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A soft computing methodology to analyze sustainable risks in surgical cotton manufacturing companies

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Abstract. A well-organized sustainable risk management in an organization often generates environmental and economic advantages. Addressing "sustainability and risk" simultaneously, an organization is more capable of enduring challenges that produce environmental and operational stability in management. In an industrial organization, these primary areas of concern involve social responsibility and a focus on occupants' health and well-being; both areas address environmental and climate change, with an end result of increasing competitiveness and profitability. The key challenge lies in exploring sustainable risks associated with the industry so that they are addressed strategically. This research work is one such attempt to find sustainable risks in the manufacturing sector. This research is the outcome of a case study conducted in three leading surgical cotton manufacturing companies in the southern part of India. A hybrid multi criteria decision making based fuzzy decision making trial and evaluation laboratory and analytic network process with preference ranking organization method for enrichment evaluations (FDANP with PROMETHEE) methodologies is used to derive the results. The final outcome of this paper presents the identified critical sustainable risks from the case study, and also serves as a model for risk managers in manufacturing sectors. By identifying sustainable risks at an early stage, a company may avert the occurrence of undesirable incidents while, at the same time, may enhance their production capacity.

Keywords. Sustainability; risk factors; F-DEMATEL; ANP; PROMETHEE.

1. Introduction

Sustainability has become an important consideration for all industries over time. To establish sustainability, it is essential to consider social and ecological factors as well as economic ones. In modern business settings, manufacturers are interested in manufacturing products with sustainable practices not only to satisfy individual requirements but also for modest markets. Balancing the competing demands of social, economic, and environmental risks with regard to sustainability is difficult in any industrial process. If it is not managed properly, the company is likely to suffer negative influences. "An inability to sustain", "Not sure to hold on to the present sustainability perspectives in an organization in the future", "The probability of losing the present sustainable processes in an organization" can be termed as Sustainability Risks. In this case, surgical cotton manufacturing companies are considered to analyze some of the sustainable risk factors that have emerged over the last ten years; these factors affect production as well as economic profit. Sustainable risk factors are primarily based on the three pillars of sustainability: environmental, social, and economic factors. For enhancing and maintaining the status of the company in society, every company should handle these risk factors. It is always difficult to control these sustainable risks in surgical cotton manufacturing industries. To accomplish the aims of sustainability, companies need to improve all three pillars of social, economic, and environmental factors [1].

Social risk factors may include the development of a company's culture and infrastructure, retention of employees, as well as health and safety issues within the workplace environment. Economic factors involve R&D expenditures, training investment, and product costs and quality. Environmental management systems, eco-design, and the broader consequences on human health and welfare are typical environmental factors. Effective sustainable risk management outlines can assist administrations to recognize the incipient problems of concern that may influence the supply chain, operations, and/or production. Sustainable

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performance is possible only if there is an effective sustainable risk management system in place. Therefore, the goal of the study is to examine the risk factors for sustainability by using multi-criteria decision making methods like united Fuzzy Decision Making Trial and Evaluation Laboratory, Analytic Network Process with Preference Ranking Organization method for Enrichment Evaluations (FDANP with PROMETHEE). Further, sustainable risks are explored by several researchers [2–5].

Moreover, in developing nations like India, there is often a lack of improvement in sustainable risk (SR) in companies because growth and profits may take priority over working conditions. Therefore, there is a particular need to investigate a country like India since it varies from several other developing countries. This paper aims to assess effectual SR in an Indian scenario and will examine the optimistic impacts and significance of SR. The literature survey helps to identify the critical SR by recognizing the factors and subfactors. This study provides exclusive involvement on both technical and methodical affairs. Brans *et al* [6] initiated the PROMETHEE method to recognize the relationship among three or more factors dependent on mathematics and sociology. It has an extensive routine application in different domains such as marketing, education, production, and administration, and it is also used as a tactic to gauge ranking, priority, alternatives, and source distribution. Therefore, we selected the PROMETHEE method to choose the critical company. The methodology adopted in this paper helps to improve and expand present literature; it also examines SR in an Indian scenario, and it is considered a novel approach that various literature resources have not yet examined. The work carried out in this paper is not limited to the Indian scenario alone. In fact, this work is applicable for both developed and developing countries to identify sustainable risk. The objective or importance of this research is to seek answers to the following questions:

a) What are the major risks involved in sustainability?
b) What are the interrelationships among the risks in sustainability?
c) How will the major risks be categorized into effect and cause groups to provide valuable insights for managers by choosing the critical company and for implementing sustainability successfully into their company?

The remainder of the paper is arranged into seven sections. Section 2 delivers a literature survey related to social, economic, and environmental sustainability as well the use of MCDM tools. We also expose gaps in the currently available literature with certain stimulating research areas of inquiry. Our suggested outline is described in section 3. Section 4 offers a method to clarify and to define the problem. Assessing SR for the application of MCDM is explained in section 5. Thorough deliberations with managerial implications and our conclusions are shown in sections 6 and 7.

2. Literature review

The literature review is categorized into four different sub-sections. The first one delivers a summary of literatures related to sustainability risks. Risk assessment in three pillars of sustainability is discussed in the second sub-sections. The third sub-section discusses the sustainable risk assessment using MCDM methods and, finally, the fourth sub-section examines and recognizes the gaps in current research and provides the focus of this study. These four classifications ensure the comprehensive scope of the notions that are highlighted in this study.

2.1 *Sustainability*

Sustainability is the theory of meeting present demand requirements while simultaneously considering the capability to meet future demands [7]. Aligned with the pillars of the triple bottom line, sustainability includes the performance of social, economic, and environmental concepts [8]. Researchers and businesses have come to view sustainability as a vital method for diminishing depletion of energy, long term risk, product and pollution liabilities [9]. Sustainability is vital for stakeholders and industries, who embed it in the primary stages of their operations and planning [10]. Maintaining sustainability is significant for industries in rising nations to control any pessimistic effects on suppliers, customers, society, the environment, or local employees [11]. Many industries execute sustainability measures with the intention of enhanced turnover rate in the long run [12]. Sustainability perspectives are much needed and a perspective approach is required in order to achieve sustainability in an organization. Not only the industries need to concentrate on production, turn over and other commercial benefits but also need to focus on environmental impacts. Therefore in order to attain the sustainability, a perspective (approach) is required and this cannot be achieved until the risks associated with perspective are mitigated or eliminated. To achieve sustainability and follow the sustainable perspectives in an organization, the risks involved in sustainability should be be eliminated [12].

2.2 *Risk assessment in three pillars of sustainability*

Social sustainability is the model that develops well-being within an organization's members and encourages the capability of upcoming generations to enhance the community of health [13]. It covers issues that influence people such as equality, communities, employees, fairness, and diversity [14]. A case study in Portuguese manufacturing industries demonstrates their creation of a taxonomy for social sustainable practices. Through their evaluations, health and safety practices and local and sustainable sourcing are critical risks in social sustainability. They also framed some insights that are useful for practitioners for controlling risks [15]. Equity, urban forms, eco-presumption, and safety are the major functions for improving social sustainability [16]. Evans *et al* [17] performed a risk assessment for enhancing social sustainability in an Australian coal firm using Sustainability Opportunity and Threat Analysis (SOTA). Their findings showed that procedures of auditing, reporting requirements, and corporate policy directives can reduce differences in performance between sites and increase minimum standards.

Economic sustainability supports long-term development in the economic perspectives without pessimistically affecting the cultural, social, or environmental aspects of the community [18]. By means of economic development, human needs are fulfilled and also provide a sustainable environment for future generations [19]. A lack of viable leadership, poor frameworks and protocols without characterization, and too few effective approaches and mechanisms with inter-operability are the critical factors affecting economic sustainability [20]. Mujkic *et al* [21] reviewed the supply chain optimization and sustainability in industry and considered the interdependencies among the environmental, economic, and social dimensions. The outcomes signified that there are various models available for supply chain optimization addressing the dimensions of sustainability.

Because of the high pressure obtained from the organizations, the social trends of awareness and global regulatory procedures also influence to implement environmental sustainability [22]. Risk assessment in environmental impacts was initiated a few years ago, and its objective is to evaluate the impacts of any project including existing or new industrial activities [23]. It is the most conventional form of sustainability. Centobelli *et al* [24] suggested the framework for improving environmental sustainability in logistics service providers using the green initiatives taxonomy. Transport, logistics service, warehouse, and management are the major functions for enhancing environmental sustainability demonstrated in the results. Employee health and safety, global warming, biodiversity, and land use are the major factors for improving environmental sustainability while assessing the indicators of environmental sustainability in a pharmaceutical industry from a global perspective [25].

2.3 *Sustainable risk assessment using MCDM*

Decision makers face added difficulty when their problems include conflicting and intangible solutions. To overcome this issue, MCDM methods are suggested to measure the rankings of conflicting intangible/tangible criteria and to select the best rank for a decision [26]. Multi-criteria decision making method is widely used in various sectors with different applications to solve the problems in decision making [27]. Mehregan *et al* [28] analyzed the criteria for the sustainable supplier selection using Fuzzy DEMATEL and ISM method; their case study was conducted in a gas industry to achieve the efficiency of suggested method. The results projected that local development, human resource capability, and technology are the best criteria for sustainable supplier selection. Vinodh and Girubha [29] identified the best orientation for the selection of sustainable concepts in the manufacturing industry using PROMETHEE method, and their results confirmed that material change is best for achieving sustainability in the manufacturing industry. Xu *et al* [30] examined the factors influencing sustainable building energy efficiency and determined the interrelationship between each factor in hotel buildings using ANP method. Major factors included the team leader's organizing capacity, trust, technical skills of the team leader, and the available technology as the primary outcomes that need to be improved. Table 1 summarizes recent literature resources that are related to sustainable risk assessment using MCDM.

2.4 *Research gap and focuses*

To achieve sustainability in their business and to trade in world markets, industry needs to be more proficient in the various processes that define sustainability. India is one of the rising nations and their industries have lacked in knowledge about sustainability. Sustainability means meeting current requirements without compromising the capability of upcoming generations to meet future requirements. This literature review recognizes the risk factors involved in the sustainability process in various industrial sectors. However, organizations may face different obstacles while undertaking the initiatives of sustainability. As a result, the influence of a particular risk factor may vary from industry to industry. In the literatures, the risk factors are not always adequately depicted; in fact, sometimes a critical element in the sustainability process is missing. To fulfill this gap, this study seeks to determine the most influential risks and the most pivotal company in the sustainability process for the case study. Accordingly, this paper uses a hybrid MCDM method for evaluating the interrelationship between various risk factors and for ranking the companies in the process of sustainability. Moreover, this paper contains several areas of emphasis that are detailed as follows:

- Recognize factors and subfactors of SR from the literature survey as well as from domain and industrial specialists that are listed in Table 2.
- Suggest an outline to assess the critical SR and company in an Indian scenario with the assistance of a hybrid multi-criteria decision making method.
- Verify the suggested outline with a case study from three local surgical cotton manufacturing companies.

Table 1. Recent literature related to sustainable risk assessment using MCDM.

MCDM methods	Application	References
SWARA and COPRAS	Iranian highway projects	[31]
AHP	Construction management in Turkish	[32]
Fuzzy TOPSIS and CRITIC	Petrochemical industry	[33]
Fuzzy MOORA	Iran electronic companies	[34]
Fuzzy VIKOR	Energy projects in Pakistan	[35]

The outcomes obtained are then contrasted with available literature.

3. Suggested outline

This research uses a three stage methodology. Questionnaire survey method is used in the first stage to determine the risk factors. Subsequently, FDANP is used in the second stage to evaluate the risk factors. In the third/final stage, companies are ranked based on the types of risks according to their respective streams using PROMETHEE method. Figure 1 shows the research outline of this paper.

3.1 *Stage I: Questionnaire survey method*

Questionnaire survey method is an assessment tool to arrive at the inputs based on the decisions obtained from the expert's panel. According to Ren and Luo [62], the decisions obtained from the team of experts are more specific than done by a disorganized team. After meeting with the experts their perspectives are gathered and examined individually by noting the inputs with due considerations [63]. In this process, experts are randomly selected based on the skill set as well as with the considerable experience in particular organizations to obtain fruitful decisions. With this process, the opinions based on the skill sets and experiences of adequate number of experts are used to derive the rating of the factors. And so, the questionnaire survey method is considered as an useful tool for choosing and evaluating the risk factors to ensure the sustainability in the success of risk management system. In this research, meetings were arranged with relevant experts to initiate the inputs. Table 2 shows a set of most important sustainable risks in the surgical cotton manufacturing companies finalized based on the opinions from experts given in "Appendix B".

3.2 *Stage II: Fuzzy DEMATEL – Analytic Network Process (FDANP)*

Satty [64] said that ANP is the extended version of AHP. This stage-by-stage method to examining the factors and sub-factors is modified from [65, 66]. In this paper, we combined Fuzzy DEMATEL and ANP to avert the unreasonable weighted super matrix which is acquired by superposition of equivalent weights for every cluster. Fuzzy DEMATEL is a multi-criteria decision making approach designed and employed to assess different risk factors. Many researchers [67–70] used Fuzzy DEMATEL effectively in their issues. The stage-by-stage method for FDANP is stated below [71–73].

Phase 1: Compute the initial relationship matrix 'P'

The first phase of FDANP is to compute the initial relationship matrix 'P' dependent on the comments from domain and industrial specialists' replies, on a scale fluctuating from 0 to 4. 0 is 'no impact', 1 is 'very low impact', 2 is 'low impact', 3 is 'high impact', and 4 is 'very high impact'.

$$P = \begin{bmatrix} 1 & p12 & p13 & \dots & p1(n-1) & p1n \\ p21 & 1 & p23 & \dots & p2(n-1) & p2n \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ p(n-1)1 & p(n-1)2 & p(n-2)3 & \dots & 1 & p(n-1)n \\ pn1 & pn2 & pn3 & \dots & pn(n-1) & 1 \end{bmatrix} \quad (1)$$

Phase 2: Compute the normalized direct relationship matrix 'Z'

The P found in phase 1 is normalized across the equations

Table 2. Factors and Subfactors for choosing critical SR.

Factors	Subfactors	Brief description	References
Social Factors (F1)	Workplace health and safety (SF1)	Workplace surroundings are full of disturbances so the employees and their workplace health and safety is important	[36, 37]
	Human rights & biodiversity (SF2)	It is essential for development of social sustainability. If biodiversity is higher, then there are more sustainable resources in environment	[38]
	Employee retention (SF3)	It refers to an organization's ability to keep its workers for a given period of time	[39, 40]
	Wages (SF4)	Wages must be sufficient for employees to meet their basic requirements	[41]
	Cultural development (SF5)	The development of culture in industries can assist managers in building their resilience while adjusting to fast changes in the global economy; it is based on ingenuity and on individual creativity	[42]
	Infrastructure development (SF6)	To accomplish better perspective for the industry, infrastructure needs to be more sustainable	[43]
	Grievance redressal system (SF7)	A suitable redressal system provides an opportunity for temporary or permanent employees or supervisors to settle grievances promptly	[44]
Economical Factors (F2)	Expenditure on R & D (SF8)	It meets both future and current demands of the industry	[45, 46]
	Investment in training (SF9)	It is the actual cost of training program to teach employees about the sustainability standards	[47]
	Product costs (SF10)	It determines the cost of final products and includes warranty, maintenance, and processing costs	[48]
	Delivery reliability (SF11)	It is the ratio of number of deliveries made without any error to the number of deliveries in a given period of time	[49]
	Quality (SF12)	It is based on quality assurance and rejection ratio	[50]
	Technology capability (SF13)	It provides strength for the technology in organization and provides chances to make it competitive	[51]
	Traditional financial information (SF14)	It provides data about the resource changes, enterprises, and claims and it is useful in evaluating prospects of cash flow	[52]
Environmental Factors (F3)	Eco design (SF15)	It is the kind of product design for reducing material consumption, recovery, reuse, material recovery and avoiding hazardous materials usage	[53, 54]
	Pollution production & transportation (SF16)	Ease of production and transportation with environmental concerns	[55]
	Environmental management system (SF17)	To maintain environmental certification like control and checking of environmental activities, environmental policies, and ISO 14000	[56]
	Emissions (SF18)	It is any pollutant that is discharged into the surrounding environment in the form of vapor or gas and that is harmful to the environment because of burning fossil fuels	[57]
	Human health and welfare (SF19)	Make sure employees' lives are promoted in matters of health and welfare	[58, 59]
	Global warming & other environmental effects (SF20)	This is the long-term rise in the normal temperature of climate system in earth	[60]
	Impact of products (SF21)	This impacts the health and environment of the public during their overall life cycle	[61]

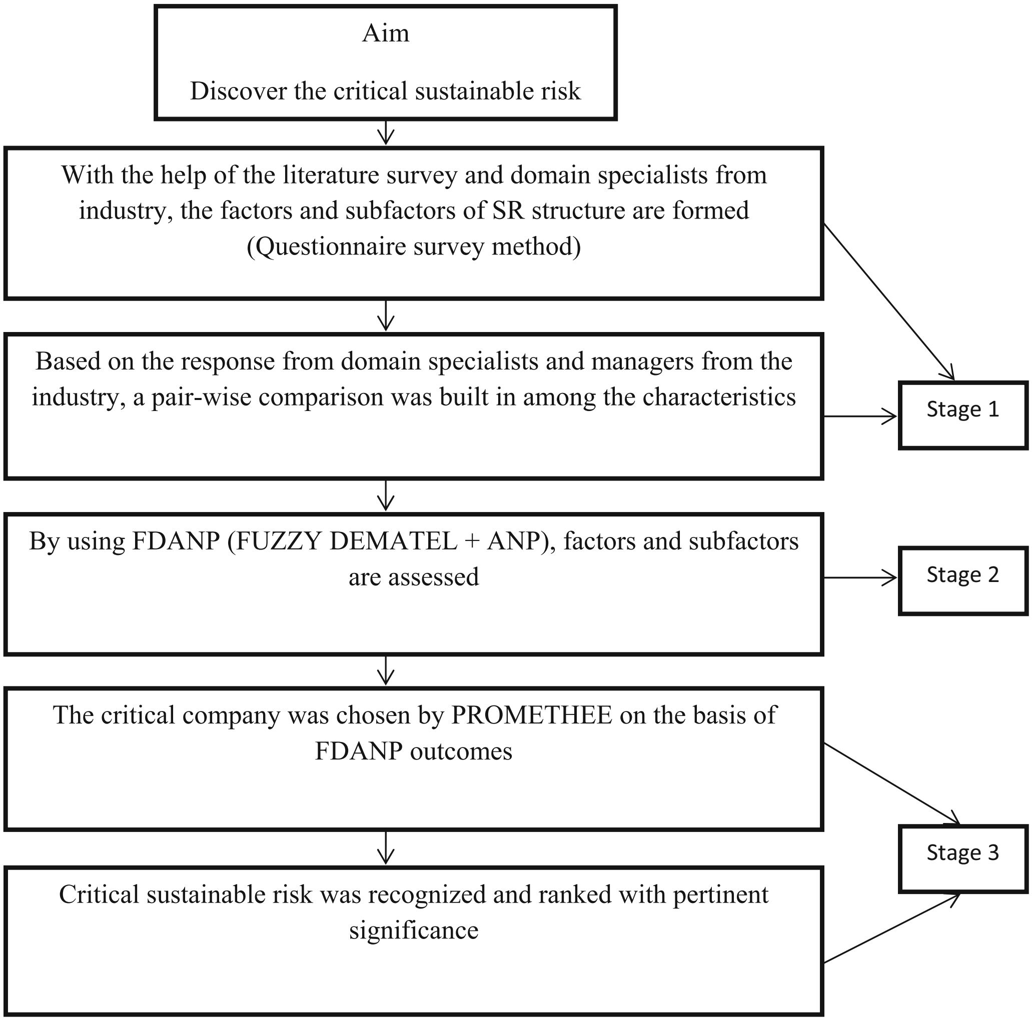

Figure 1. Suggested outline for recognizing the critical SR.

$$M = \frac{1}{\max_{1 \le i \le n}} \sum_{j=1}^{n} I_{ij} \tag{2}$$

$$Z = M \times P \tag{3}$$

Phase 3: Compute the total-influence matrix 'TI'

The following phase recognizes the total-influence matrix. It is found with the help of 'Z' which is computed in the past phase by using Eq (4) where I denotes the Identity matrix.

$$TI = Z + Z^2 + \cdots + Z^g = Z(I - Z)^{-1}, \text{ when } \lim_{g \to \infty} Z^g = [0]_{n \times n} \tag{4}$$

Description,

$$TI = Z + Z^2 + \cdots + Z^g = Z(I + Z + Z^2 + \cdots + Z^{g-1})$$
$$(I - Z)(I - Z)^{-1} = Z(I - Z^g)(I - Z)^{-1}$$

Then,

$$TI = Z(I - Z)^{-1}, \; when \; g \to \infty$$

Phase 4: Compute the summation of rows and columns

$'ro'$ and $'co'$ indicate the summation of rows and columns. It is acquired through Eqs. (5) and (6).

$$ro = [ro_i]_{n \times 1} = \left[\sum_{j=1}^{n} TI_{ij} \right]_{n \times 1}, \tag{5}$$

$$co = [co_j]_{n \times 1} = \left[\sum_{i=1}^{n} TI_{ij} \right]'_{1 \times n} \tag{6}$$

$$TI = [ti_{ij}], \quad i,j = 1, 2, \ldots, n,$$

Phase 5: Build up Causal figure

If ro_i is the summation of ith row in matrix TI, then ro_iindicates the summation of impact of factor i on various factors. If co_j is the summation of jth column in matrix TI, then co_j indicates the summation of impact of factor j on various factors. $'ro'$ and $'co'$ help to build up the causal figure.

Phase 6: Compute an unweighted super matrix 'UW'

The total-influence matrix of factors and subfactors is specified as T_S and T_F. T_S is acquired as seen in Eq (7)

$$T_S = \begin{bmatrix} T_S^{11} & \dots & T_S^{1j} & \dots & T_S^{1n} \\ \dots & \dots & \dots & \dots & \dots \\ T_S^{i1} & \dots & T_S^{ij} & \dots & T_S^{in} \\ \dots & \dots & \dots & \dots & \dots \\ T_S^{n1} & \dots & T_S^{nj} & \dots & T_S^{nn} \end{bmatrix} \quad (7)$$

The total-influence matrix T_S is normalized by subfactors and the normalized matrix is specified as T_S^{β} as in Eq (8).

$$T_S^{\beta} = \begin{bmatrix} T_S^{\beta 11} & \dots & T_S^{\beta 1j} & \dots & T_S^{\beta 1n} \\ \dots & \dots & \dots & \dots & \dots \\ T_S^{\beta i1} & \dots & T_S^{\beta ij} & \dots & T_S^{\beta in} \\ \dots & \dots & \dots & \dots & \dots \\ T_S^{\beta n1} & \dots & T_S^{\beta nj} & \dots & T_S^{\beta nn} \end{bmatrix} \quad (8)$$

Normalization $T_S^{\beta 11}$ is described in brief, and exhibited as Eqs (9) – (10), and other $T_S^{\beta nn}$ esteems are beyond.

$$e_{si}^{11} = \sum_{j=1}^{m_1} t_{sij}^{11}, \quad i = 1, 2, \dots, m_1$$

$$T_S^{\beta 11} = \begin{bmatrix} t_{S11}^{11}/e_{s1}^{11} & \dots & t_{S1j}^{11}/e_{S1}^{11} & \dots & t_{S1m_1}^{11}/e_{S1}^{11} \\ \dots & \dots & \dots & \dots & \dots \\ t_{Si1}^{11}/e_{Si}^{11} & \dots & t_{Sij}^{11}/e_{Si}^{11} & \dots & t_{Sim_1}^{11}/e_{Si}^{11} \\ \dots & \dots & \dots & \dots & \dots \\ t_{Sm_1 1}^{11}/e_{Sm_1}^{11} & \dots & t_{Sm_1 J}^{11}/e_{Sm_1}^{11} & \dots & t_{Sm_1 m}^{11}/e_{Sm_1}^{11} \end{bmatrix} \quad (9)$$

$$= \begin{bmatrix} t_{S11}^{\beta 11} & \dots & t_{S1j}^{\beta 11} & \dots & t_{S1m_1}^{\beta 11} \\ \dots & \dots & \dots & \dots & \dots \\ t_{Si1}^{\beta 11} & \dots & t_{Sij}^{\beta 11} & \dots & t_{Sim_1}^{\beta 11} \\ \dots & \dots & \dots & \dots & \dots \\ t_{Sm_1 1}^{\beta 11} & \dots & t_{Sm_1 J}^{\beta 11} & \dots & t_{Sm_1 m_1}^{\beta 11} \end{bmatrix} \quad (10)$$

An unweighted supermatrix is the total influence matrix that wants to be equivalent and which packs in the inter-reliance exhibited in Eq (11). This process is completed through transposing the normalized influence matrix T_S^{β} by subfactors.

$$UW = \left(T_S^{\beta}\right)' . UW = \left(T_S^{\beta}\right)'$$

$$= \begin{bmatrix} UW^{11} & \dots & UW^{i1} & \dots & UW^{n1} \\ \dots & \dots & \dots & \dots & \dots \\ UW^{1j} & \dots & UW^{ij} & \dots & UW^{nj} \\ \dots & \dots & \dots & \dots & \dots \\ UW^{1n} & \dots & UW^{in} & \dots & UW^{nn} \end{bmatrix} \quad (11)$$

If the matrix among the factors is impartial and with no inter-reliance, then it is affirmed that the matrix UW^{11} is empty or 0 as exhibited in Eq (12) and the various UW^{nn} esteems are further.

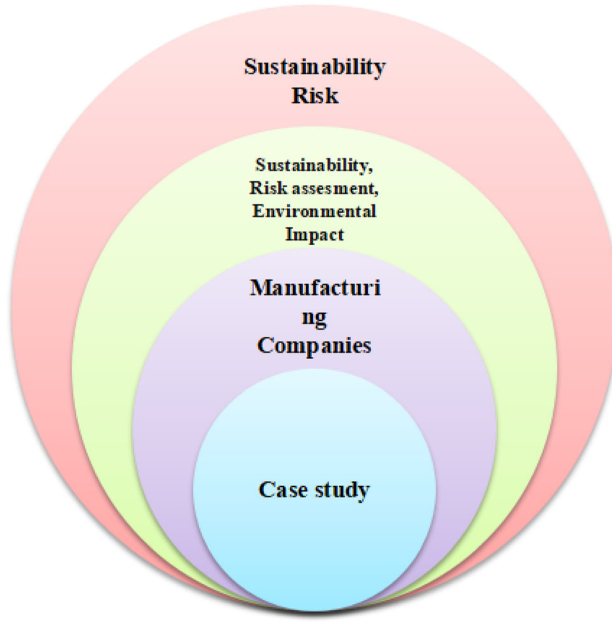

Figure 2. Scope diagram of our study.

$$UW^{11} = \begin{bmatrix} t_{S11}^{\beta 11} & \dots & t_{Si1}^{\beta 11} & \dots & t_{Sm_1 1}^{\beta 11} \\ \dots & \dots & \dots & \dots & \dots \\ t_{S1j}^{\beta 11} & \dots & t_{Sij}^{\beta 11} & \dots & t_{Sm_1 j}^{\beta 11} \\ \dots & \dots & \dots & \dots & \dots \\ t_{S1m_1}^{\beta 11} & \dots & t_{Sim_1}^{\beta 11} & \dots & t_{Sm_1 m_1}^{\beta 11} \end{bmatrix} \quad (12)$$

Phase 7: Compute the weighted super matrix

To find the weighted super matrix, there is a need for normalization which originates from the summation on every column as exhibited in Eq (13).

$$T_F = \begin{bmatrix} t_F^{11} & \dots & t_F^{1j} & \dots & t_F^{1n} \\ \dots & \dots & \dots & \dots & \dots \\ t_F^{i1} & \dots & t_F^{ij} & \dots & t_F^{in} \\ \dots & \dots & \dots & \dots & \dots \\ t_F^{n1} & \dots & t_F^{nj} & \dots & t_F^{nn} \end{bmatrix} \quad (13)$$

We normalized the total-influence matrix T_F and acquired a new matrix T_F^{β} as depicted in Eq (14) (where $t_F^{\beta ij} = t_F^{ij}/e_i$).

$$T_F^{\beta} = \begin{bmatrix} t_F^{11}/e_1 & \dots & t_F^{1j}/e_1 & \dots & t_F^{1n}/e_1 \\ \dots & \dots & \dots & \dots & \dots \\ t_F^{i1}/e_i & \dots & t_F^{ij}/e_i & \dots & t_F^{in}/e_i \\ \dots & \dots & \dots & \dots & \dots \\ t_F^{n1}/e_n & \dots & t_F^{nj}/e_n & \dots & t_f^{nn}/e_n \end{bmatrix}$$

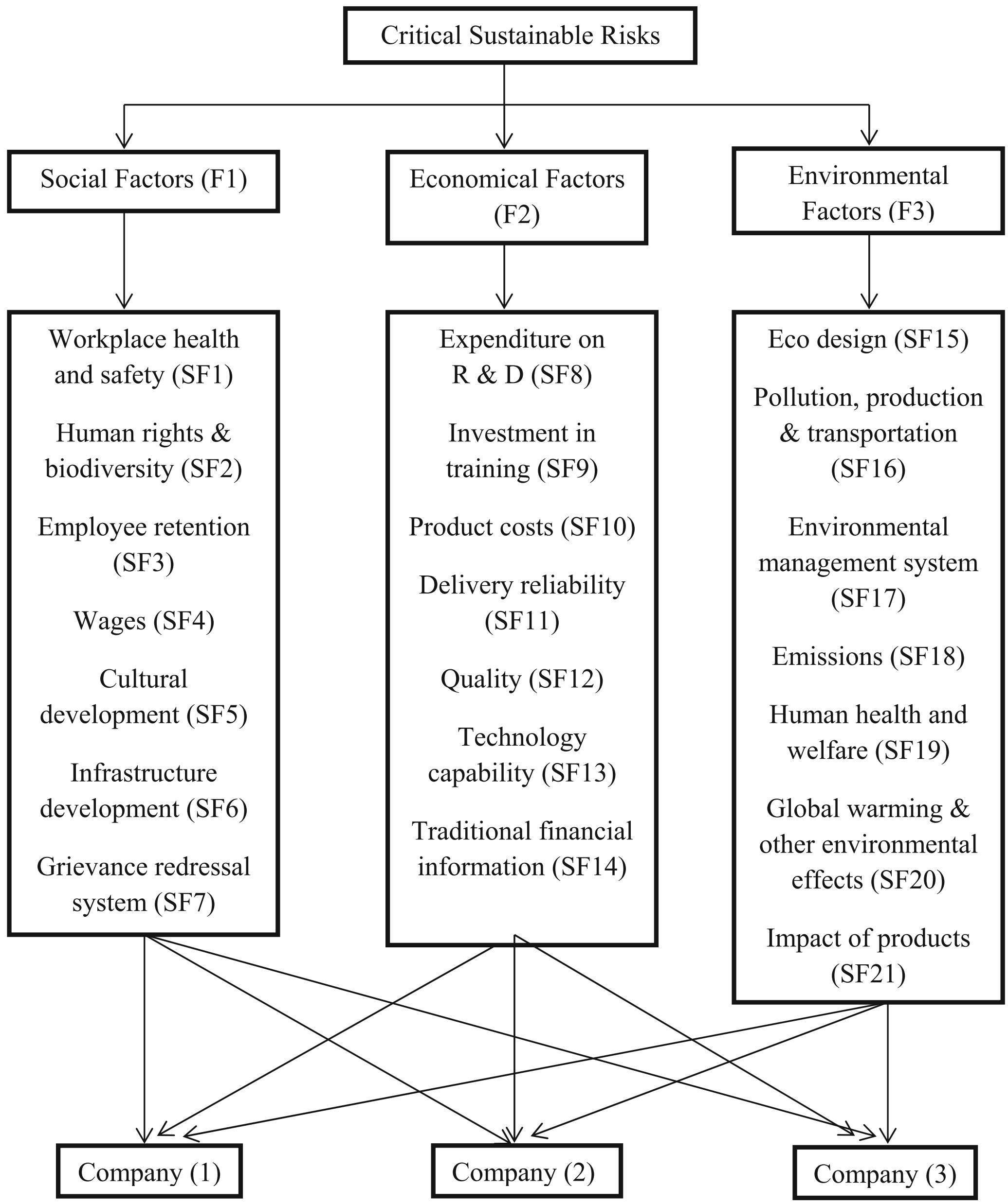

Figure 3. The ranked replica for choosing SR.

$$= \begin{bmatrix} t_F^{\beta 11} & \dots & t_F^{\beta 1j} & \dots & t_F^{\beta 1n} \\ \dots & \dots & \dots & \dots & \dots \\ t_F^{\beta i1} & \dots & t_F^{\beta ij} & \dots & t_F^{\beta in} \\ \dots & \dots & \dots & \dots & \dots \\ t_F^{\beta n1} & \dots & t_F^{\beta nj} & \dots & t_F^{\beta nn} \end{bmatrix} \tag{14}$$

The normalized total-influence matrix T_F^{β} has to be multiplied by the unweighted super matrix to get the weighted super matrix which appears in Eq (15).

$$WE^{\beta} = T_F^{\beta} \times UW$$
$$= \begin{bmatrix} t_F^{\beta 11} \times UW^{11} & \dots & t_F^{\beta i1} \times UW^{i1} & \dots & t_F^{\beta n1} \times UW^{n1} \\ \dots & \dots & \dots & \dots & \dots \\ t_F^{\beta 1j} \times UW^{1j} & \dots & t_F^{\beta ij} \times UW^{ij} & \dots & t_F^{\beta nj} \times UW^{nj} \\ \dots & \dots & \dots & \dots & \dots \\ t_F^{\beta 1n} \times UW^{1n} & \dots & t_F^{\beta in} \times UW^{in} & \dots & t_F^{\beta nn} \times UW^{nn} \end{bmatrix} \tag{15}$$

Phase 8: Limit the weighted super matrix

By expanding it to sufficiently high power f, it is essential to limit the weighted super matrix until it has

Table 3. Initial Influence matrix for subfactor 'P_{SF}'.

Subfactors	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SF 10	SF11	SF12	SF13	SF14	SF15	SF16	SF17	SF18	SF19	SF20	SF21
SF1	0	1	1	2	1	3	3	1	4	1	1	1	2	0	4	4	4	1	4	1	3
SF2	1	0	2	2	1	1	1	2	1	2	0	0	0	1	3	2	1	0	3	1	0
SF3	2	1	0	3	1	1	0	1	2	1	0	0	0	2	1	0	1	0	1	0	0
SF4	1	1	3	0	1	1	0	0	2	1	0	1	0	2	0	3	0	0	3	1	2
SF5	1	1	2	0	0	1	1	1	2	0	2	1	1	1	1	0	1	0	3	0	1
SF6	4	1	1	1	1	0	2	3	1	0	0	0	2	3	4	2	2	2	1	1	2
SF7	3	1	1	0	2	3	0	2	2	3	3	2	2	2	3	1	3	1	4	1	3
SF8	1	1	2	2	1	2	2	0	2	3	1	3	1	3	1	0	0	0	1	0	3
SF9	2	1	1	1	2	1	1	1	0	1	0	0	1	3	1	0	0	0	3	0	0
SF10	0	2	1	3	2	0	3	1	0	0	1	1	0	3	0	0	0	0	1	0	4
SF11	0	1	2	0	1	0	3	0	0	1	0	1	0	1	0	3	0	1	1	0	3
SF12	0	1	1	0	2	3	2	4	3	3	1	0	3	3	2	2	1	3	1	2	3
SF13	3	0	1	0	1	4	2	2	1	2	0	2	0	3	2	1	1	1	0	1	2
SF14	2	1	1	3	1	3	2	2	3	3	2	4	2	0	2	4	3	1	1	1	2
SF15	4	1	1	0	1	4	2	1	0	0	0	2	1	2	0	2	4	2	3	3	3
SF16	3	1	1	0	1	2	2	1	0	1	3	0	1	2	2	0	2	3	2	3	3
SF17	4	1	1	0	2	4	3	3	2	0	0	2	2	3	3	2	0	2	3	3	3
SF18	3	1	0	0	1	2	3	1	1	0	0	0	2	2	1	3	1	0	1	3	2
SF19	4	2	2	0	2	2	3	1	3	1	0	1	1	2	2	2	2	2	0	3	1
SF20	3	1	0	0	0	2	3	2	1	0	0	0	2	3	3	3	3	3	4	0	2
SF21	2	3	2	3	2	2	4	4	3	4	3	4	3	3	2	3	2	2	3	2	0

Table 4. Initial influence matrix for Factors 'P_F'.

	F1	F2	F3
F1	0	4	3
F2	3	0	3
F3	3	4	0

united and turned into a constant super matrix to acquire the global priority ratings, known as FDANP (Fuzzy DEMATEL based ANP) influential weights. For instance, $\lim_{f\to\infty}\left(WE^{\beta}\right)^{f}$ where f signifies slight or no powers [74].

3.3 *Stage III: PROMETHEE*

Brans *et al* [6] suggested that PROMETHEE is an outranking technique. Albadvi *et al* [75] said that PROMETHEE was the finest appropriate technique if a finite set of alternatives was to be ranked.

3.3a Rankings of PROMETHEE: The rankings depend on their stream – departing, arriving, and total stream – which is detailed as follows.

Departing stream is described as the summation of amounts of arc of departing node 'p' and is depicted in Eq (16).

$$\phi^{+}(p) = \sum_{q \in f} II(p,q) \tag{16}$$

Arriving stream computes the outranked type of 'p', which appears in Eq (17).

$$\phi^{-}(p) = \sum_{q \in f} II(q,p) \tag{17}$$

Hence, the total stream is

$$\phi(p) = \phi^{+}(p) - \phi^{-}(p) \tag{18}$$

3.3.b PROMETHEE I: PROMETHEE I is the incomplete preorder of (A_1, J_1, C) acquired by deliberating the connection of two preorders, and it is affirmed by the incomplete preorder which is denoted beneath in Eq (19). Departing and arriving streams will be recognized in PROMETHEE.

$$\begin{array}{ll} pA_1q\,(\text{p outranks q}) & \text{if } pA^{+}q \text{ and } pA^{-}q, \\ & \text{Or } pA^{+}q \text{ and } pA^{-}q, \\ & \text{Or } pA^{+}q \text{ and } pA^{-}q; \\ pJ_1q\,(\text{p is dissimilar to q}) & \text{if } pJ^{+}q \text{ and } pJ^{-}q; \\ pCq\,(\text{p and q are unequaled}) & \text{if } pJ^{+}q \text{ and } pJ^{-}q; \\ & \text{Else} \end{array} \tag{19}$$

3.3c PROMETHEE II: PROMETHEE II gives the impartial preorder and is persuaded by the total stream. The impartial preorder appears in Eq (20):

$$\begin{array}{ll} pA_{11}b\,(\text{p outranks q}) & \text{if } \phi(p) > \phi(q) \\ pJ_{11}q\,(\text{p is similar to q}) & \text{if } \phi(p) = \phi(q) \end{array} \tag{20}$$

4. Assessment of SR for the application of hybrid MCDM

With the intention of exemplifying the proposed system, we examined three leading surgical cotton manufacturing companies, each with ISO certification, in the southern region of India. Their managers were approached for further assistance. Although the managers expressed their willingness to participate in this study, they had some restrictions from their stakeholders and pressures from the workplace. Surgical cotton manufacturing companies have faced critical sustainability problems over the past ten years. These companies manufacture surgical cotton for medical purposes in four shifts, with labor provided by 5,000 employees, both directly and indirectly. They produce around 15,000 bundles of surgical cotton per day. During the process the companies have to consider several factors related to sustainability. Until now, it was very difficult to discover the critical SR from the three companies for well-organized sustainable management. Hence, to recognize the critical SR, our group helps them with our suggested outline (figure 1). The phases for recognizing the SR are deliberated below. The scope diagram for our study is shown in figure 2.

Phase 1: Shape the factors for recognizing the critical SR

The first phase is to shape the factors to choose the critical SR from the three local case companies. The factors are shaped by using the literature survey, specialists' views, and managers' views from the industries. We deliberated upon three factors and 21 subfactors for the assessment of SR. Depending on the factors and details of the industry, the issue was separated into the flow chart depicted in figure 3.

Phase 2: Questionnaire survey method and pair-wise comparison

Data for this research is gathered through questionnaire survey method based on the sustainable risks those exist in surgical cotton manufacturing companies. This survey is conducted involving experts from three surgical cotton manufacturing companies in India by providing questionnaires. The survey questions seek to isolate risk factors in sustainability and to obtain expert opinions about the collected risk factors and their inter-dependencies. Initially, the pilot interviews have been arranged with experts to discuss and consult about risk factors. Pilot interviews are organized for the managers from three companies and five domain experts are briefed about the significance of the study by inviting them through mobile and mails to participate in the meeting. In this study only five experts were approached, but each of the five experts was well-versed about SR. They were from different fields: one from the

Table 5. Normalized direct influence matrix (Z) for subfactor.

Subfactors	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SF10	SF11	SF12	SF13	SF14	SF15	SF16	SF17	SF18	SF19	SF20	SF21
SF1	0.006	0.020	0.020	0.037	0.020	0.053	0.053	0.020	0.069	0.020	0.020	0.020	0.037	0.006	0.069	0.069	0.069	0.020	0.069	0.020	0.053
SF2	0.020	0.006	0.037	0.037	0.020	0.020	0.020	0.037	0.020	0.037	0.006	0.006	0.006	0.020	0.053	0.037	0.020	0.006	0.053	0.020	0.006
SF3	0.037	0.020	0.006	0.053	0.020	0.020	0.006	0.020	0.037	0.020	0.006	0.006	0.006	0.037	0.020	0.006	0.020	0.006	0.020	0.006	0.006
SF4	0.020	0.020	0.053	0.006	0.020	0.020	0.006	0.006	0.037	0.020	0.006	0.020	0.006	0.037	0.006	0.053	0.006	0.006	0.053	0.020	0.053
SF5	0.020	0.020	0.037	0.006	0.006	0.020	0.020	0.020	0.037	0.006	0.037	0.020	0.020	0.020	0.020	0.006	0.020	0.006	0.053	0.006	0.020
SF6	0.069	0.020	0.020	0.020	0.020	0.006	0.037	0.053	0.020	0.006	0.006	0.006	0.037	0.053	0.069	0.037	0.037	0.037	0.020	0.020	0.037
SF7	0.053	0.020	0.020	0.006	0.037	0.053	0.006	0.037	0.037	0.053	0.053	0.037	0.037	0.037	0.053	0.020	0.053	0.020	0.069	0.020	0.053
SF8	0.020	0.020	0.037	0.037	0.020	0.037	0.037	0.006	0.037	0.053	0.020	0.053	0.020	0.053	0.020	0.006	0.006	0.006	0.020	0.006	0.053
SF9	0.037	0.020	0.020	0.020	0.037	0.020	0.020	0.020	0.006	0.020	0.006	0.006	0.020	0.053	0.020	0.006	0.006	0.006	0.053	0.006	0.006
SF10	0.006	0.037	0.020	0.053	0.037	0.006	0.053	0.020	0.006	0.006	0.020	0.020	0.006	0.053	0.006	0.006	0.006	0.006	0.020	0.006	0.069
SF11	0.006	0.020	0.037	0.006	0.020	0.006	0.053	0.006	0.006	0.020	0.006	0.020	0.006	0.020	0.006	0.053	0.006	0.020	0.020	0.006	0.053
SF12	0.006	0.020	0.020	0.006	0.037	0.053	0.037	0.069	0.053	0.053	0.020	0.006	0.053	0.053	0.037	0.037	0.020	0.053	0.020	0.037	0.053
SF13	0.053	0.006	0.020	0.006	0.020	0.069	0.037	0.037	0.020	0.037	0.006	0.037	0.006	0.053	0.037	0.020	0.020	0.020	0.006	0.020	0.037
SF14	0.037	0.020	0.020	0.053	0.020	0.053	0.037	0.037	0.053	0.053	0.037	0.069	0.037	0.006	0.037	0.069	0.053	0.020	0.020	0.020	0.037
SF15	0.069	0.020	0.020	0.006	0.020	0.069	0.037	0.020	0.006	0.006	0.006	0.037	0.020	0.037	0.006	0.037	0.069	0.037	0.053	0.053	0.053
SF16	0.053	0.020	0.020	0.006	0.020	0.037	0.037	0.020	0.006	0.020	0.053	0.006	0.020	0.037	0.037	0.006	0.037	0.053	0.037	0.053	0.053
SF17	0.069	0.020	0.020	0.006	0.037	0.069	0.053	0.053	0.037	0.006	0.006	0.037	0.037	0.053	0.053	0.037	0.006	0.037	0.053	0.053	0.053
SF18	0.053	0.020	0.006	0.006	0.020	0.037	0.053	0.020	0.020	0.006	0.006	0.006	0.037	0.037	0.020	0.053	0.020	0.006	0.020	0.053	0.037
SF19	0.069	0.037	0.037	0.006	0.037	0.037	0.053	0.020	0.053	0.020	0.006	0.020	0.020	0.037	0.037	0.037	0.037	0.037	0.006	0.053	0.020
SF20	0.053	0.020	0.006	0.006	0.006	0.037	0.053	0.037	0.020	0.006	0.006	0.006	0.037	0.053	0.053	0.053	0.053	0.053	0.069	0.006	0.037
SF21	0.037	0.053	0.037	0.053	0.037	0.037	0.069	0.069	0.053	0.069	0.053	0.069	0.053	0.053	0.037	0.053	0.037	0.037	0.053	0.037	0.006

Table 6. Total influence matrix 'TI' for subfactor.

Sub-Factors	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SF 10	SF11	SF12	SF13	SF14	SF15	SF16	SF17	SF18	SF19	SF20	SF21
SF1	0.097	0.070	0.073	0.079	0.075	0.134	0.133	0.087	0.134	0.075	0.062	0.075	0.093	0.091	0.144	0.139	0.135	0.075	0.152	0.080	0.133
SF2	0.073	0.036	0.069	0.064	0.053	0.069	0.068	0.074	0.061	0.069	0.031	0.039	0.038	0.070	0.096	0.079	0.061	0.038	0.102	0.055	0.056
SF3	0.075	0.043	0.032	0.075	0.045	0.057	0.043	0.050	0.069	0.046	0.025	0.032	0.031	0.074	0.055	0.041	0.051	0.029	0.060	0.031	0.044
SF4	0.072	0.051	0.084	0.037	0.053	0.067	0.055	0.047	0.078	0.056	0.033	0.053	0.040	0.086	0.051	0.096	0.047	0.039	0.101	0.054	0.098
SF5	0.065	0.046	0.065	0.031	0.035	0.062	0.063	0.055	0.073	0.037	0.057	0.049	0.049	0.063	0.059	0.044	0.055	0.033	0.094	0.035	0.061
SF6	0.141	0.060	0.063	0.059	0.064	0.078	0.105	0.107	0.078	0.054	0.042	0.055	0.084	0.119	0.132	0.099	0.096	0.080	0.091	0.069	0.105
SF7	0.137	0.070	0.073	0.052	0.090	0.132	0.090	0.103	0.104	0.108	0.093	0.092	0.092	0.118	0.127	0.093	0.118	0.073	0.148	0.076	0.134
SF8	0.078	0.057	0.075	0.073	0.060	0.092	0.094	0.056	0.086	0.097	0.052	0.094	0.061	0.112	0.072	0.059	0.053	0.043	0.078	0.044	0.111
SF9	0.080	0.046	0.048	0.045	0.064	0.062	0.061	0.053	0.043	0.050	0.028	0.036	0.049	0.093	0.059	0.045	0.042	0.032	0.094	0.034	0.048
SF10	0.054	0.067	0.055	0.083	0.069	0.053	0.099	0.061	0.050	0.045	0.049	0.057	0.040	0.101	0.050	0.051	0.045	0.036	0.071	0.038	0.116
SF11	0.050	0.047	0.064	0.031	0.049	0.047	0.094	0.042	0.042	0.053	0.032	0.050	0.036	0.063	0.045	0.089	0.041	0.048	0.063	0.036	0.094
SF12	0.086	0.066	0.068	0.051	0.086	0.127	0.113	0.131	0.113	0.107	0.061	0.060	0.105	0.132	0.105	0.102	0.081	0.100	0.095	0.087	0.128
SF13	0.116	0.043	0.058	0.043	0.061	0.130	0.098	0.088	0.072	0.080	0.039	0.080	0.051	0.114	0.095	0.076	0.073	0.060	0.068	0.061	0.099
SF14	0.119	0.069	0.073	0.097	0.075	0.132	0.117	0.103	0.118	0.109	0.079	0.122	0.092	0.090	0.110	0.139	0.116	0.074	0.102	0.076	0.120
SF15	0.151	0.066	0.067	0.048	0.070	0.146	0.114	0.085	0.072	0.058	0.046	0.087	0.076	0.113	0.082	0.107	0.134	0.089	0.130	0.107	0.128
SF16	0.124	0.061	0.062	0.044	0.064	0.104	0.107	0.076	0.062	0.066	0.087	0.053	0.068	0.103	0.100	0.071	0.094	0.097	0.105	0.100	0.120
SF17	0.160	0.071	0.074	0.054	0.092	0.155	0.138	0.123	0.109	0.067	0.051	0.095	0.098	0.138	0.134	0.114	0.081	0.093	0.139	0.112	0.137
SF18	0.116	0.055	0.043	0.038	0.058	0.097	0.112	0.069	0.069	0.048	0.039	0.047	0.079	0.095	0.078	0.106	0.072	0.046	0.082	0.093	0.095
SF19	0.143	0.078	0.080	0.046	0.082	0.108	0.122	0.078	0.111	0.068	0.043	0.066	0.070	0.107	0.104	0.100	0.097	0.082	0.081	0.100	0.090
SF20	0.134	0.064	0.052	0.046	0.055	0.114	0.128	0.096	0.082	0.057	0.045	0.058	0.089	0.126	0.123	0.120	0.117	0.102	0.142	0.061	0.110
SF21	0.138	0.112	0.102	0.109	0.103	0.134	0.167	0.149	0.134	0.140	0.104	0.136	0.120	0.154	0.126	0.140	0.115	0.100	0.152	0.103	0.109

Table 7. Total of influences provided and received on a subfactor.

	ro_i	co_i	$ro_i + co_i$	$ro_i - co_i$
SF1	2.135	2.209	4.344	– 0.073
SF2	1.305	1.278	2.583	0.026
SF3	1.010	1.378	2.388	– 0.368
SF4	1.299	1.203	2.502	0.096
SF5	1.133	1.405	2.538	– 0.272
SF6	1.782	2.101	3.883	– 0.319
SF7	2.125	2.120	4.244	0.005
SF8	1.546	1.733	3.279	– 0.187
SF9	1.114	1.761	2.875	– 0.647
SF10	1.291	1.492	2.782	– 0.201
SF11	1.114	1.100	2.214	0.014
SF12	2.005	1.437	3.442	0.568
SF13	1.605	1.463	3.068	0.142
SF14	2.132	2.163	4.295	– 0.032
SF15	1.975	1.947	3.922	0.028
SF16	1.769	1.910	3.679	– 0.141
SF17	2.237	1.723	3.960	0.514
SF18	1.536	1.371	2.907	0.165
SF19	1.856	2.150	4.006	– 0.294
SF20	1.922	1.455	3.377	0.467
SF21	2.648	2.138	4.786	0.509

Table 8. Total of influences provided and received on a factor.

Factors	ro_i	co_i	$ro_i + co_i$	$ro_i - co_i$
F1	6.875	7.39849	14.27349	– 0.52349
F2	6.786765	7.39849	14.18525	– 0.61173
F3	7.875	6.739785	14.61478	1.135215

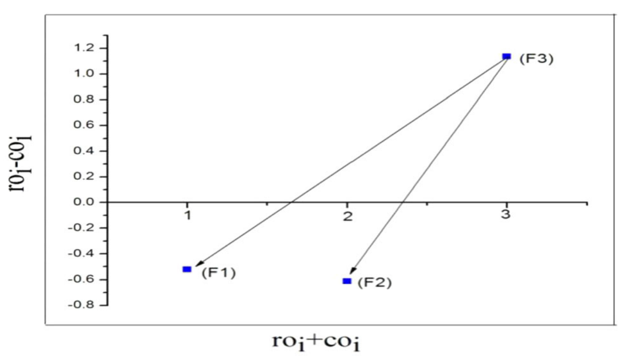

Figure 4. Causal figure for factors.

government sector, two from industrial sectors, and two from NGOs. After the consultation with experts, the questionnaire have been developed based on the five-point

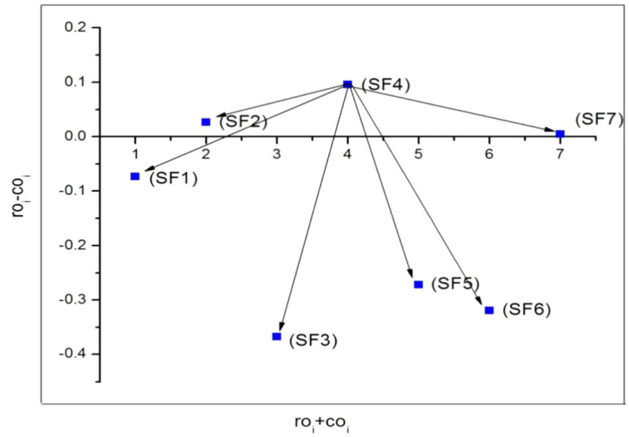

Figure 5. Causal figure for subfactors under F1.

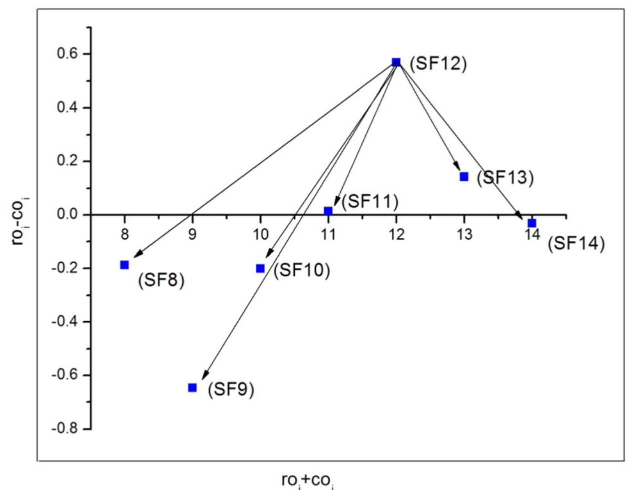

Figure 6. Causal figure for subfactors under F2.

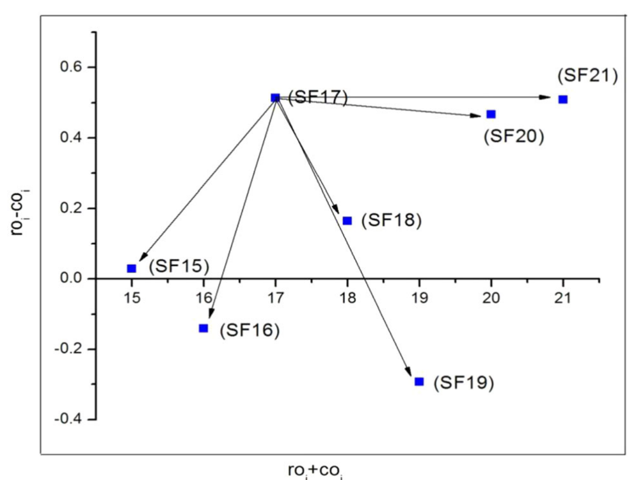

Figure 7. Causal figure for subfactors under F3.

Table 9. The unweighted super matrix 'UW'.

Sub-Factors	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SF 10	SF11	SF12	SF13	SF14	SF15	SF16	SF17	SF18	SF19	SF20	SF21
SF1	0.061	0.037	0.028	0.036	0.032	0.051	0.059	0.042	0.031	0.036	0.031	0.056	0.045	0.060	0.057	0.051	0.063	0.044	0.053	0.055	0.074
SF2	0.060	0.037	0.028	0.037	0.032	0.050	0.060	0.044	0.031	0.037	0.032	0.056	0.045	0.061	0.056	0.050	0.062	0.043	0.052	0.054	0.074
SF3	0.060	0.037	0.029	0.036	0.032	0.050	0.060	0.044	0.031	0.038	0.031	0.056	0.044	0.061	0.055	0.050	0.062	0.043	0.051	0.053	0.076
SF4	0.058	0.036	0.028	0.037	0.032	0.050	0.060	0.045	0.031	0.038	0.032	0.057	0.046	0.060	0.055	0.050	0.062	0.043	0.052	0.053	0.075
SF5	0.060	0.036	0.028	0.036	0.032	0.050	0.060	0.044	0.031	0.037	0.032	0.056	0.045	0.061	0.056	0.050	0.062	0.043	0.052	0.054	0.075
SF6	0.060	0.036	0.028	0.036	0.031	0.051	0.060	0.043	0.031	0.036	0.031	0.056	0.045	0.060	0.057	0.050	0.063	0.044	0.052	0.055	0.074
SF7	0.060	0.036	0.028	0.036	0.032	0.050	0.061	0.043	0.031	0.036	0.031	0.057	0.045	0.060	0.057	0.051	0.063	0.043	0.052	0.054	0.074
SF8	0.060	0.035	0.028	0.036	0.031	0.050	0.060	0.044	0.030	0.037	0.032	0.056	0.046	0.061	0.057	0.050	0.063	0.044	0.052	0.054	0.074
SF9	0.059	0.036	0.028	0.036	0.032	0.050	0.060	0.044	0.032	0.037	0.031	0.055	0.045	0.060	0.057	0.050	0.063	0.043	0.052	0.054	0.074
SF10	0.059	0.035	0.028	0.036	0.032	0.050	0.059	0.045	0.031	0.038	0.032	0.056	0.045	0.061	0.056	0.050	0.063	0.043	0.051	0.054	0.075
SF11	0.059	0.036	0.028	0.037	0.031	0.050	0.059	0.044	0.031	0.038	0.033	0.057	0.046	0.060	0.056	0.050	0.063	0.044	0.052	0.054	0.074
SF12	0.060	0.036	0.028	0.036	0.031	0.051	0.060	0.044	0.031	0.038	0.031	0.057	0.045	0.060	0.056	0.050	0.063	0.043	0.051	0.055	0.074
SF13	0.060	0.036	0.028	0.036	0.031	0.050	0.060	0.043	0.030	0.036	0.031	0.056	0.046	0.060	0.058	0.051	0.064	0.044	0.053	0.055	0.074
SF14	0.061	0.036	0.028	0.036	0.032	0.050	0.060	0.044	0.030	0.036	0.031	0.057	0.045	0.061	0.056	0.050	0.063	0.043	0.052	0.054	0.075
SF15	0.060	0.036	0.028	0.036	0.031	0.050	0.059	0.043	0.031	0.036	0.031	0.056	0.045	0.060	0.058	0.051	0.064	0.044	0.053	0.055	0.074
SF16	0.059	0.036	0.029	0.036	0.032	0.051	0.060	0.043	0.031	0.037	0.031	0.056	0.045	0.060	0.057	0.052	0.063	0.043	0.052	0.054	0.074
SF17	0.060	0.036	0.028	0.036	0.031	0.051	0.059	0.043	0.031	0.036	0.031	0.056	0.045	0.059	0.057	0.051	0.064	0.044	0.053	0.055	0.073
SF18	0.061	0.036	0.027	0.036	0.031	0.050	0.060	0.043	0.030	0.036	0.031	0.055	0.045	0.061	0.058	0.051	0.064	0.044	0.052	0.055	0.074
SF19	0.060	0.036	0.029	0.036	0.031	0.051	0.059	0.043	0.031	0.037	0.031	0.056	0.045	0.060	0.056	0.051	0.063	0.044	0.053	0.054	0.074
SF20	0.061	0.036	0.028	0.036	0.031	0.051	0.060	0.043	0.031	0.036	0.032	0.055	0.045	0.061	0.057	0.051	0.063	0.043	0.052	0.056	0.074
SF21	0.060	0.037	0.028	0.035	0.031	0.050	0.060	0.044	0.031	0.036	0.031	0.056	0.045	0.061	0.056	0.051	0.062	0.043	0.052	0.054	0.076

Table 10. New matrix attained by normalizing in dimensions TI_F^{β}.

Factors	F1	F2	F3
F1	0.308	0.308	0.345
F2	0.314	0.314	0.318
F3	0.378	0.378	0.338

linguistic scale (Likert scale), which is shown in "Appendix A". A five-point linguistic scale is used to measure attitudes from respondents by allocating numerical values on the importance of every risk factor. According to Zhang *et al* [76] it is the easiest understanding method for collecting opinions on the importance level of the factors. Based on the representation of the linguistic scale, experts who participated in the meetings were requested to rate the factors from 0 to 4 points. An example question is 'Does the social factor (F1) have an impact on economic factors (F2)'?. Similarly, the questionnaire is developed relevant to every specific factor and all subfactors. Lastly, the pair-wise comparison is formulated with the help of comments obtained from all experts who participated in the pilot interviews. Finally, FDANP+PROMETHEE method is used to analyze the survey data. The outcomes of this research are then validated and interpreted through inputs from experts.

Phase 3: Examining the factors and sub-factors using FDANP

To assess the SR, we evaluated initially the factors and their corresponding sub-factors using FDANP. As deliberated in the previous phase, examining the sub-factors with FDANP was made via some stages which include:

(i) Computing the initial relationship matrix 'P'

Depending on the comments from industrial managers and experts, the initial relationship matrix for factors and sub-factors was framed using Eq (1) and it appears in tables 3 and 4 in "Appendix A", correspondingly. Although the same processes are adopted to recognize the factors and sub-factors, only the mathematical calculations are given for the sub-factors.

(ii) Computing the normalized direct relationship matrix 'Z'

The P is normalized by Eqs (2) and (3) to shape the normalized direct relationship matrix 'Z' which appears in table 5 in "Appendix A".

(iii) Computing the total influence matrix 'TI'

Z is obtained through Eq (4) to acquire the total-influence matrix 'TI' which appears in table 6 in "Appendix A".

(iv) Computing the summation of rows and columns

By using TI, the summation of rows and columns is computed; the summation of rows is denoted as $'ro_i'$ and the summation of columns $'co_i'$ with the help of the Eqs (5) and (6), both factors and sub-factors are presented in tables 7 and 8 in "Appendix A".

(v) Building causal figure

The causal figure consists of two axes, one framed by $ro_i + co_i$ and other by $ro_i - co_i$ shown in X and Y axis, respectively. The factor placed on the upper side of the figure is the most impacting factor among the others. The factor on the lower side of the figure is the smallest impacting factor among the others. The causal figure for both factors and sub-factors appears in figures 4, 5, 6, and 7.

(vi) Constructing an unweighted super matrix and weighted super matrix

The unweighted super matrix 'UW' (table 9) is found by using Eqs (7), (8), and (11). Then the new factors of normalized matrix 'TI_F^{β}' (table 10) and weighted super matrix 'we^{β}' (table 11) are found by using Eqs (13) – (15).

(vii) Limiting the weighted super matrix

The final stage of FDANP is to limit the weighted super matrix given in table 12 in "Appendix A" and specified as $\lim_{f\to\infty}\left(WE^{\beta}\right)^{f}$.

Phase 4: Assessing the critical SR using PROMETHEE method

Depending on the FDANP outcomes, critical SR is assessed by using PROMETHEE and exhibited in table 13 in "Appendix A". PROMETHEE I and PROMETHEE II stream outcomes appear in figuress 8 and 9, respectively.

5. Discussion and managerial implications

By using Fuzzy DEMATEL, the sustainable risk factors and sub-factors were assessed and outcomes summarized as seen in figures 4, 5, 6, and 7. Figure 4 demonstrates the impact among the factors and exposes that F3 (Environmental factors) is the one that impacts other factors in SR execution. In India, many industries aimed for only quick production as well as turnover; hence, in many companies SR is very high. This is due to the poor management and lack of knowledge among the personnel on the execution of SR. Due to external pressures from shareholders, clients, and related organizations it is necessary to find the range of SR execution with regard to developing nations. The precedence of factors rank in the following order: F3 > F1 > F2. Together with these factors, every single sub-factor is investigated to show its impact on SR execution. As demonstrated from Fuzzy DEMATEL, the computations are pursued with ANP and PROMETHEE. Table 13 in Appendix A shows that SR total stream values as -0.049, -

Table 11. The weighted super matrix 'we^{β}'.

Sub-Factors	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SF 10	SF11	SF12	SF13	SF14	SF15	SF16	SF17	SF18	SF19	SF20	SF21
SF1	0.019	0.011	0.010	0.011	0.010	0.017	0.018	0.013	0.011	0.011	0.010	0.019	0.014	0.018	0.020	0.016	0.019	0.015	0.016	0.017	0.025
SF2	0.018	0.011	0.010	0.011	0.010	0.017	0.019	0.014	0.011	0.011	0.010	0.019	0.014	0.019	0.019	0.016	0.019	0.015	0.016	0.016	0.026
SF3	0.018	0.011	0.010	0.011	0.010	0.017	0.018	0.014	0.011	0.012	0.010	0.019	0.014	0.019	0.019	0.015	0.019	0.015	0.016	0.016	0.026
SF4	0.018	0.011	0.010	0.012	0.010	0.017	0.018	0.014	0.011	0.012	0.010	0.020	0.014	0.018	0.019	0.015	0.019	0.015	0.016	0.016	0.026
SF5	0.019	0.011	0.010	0.011	0.010	0.017	0.018	0.014	0.011	0.011	0.010	0.019	0.014	0.019	0.019	0.015	0.019	0.015	0.016	0.017	0.026
SF6	0.019	0.011	0.010	0.011	0.010	0.018	0.018	0.013	0.011	0.011	0.010	0.019	0.014	0.019	0.020	0.016	0.019	0.015	0.016	0.017	0.026
SF7	0.018	0.011	0.010	0.011	0.010	0.017	0.019	0.013	0.011	0.011	0.010	0.019	0.014	0.019	0.020	0.016	0.019	0.015	0.016	0.017	0.026
SF8	0.019	0.011	0.009	0.011	0.010	0.016	0.019	0.014	0.010	0.012	0.010	0.018	0.014	0.019	0.018	0.016	0.020	0.014	0.016	0.017	0.024
SF9	0.019	0.011	0.009	0.011	0.010	0.016	0.019	0.012	0.010	0.012	0.010	0.018	0.014	0.019	0.018	0.016	0.020	0.014	0.016	0.017	0.024
SF10	0.019	0.011	0.009	0.011	0.010	0.016	0.019	0.013	0.010	0.012	0.010	0.018	0.014	0.019	0.018	0.016	0.020	0.014	0.016	0.017	0.024
SF11	0.019	0.011	0.009	0.011	0.010	0.016	0.019	0.012	0.010	0.012	0.010	0.018	0.014	0.019	0.018	0.016	0.020	0.014	0.016	0.017	0.024
SF12	0.019	0.011	0.009	0.011	0.010	0.016	0.019	0.012	0.010	0.012	0.010	0.018	0.014	0.019	0.018	0.016	0.020	0.014	0.016	0.017	0.024
SF13	0.019	0.011	0.009	0.011	0.010	0.016	0.019	0.012	0.010	0.011	0.010	0.018	0.014	0.019	0.018	0.016	0.020	0.014	0.016	0.017	0.023
SF14	0.019	0.011	0.009	0.011	0.010	0.016	0.019	0.012	0.010	0.011	0.010	0.018	0.014	0.019	0.018	0.016	0.020	0.014	0.016	0.017	0.024
SF15	0.023	0.013	0.009	0.014	0.012	0.017	0.023	0.016	0.010	0.014	0.012	0.019	0.017	0.023	0.020	0.019	0.024	0.015	0.020	0.021	0.025
SF16	0.022	0.014	0.010	0.013	0.012	0.017	0.023	0.016	0.010	0.014	0.012	0.019	0.017	0.023	0.019	0.020	0.024	0.015	0.020	0.021	0.025
SF17	0.023	0.014	0.009	0.014	0.012	0.017	0.022	0.016	0.010	0.014	0.012	0.019	0.017	0.022	0.019	0.019	0.024	0.015	0.020	0.021	0.025
SF18	0.061	0.036	0.027	0.036	0.031	0.050	0.060	0.043	0.030	0.036	0.031	0.055	0.045	0.061	0.058	0.051	0.064	0.044	0.052	0.055	0.074
SF19	0.060	0.036	0.029	0.036	0.031	0.051	0.059	0.043	0.031	0.037	0.031	0.056	0.045	0.060	0.056	0.051	0.063	0.044	0.053	0.054	0.074
SF20	0.061	0.036	0.028	0.036	0.031	0.051	0.060	0.043	0.031	0.036	0.032	0.055	0.045	0.061	0.057	0.051	0.063	0.043	0.052	0.056	0.074
SF21	0.060	0.037	0.028	0.035	0.031	0.050	0.060	0.044	0.031	0.036	0.031	0.056	0.045	0.061	0.056	0.051	0.062	0.043	0.052	0.054	0.076

Table 12. Limit the super matrix $\lim_{f\to\infty}\left(WE^{\beta}\right)^{f}$.

Sub-Factors	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SF 10	SF11	SF12	SF13	SF14	SF15	SF16	SF17	SF18	SF19	SF20	SF21
SF1	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
SF2	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
SF3	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
SF4	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
SF5	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
SF6	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
SF7	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
SF8	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
SF9	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
SF10	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
SF11	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
SF12	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
SF13	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
SF14	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
SF15	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
SF16	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
SF17	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
SF18	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
SF19	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
SF20	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
SF21	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017

Table 13. Assessment of critical SR from companies using PROMETHEE.

	Company1	Company2	Company3
Departing stream	2.205	2.058	2.499
Arriving stream	2.254	2.254	2.254
Total stream	−0.049	−0.196	0.245
PROMETHEE II rank	2	3	1

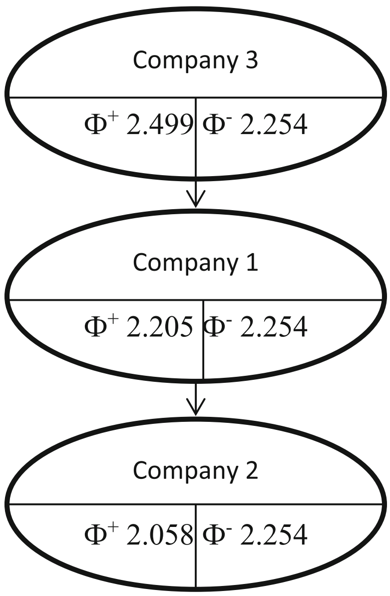

Figure 8. PROMETHEE I – Incomplete ranking.

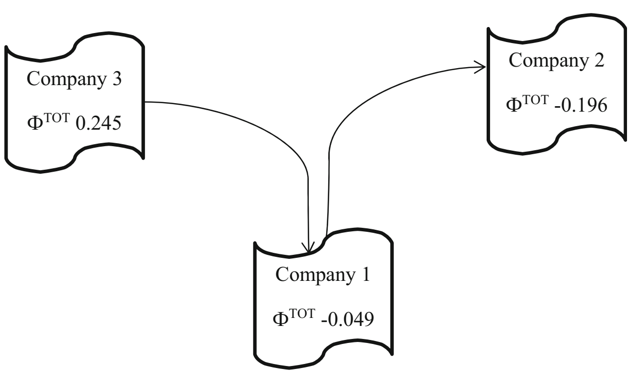

Figure 9. PROMETHEE II – Final ranking.

0.196, and 0.245. Company 3 has the maximum value (0.245) and is recognized as having the most critical sustainable risks. The precedence of companies is illustrated below: Company 3 > Company 1 > Company 2. There are two phases included in PROMETHEE I and II which were revealed in past segments; the outcomes of both phases of PROMETHEE appear in figures 8 and 9, and indicate incomplete ranking and final ranking of the company.

The outcomes of this study revealed that Company 3 has the highest critical sustainable risk among the other two companies; it is also aligned with the existing literature. In India, obligatory factors such as rules and regulations and legislative directions are considered as effective components of SR. Enhancing the sustainable risk in Company 3 raises both its financial and its ecological value, although pollution prevention and emission problems correspond to environmental factors. Rusinko [77] presented pollution production and transportation as critical risks to influence industries functioning in both financial and ecological fields. Developing countries like India face enormous shortages in assets in numerous applications because of the regular misuse of the assets owing to a scarcity of knowledge. In India, knowledge of SR is not considered to be constant in a primary stage. From the above qualities, the selected sustainable risks play an eco-efficient part in all companies.

The outcomes of the study presented here were reached with the help of industrial managers/practitioners. It is noteworthy that from the experts' views, as well as from our study results, that F3 is the most important factor to be taken into consideration. So far, the company did not concentrate on problems that confirmed SR's major role; due to a lack of concentration in analysing these factors, managers allowed the company to proceed with weak SR execution. Once the company recognizes the need to focus on critical SR factors, the results derived from the study will be helpful for successful SR execution. Managers would likely to acknowledge that this paper could assist them in advance for the implementation of valuable SR execution. In this regard, the results obtained are shared with industrial managers to seek their response about SR execution. They strongly acknowledged that their functioning of SR was raised by handling problems such as poor administration and lack of awareness of SR as seen in the chosen Company 3. Hence, these issues play a major role in the company.

This paper offers some managerial implications for SR assessment process. They are as follows:

- Based on the outcomes, managers and the company can focus their effort in achieving the sustainable process more efficiently.
- Providing guidelines/policy decision to industry managers for the advancement of risk management by determining risk factors that influence each other.
- Providing supporting information to the managers and industry experts to take financially sound and environmentally-friendly decisions across the sustainability projects.
- To address these risks and critical company, managers must be proactive in mitigating the impact of risk

factors. These results will assist managers in reducing costs, by concentrating on developing proficiency and customer satisfaction.

6. Conclusion

In this paper, a hybrid MCDM method is used to find the cause and effect relationships among the recognized risks and to determine the critical company in the sustainability process. The current case of sustainable risk management paves the way for improving the strategies of risk mitigation towards lessening the risks in sustainability. The findings of this paper indicated that one risk is obtained from the cause group and two risks are obtained from the effect group. Environmental sustainability (F3) took the first rank in the cause group which can hinder the sustainability process. Subsequently, company need to consider factors like impact of products, environmental management system and global warming which has a robust role for ascertaining the environmental sustainability. On the other hand, social sustainability (F1) is located at the top of the effect group.

- The outcomes depicted that environmental sustainability is the most influential risk among others and it helpful for managers of surgical cotton manufacturing companies to predict the sustainable risks.
- Additionally, this outcome helps to implement sustainable process successfully by focusing on improving skill sets to reduce the risks.
- All these managerial implications of risks in effect group risks will aid to eliminate risks in cause group.
- The suggested hybrid MCDM method is used to analyze the interaction among risks and also to rank the company in the sustainability process by providing useful information about the risks involved in building a successful sustainability process in a secured and resilient manner.

As it is evident that the proposed methodology is found to be effective in the surgical cotton manufacturing companies of the South India, an appropriate model can be built by the operational executives of any industry by identifying the correct risk factors by employing the proposed hybrid MCDM method, for the sustainability of any industry concerned within and or outside India.

Table 14. Fuzzy semantic scale used in this research.

Five-point score for decision makers preference	Linguistic constants and their description	Trapezoidal fuzzy numbers (TrapFN) for equivalent scores
0	No impact (No)	(0,0,0.1,0.2)
1	Very low impact (VL)	(0.1,0.2,0.3,0.4)
2	Low impact (L)	(0.3,0.4,0.5,0.6)
3	High impact (H)	(0.5,0.6,0.7,0.8)
4	Very high impact (VH)	(0.7,0.8,0.9,1)

Appendix A

See Tables 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13.

Appendix B: Questionnaire

A questionnaire for the survey is provided to the industrial domain specialists to evaluate sustainable risk factors in the three surgical cotton manufacturing companies. The gathered data will be used for research purposes only. The replies from you will be kept confidential; it will not be shared on social media or with any third party. Your input is very much important and will assist in bringing about an optimistic outcome in this research. My heartfelt thanks to you for your time and effort on giving the rating.

Please tick [ ] any one rating that you feel suitable for each item. (Refer to Table 14)

Risk Factors	F1	F2	F3
Social Factors (F1)			
Economical Factors (F2)			
Environmental Factors (F3)			

Please tick [ ] any one rating that you feel suitable for each item. (Refer to Table 14)

Sub-Factors	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SF10	SF11	SF12	SF13	SF14	SF15	SF16	SF17	SF18	SF19	SF20	SF21
SF1																					
SF2																					
SF3																					
SF4																					
SF5																					
SF6																					
SF7																					
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SF14																					
SF15																					
SF16																					
SF17																					
SF18																					
SF19																					
SF20																					
SF21																					

Profile of the expert:

1. Name: ……………………………………..
2. Experience in surgical cotton manufacturing company (in years): ………..
3. Name of organization: ………………………..
4. Current position in organization:
5. Mobile no & Email: …………………………..

Thank you very much for your time and effort in filling this questionnaire.

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