk. Based on equations (20) and (21), the rough numbers $\tilde{x}_i$ and $\tilde{y}_i$ are converted into crisp forms $x_i^{der}$ and $y_i^{der}$ to determine the "Prominence" and the "Relation".

***4) Calculation of the "Prominence" and "Relation"***

To sort risks and analyze the cause-effect relations between them, both equations (23) and (24) are used to calculate the "Prominence" $P_i$ and relation $R_i$ values. The results are presented in table 11.

**Table 11.** The values of Prominence, Relation and Ranking of sustainability risks

| Risk | $P_i$ | $R_i$ | Ranking |
|---|---|---|---|
| R1: Weather variability | 0.0496 | 0,119 | 11 |
| R2: Water scarcity | 0.0333 | 0,53 | 12 |
| R3: Waste | 0.075 | 0,192 | 8 |
| R4: Pollution | 0.023 | -0.1806 | 13 |
| R5: Lack of linkage between institution, industry and government | 0.1328 | 0,159 | 6 |
| R6: Unhealthy and dangerous working environment | 0.0147 | 0,1578 | 14 |
| R7: Large number of intermediaries | 0.3012 | -0.1537 | 1 |
| R8: Corruption | 0.1311 | -0.149 | 7 |
| R9: Volatility of price and cost | 0,1456 | 0,313 | 4 |
| R10: Inflation and currency exchange rates | 0.06 | 0,185 | 10 |
| R11: Financial crisis | 0.057 | -0.1853 | 9 |
| R12: Demand disruption | 0.1378 | 0,196 | 5 |
| R13: Transport Disruptions | 0.1643 | -0.204 | 3 |
| R 14: Lack of proper storage facilities | 0.272 | -0.1328 | 2 |

## 6. Results and Discussions

In this work, a literature review was performed to identify the risks under four dimensions of sustainability of the dairy industry, and three experts 'were invited to verify the relevance of these risks. The identified risks were sorted into environmental, economic, social and operational dimensions of sustainability according to literature review and experts 'opinions. Further, a rough DEMATEL was applied for ranking risks. The computed results are summarized in figure 5. Several practical insights can be derived as follows. Firstly, the results show that the most critical risk is "Large number of intermediaries (R7)" with the highest value of 0.3012. the managers should stress requirements of the efficient design of short milk supply chain in order to reduce the distances and eliminate informal intermediaries. The major objective in such cases is increasing productivity and the position of farmers in food markets (Sellito et al., 2018). Next the "Lack of proper storage facilities (R14)" received the second position with the weight of 0.272. This second ranking indicates that this risk should be seriously treated by managers to improve the dairy industry performance. As an emerging country, Tunisia suffers from the milk losses in the supply chain. This loss is mostly occurring in the first stage of production and collection. It is necessary for managers to remedy to the lack of storage equipment by proposing the design of collection centers for temporary storages for raw milk to reduce the loss and ensue the proper storage (Kazancoglu et al., 2018). Our findings suggest that "Transport disruption (R13)" can act as the third most important risk for the dairy industry with a weight of 0.1643. Transport disruption can be caused by different factors such as time uncertainty, traffic congestion, weather variability. Given the perishable nature of milk, the risk must be addressed in order to preserve the quality of product (Huang et al., 2019). In this study, "Volatility of price and cost (R9)" identified as the fourth risk with a weight of 0.1453. This risk can be a serious economic risk because the fluctuation of prices may cause negative consequences on the whole performance of supply chain. The risk "Demand disruption (R12)" holds the fifth position with a weight of 0.1378. Next, the sixth is risk "Lack of linkage between institution, industry and government (R5)" and the seventh risk is "Corruption".

The others risks are ranked as follows: $R3 < R11 < R10 < R1 < R2 < R4 < R6$. The ranking of all risks under four dimensions of sustainability is described in figure 5.

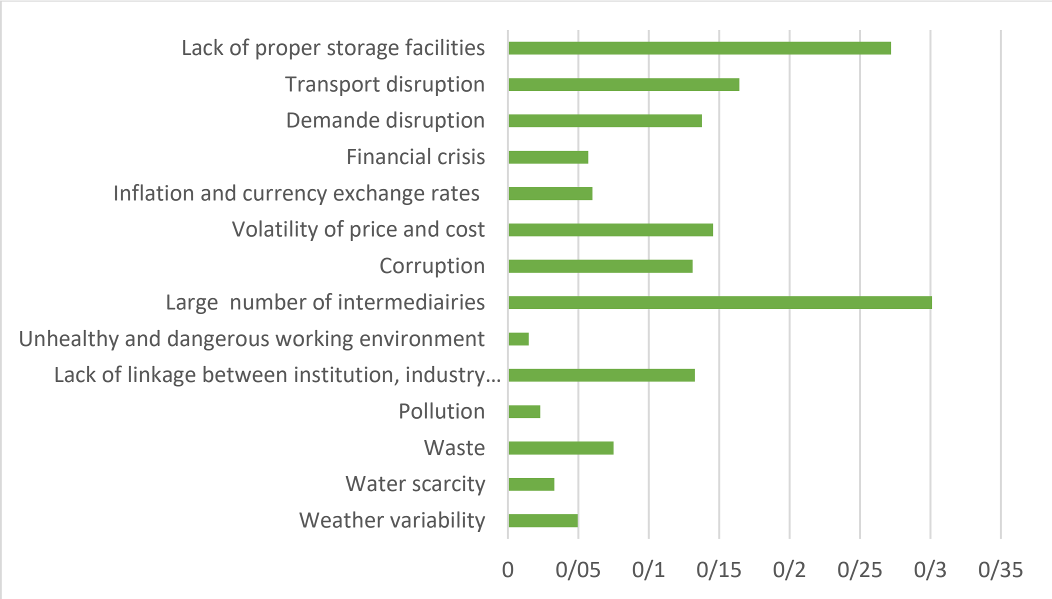


**Figure 5.** The ranking of risks under four dimensions of sustainability

Based on the value of "Prominence" and "Relation", the impact-relation map of risks can be shown by mapping the dataset of $(P_i;\ R_i)$, as illustrated in figure 6. The prominence axis shows how important a risk relative to the available set of SSCM risks, whereas the relation axis will divide the risks into cause and effect groups. All risks are divided into two categories based on $R_i$, as shown in table 11 and figure 6:

- ✓ Causes category with positive relation: There are eight risks: $R1$ (Weather variability); $R2$ (Water scarcity); $R3$ (Waste); $R5$ (Lack of linkage between institution, industry and government); $R6$ (Unhealthy and dangerous working environment); $R10$ (Inflation and currency exchange rates) and $R12$ (Demand disruption).
- ✓ Effect category with negative relationship: Other risks $R4$ (Pollution), $R7$ (Large number of intermediaries), $R8$ (Corruption), $R11$ (Financial crisis), $R13$ (Transport disruption) and $R14$ (Lack of proper storage facilities) are classified into effect group risks.

The results of risk assessment in the field of SSCM provide significant insights into the theory and practice. Based on our findings, decision makers can take specific measures to manage and deal with the most critical risks. From the theoretical perspective, this work develops a framework to prioritize SSCM risks by taking into account simultaneously the strength and the direct influence among risks. The proposed methodology could help managers to understand the mechanism of interactions between risks and make easier the implementation of reasonable risk management strategies.

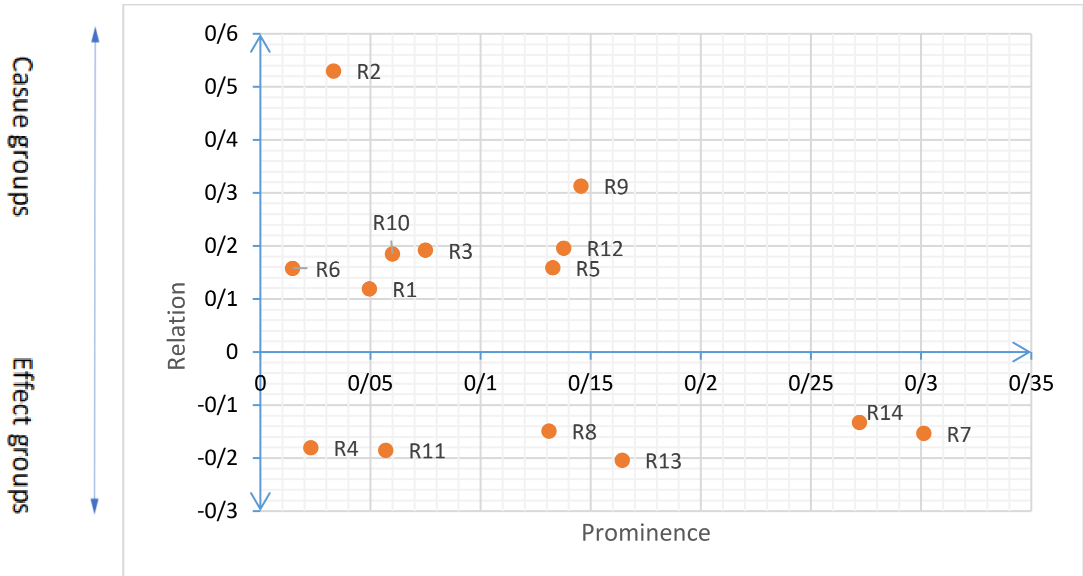


**Figure 6.** The cause-effect relation between risks under four dimensions of sustainability

**Table 12.** The comparative analysis between methods of ranking risks

| Risk | Rough DEMATEL | | Crisp DEMATEL | | AHP | |
|---|---|---|---|---|---|---|
| | Importance | Ranking | Importance | Ranking | Importance | Ranking |
| R1 | 0.0496 | 11 | 0.062 | 10 | 0,0675 | 6 |
| R2 | 0.0333 | 12 | 0.0475 | 12 | 0,1255 | 2 |
| R3 | 0.075 | 8 | 0.132 | 8 | 0,0805 | 5 |
| R4 | 0.023 | 13 | 0.028 | 13 | 0,0665 | 7 |
| R5 | 0.1328 | 6 | 0.32 | 2 | 0,1265 | 1 |
| R6 | 0.0147 | 14 | 0.0158 | 14 | 0,0445 | 12 |
| R7 | 0.3012 | 1 | 0.1352 | 7 | 0,0605 | 9 |
| R8 | 0.1311 | 7 | 0.125 | 9 | 0,0985 | 3 |
| R9 | 0,1456 | 4 | 0.135 | 6 | 0,0975 | 4 |
| R10 | 0.06 | 10 | 0.28 | 3 | 0,0425 | 13 |
| R11 | 0.057 | 9 | 0.048 | 11 | 0,035 | 14 |
| R12 | 0.1378 | 5 | 0.147 | 5 | 0,057 | 11 |
| R13 | 0.1643 | 3 | 0.1643 | 4 | 0,065 | 10 |
| R14 | 0.272 | 2 | 0.402 | 1 | 0,033 | 8 |

To validae the effectiveness and strengths of the proposed approach, a comparative analysis is performed to solve the same problem. The comparative methods include the crisp DEMATEL (Trivedi et al., 2021) and AHP (Nejad et al., 2021) methods. The ranking of fourteen risks under four dimensions of sustainability provided by each method is presented in table 12. Figure 7 presents the comparison of the ranikng of three methods. Some differences between the obtained results from three methods are obtained. The first comparison is conducted with the crisp DEMATEL. As seen in table 12 and and provided in figure 7, the ranking results obtained by the proposed approach and crisp DEMATEL are different except R2; R3; R4; R6 and R12. For instance, the risk R7 "Large number of intermediairies" is considered as the most important risk in the proposed framework and is obtained the rank 7 in the DEMATEL method R7(1→7). This is because the proposed method manipulate the uncertainty related to verbal judgement of experts by integrating the rough numbers. The second comparison is conducted with the results obtained by AHP. Using the AHP method, the obtained results are provided in table 12 and figure 7. As can be seen in table 12, only one risk R9 "Volatility of price and cost" has the same ranking with the proposed approach. The rankings of others risks obtained by the rough DEMATEL are different from those obtained by AHP method. This is due to the main disadvantage of the AHP that does not integrate the direct influece between risks into its framework.

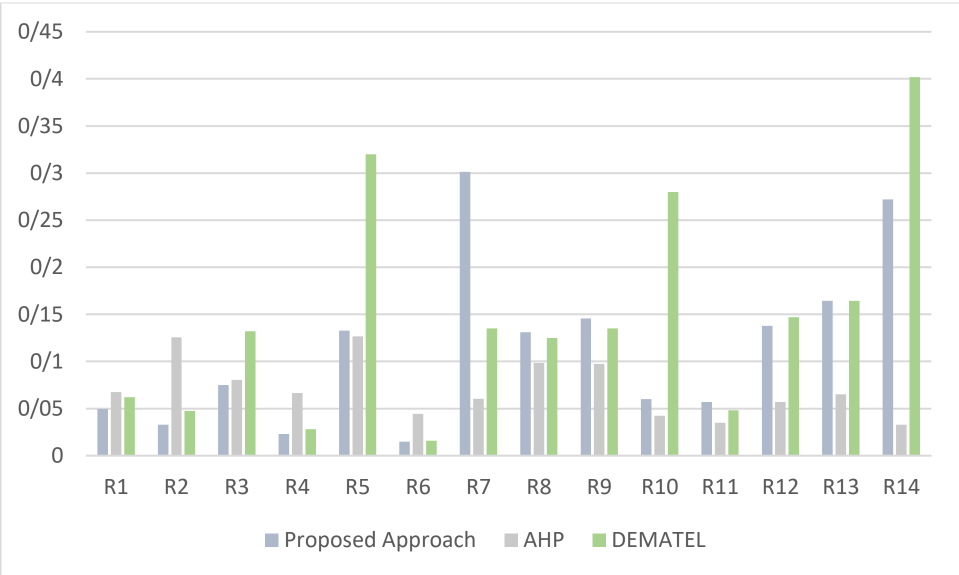


**Figure 7.** Comparative analysis of ranking risks by different approaches

## 7. Cconclusion

Although several works have investigated the supply chain risks, little consideration is paid to sustainable supply chain risk assessment that consist the idea of sustainability and the risk assessment simultaneously. This study fills the gaps of assessing the identified risks in SSCM by providing the interrelation of the two most important issues: sustainable supply chain management and risk assessment, which are treated mostly separately. This study aims to evaluate risks in sustainable dairy supply chain by developing an integrated rough-DEMATEL method that takes into consideration simultaneously the internal strength and external impact between various risks and manipulate the subjective judgement of different experts. A real-world case study was done to test the efficiency of the proposed method, which is a Tunisian dairy Company. The finding determined the ranking and interrelationship among the identified risks for an DSC. It was clear from the finding that that “Large number of intermediaries” is the most important risk for the supply chain. Other important risks are “Lack of proper storage facilities”, “Transportation disruption”, and “Volatility of price and cost”. On the other hand, the findings revealed that “Weather variability”, “Water scarcity”, “Lack of linkage between institutions”, “Financial crisis”, “Demand disruption” and “Lack of proper storage facilities” were obtained as causal risks. Whereas, the other risks were found as effect risks. Consequently, the obtained results are useful for dairy industries managers to select the best risk management strategies. In this research, a generic rough-DEMATEL model is presented for sustainable risk assessment in dairy industry case from Tunisia. The model is also expected to be applicable and beneficial to any other country context for improving the dairy supply chain. Additionally, this proposed framework can be investigated in other industrial domains of other regions. To do this, the decision-makers on a specific industry are invited to verify and validate the risks collected from literature. Then, a rough-DEMATEL method can be performed to find out the most critical risks related to the industry and to rank them into cause-and-effect groups. The proposed model can be linked with the probability that can help to measure the occurrence of risks and can be further extended and validated using other hybrid MCDM methods.

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