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Research article

Critical barriers to adopt sustainable manufacturing practices in medium-sized ready-made garment manufacturing enterprises and their mitigation strategies

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ABSTRACT

This study delves into the critical barriers hindering sustainable manufacturing practices in medium-sized ready-made garments manufacturing enterprises. Initially, barriers were identified through a literature review and expert opinions. Then, the fuzzy Delphi Method and expert consensus were used to prioritize the critical barriers. Finally, based on the insights from a focus group discussion and the supported literature, strategies to mitigate the identified critical barriers were formulated. In this study, the initial barriers identified encompassed various dimensions. The top three critical barriers were identified as higher prices of sustainable products, limited supplier commitment, and lack of access to information. Strategies to address these critical barriers include adopting collaborative business approaches, incorporating sustainability standards, investing in technology, implementing sustainable manufacturing techniques, and integrating green supply chain management practices. Overall, by focusing on these strategies, medium-sized garment manufacturing enterprises can enhance their sustainability efforts and gain economic, environmental, and social benefits.

1. Introduction

Medium-sized garment manufacturing enterprises (MGMEs) refer to businesses within the apparel industry that have a moderate scale of operations, typically characterized by their size, production capacity, workforce, and revenue. These enterprises usually employ between 50 and 250 workers [1,2], often handle orders ranging from thousands to tens of thousands of units per month, and generally have an annual revenue ranging from £2.5 million to £20 million [3]. These businesses can meet the demands of both local and international clients and often have more complex organizational structures and operations, including specialized departments for design, production, quality control, logistics, and sales.

Moreover, these organizations play a significant role in the development of economies by contributing to economic growth, employment generation, and industrial development, particularly in developing countries [4–6]. These garment enterprises, being labor-intensive, absorb a large workforce especially in developing countries, and serve as a vital source of employment and income for many individuals [7,8]. The export-oriented nature of these garment manufacturing enterprises in developing countries plays a vital role in foreign exchange earnings, improving trade balances, and supporting overall economic development [9,10]. Additionally, the

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establishment clusters of MGME can promote agglomeration effects, fostering collaboration, knowledge sharing, and efficiency improvements among enterprises, thereby enhancing the competitiveness of the sector and driving economic growth [11,12].

Despite these significant contributions, the existing literature [13–22] identifies several barriers that small and medium-sized manufacturing enterprises (SMMEs) frequently face when attempting to implement sustainable manufacturing practices. These barriers span various categories and highlight the multifaceted challenges that medium-sized garment manufacturing enterprises (MGMEs) may encounter when transitioning to sustainable manufacturing practices. Consequently, it is imperative to identify critical barriers specific to MGMEs when implementing sustainable manufacturing practices for several reasons. Firstly, understanding these barriers allows for the prioritization of efforts and resources towards addressing the most significant challenges. Secondly, by recognizing and ranking these barriers, decision-makers can develop effective strategies tailored to the unique needs of MGMEs, enhancing the likelihood of successful implementation. Additionally, identifying critical barriers enables the establishment of sustainable action plans [23] that are essential for overcoming challenges and scaling up sustainable practices within MGMEs. Furthermore, formulating strategies to mitigate these barriers is crucial, as tailored strategies can lead to increased competitiveness, market differentiation, and enhanced brand reputation [24]. Moreover, mitigating these barriers can aid in compliance with regulations, standards, and customer requirements related to sustainability, ensuring long-term business viability and growth [24].

Based on the evidence presented above and in the literature review section, it is apparent that medium-sized garment enterprises significantly contribute to economic growth, employment, and industrial development, especially in developing countries, by providing large-scale employment and generating foreign exchange through exports. By focusing on quality management, growth factors, sustainability, technological innovation, and workplace ergonomics, MGMEs can enhance their operational efficiency, competitiveness, and long-term sustainability in the dynamic global market. While previous research has highlighted the importance of technological advancement, strategic management practices, and sustainability initiatives for MGMEs' sustainable growth, there is limited understanding of the specific barriers MGMEs face in implementing sustainable practices. Besides, existing studies have largely focused on general small and medium-sized enterprises (SMEs) without distinguishing the challenges or barriers specific to MGMEs. In addition, to the best of our knowledge, no study has yet proposed the strategies required to overcome the barriers to adopting sustainable manufacturing practices in MGMEs. Hence, this study aims to fill these gaps by identifying the critical barriers specific to MGMEs and proposing strategic measures to overcome them while implementing sustainable manufacturing practices in MGMEs.

Therefore, the objectives of this study are to (i) identify and prioritize the barriers critical to adopting sustainable manufacturing practices in medium-sized garment manufacturing enterprises and (ii) formulate the strategies required to overcome these identified barriers. In these contexts, this study tries to answer the following research questions:

RQ1. What are the critical barriers that hinder medium-sized garment manufacturing enterprises from adopting sustainable manufacturing practices?

RQ2. How can medium-sized garment manufacturing enterprises willing to adopt sustainable manufacturing practices implement the strategies to mitigate the identified critical barriers?

The remaining part of the paper proceeds as follows: a literature review is presented in Section 2. The third section is concerned with the methodology used for this study. Then, the results and discussion are reported in section 4. The concluding remarks are stated in section 5; finally, implications for managers and academicians are addressed in this section.

2. Literature review

In this section, literature related to sustainability issues in the manufacturing sector was summarized to clarify the research context, identify the knowledge gap, and explain the significance of fuzzy-based prioritization strategies for this study. In light of the sustainable growth and competitiveness of the garment industry, researchers focused on advancements in technology and strategic management practices. Ye et al. [25] introduced the concept of Mass Selective Customization-Centralized Manufacturing for clothing enterprises utilizing 3D printing technology to enhance customization capabilities in garment production. Similarly, Yan and Ma [26] emphasized the importance of developing garment design models integrating advanced technologies like Bayesian classifiers and decision tree algorithms for intelligent manufacturing in the clothing industry. Additionally, Wendra et al. [27] shed light on the relationship between dynamic capabilities, intellectual capital, and innovation performance in the garment manufacturing industry, stressing the importance of considering these factors for sustainable growth and competitiveness. Regarding performance evaluation, Wang et al. [8] conducted a study to assist textile and garment enterprises in identifying areas for improvement and enhancing operational efficiency, providing a framework for performance evaluation in the industry. Hemphill and White [28] emphasized the importance of a more inclusive approach to corporate social responsibility in the apparel industry, considering the well-being of garment workers, local communities, and the environment in manufacturing operations.

With increasing global attention to sustainability, particularly in the apparel sector, there is a growing demand for sustainable manufacturing practices [29]. In this context, adopting sustainable manufacturing practices has become a critical focus for medium-sized garment manufacturing enterprises for several reasons. Firstly, integrating green supply chain management practices can enhance operational performance, reduce environmental impact, and promote sustainability throughout the supply chain [30–32]. By considering internal green supply chain management practices along with collaboration with customers and suppliers, garment manufacturers can minimize waste, optimize resource usage, and improve overall environmental sustainability. Secondly, the garment industry's shift towards sustainable practices is essential for meeting institutional pressures for sustainability, enhancing corporate social responsibility, and attracting foreign investment [29,33,34]. Emphasizing sustainable manufacturing practices not only aligns with global sustainability goals but also helps in building a positive reputation, meeting ethical trade standards, and

fostering long-term relationships with stakeholders.

Numerous studies have attempted to explain strategies to enhance the performance and sustainability of garment enterprises across different contexts and sizes. For instance, Gobodzo [35] delves into implementing Total Quality Management (TQM) in small to medium garment production enterprises in Ghana, emphasizing the role of commitment, customer focus, and process monitoring in enhancing garment quality and overall business performance. Karuppiah et al. [36], explored the role of ergonomic factors in affecting production in leather garment-based SMEs in India, highlighting the importance of considering ergonomic aspects for social sustainability. Sun [37] highlighted the significance of logistics business optimization for small and medium-sized garment manufacturing enterprises to enhance efficiency in their operations through strategies such as logistics business process reengineering and e-commerce systems construction. Moreover, Cassia and Colombelli [38] studied growth factors for medium-sized enterprises, highlighting proactivity, risk-taking, and investment for growth as significant determinants of success. This sheds light on the strategic aspects that medium-sized garment manufacturing enterprises needed to consider to foster sustainable growth and expansion in the industry.

Nevertheless, medium-sized garment manufacturing enterprises, often categorized as small and medium-sized manufacturing enterprises (SMMEs), encounter numerous obstacles when it comes to adopting and implementing sustainable manufacturing practices. Such obstacles or barriers can be categorized into various dimensions, including training and skills development, financial, technological, informational, managerial and attitudinal, governmental, market and business context, and organizational [24]. In general, the barriers that hinder the implementation of sustainable manufacturing practices include limited or lack of customer awareness and education [16,21], time and resource (money & human resource) constraints [14,16,18,20], lack of knowledge and skills [24], lack of government support and regulations or regulatory and policy barriers [17,19], organizational and managerial barriers [24], limited access to information and training [24], Market and Business Context [18,24] supply chain integration challenges [14], lack of collaboration and networking [14,22], lack of technical expertise [13], and Technological Barriers [13,18]. Overcoming these barriers requires addressing the gaps in customer awareness, providing financial support and resources, offering training and skills development programs, creating supportive government policies, promoting collaboration and communication within supply chains, and facilitating access to advanced technologies.

In the realm of tackling barriers to innovation and sustainable practices, a plethora of scholarly endeavors have emerged, each wielding a distinct methodology to elucidate and address critical challenges. Gupta and Barua [39] constructed a framework utilizing BMW and fuzzy TOPSIS to assist SMMEs in overcoming hurdles to green innovation. In their study, BWM was used to rank barriers obtained from the literature review and the selective managers' opinions, and Fuzzy TOPSIS was used to rank solutions to surmount these barriers. Shah et al. [40] finalized and categorized barriers critical to the adoption of renewable energy technologies in Pakistan using modified Delphi and fuzzy AHP. Utilizing fuzzy AHP and fuzzy TOPSIS, Musaad et al. [41] ranked impediments and solutions to the adoption of green practices by small and medium-sized enterprises (SMMEs) in Saudi Arabia. Solangi et al. [42] used an integrated analytical hierarchical process (AHP) and fuzzy TOPSIS approach to identify and prioritize seven renewable energy hurdles and twenty-nine sub-barriers that impede the development of renewable energy technology in Pakistan. Using fuzzy AHP and fuzzy TOPSIS, Chien et al. [43] identified critical barriers and approached addressing those barriers to green innovation practices in Saudi Arabian SMMEs.

In addition, critical barriers often possess qualitative characteristics that need to be converted into a comparable scale. To address this issue, many scholars utilize fuzzy-based prioritization strategies. In this context, the fuzzy Delphi method is frequently employed to systematically derive reliable and consistent attributes from qualitative data sources. This approach ensures credibility in identifying and assessing critical barriers across various research domains. Bouzon et al. [44] used the fuzzy Delphi method to identify the critical barriers hindering the implementation of reverse logistics (RL) in the electrical-electronic industry sector. Dong and Huo [45] applied fuzzy Delphi method to extract significant financial barriers from a set of potential barriers under uncertain circumstances. Mahdiyar et al. [46] proposed an integrated fuzzy-based MCDM approach where fuzzy Delphi method was used to identify critical barriers to green roof installation in Malaysia. In 2020, Bui and colleagues [47] employed the fuzzy Delphi method to recognize major obstacles and challenges in upholding sustainable practices for managing solid waste. Karam et al. [48] suggested a hybrid fuzzy Delphi-AHP approach in which critical barriers to implementing horizontal transport collaboration were identified using fuzzy Delphi method. Rejeb et al. [49] proposed an integrated fuzzy Delphi and best-worst method to prioritize the barriers crucial for blockchain adoption in circular economy, where the critical barriers were first identified using the fuzzy Delphi method. Among the potential obstacles obtained from the literature review, Ashour et al. [50] used a two-round improved fuzzy Delphi technique to identify the most significant impediments to practicing sustainable interior architecture and design. Overall, the integration of Multi-Criteria Decision--Making (MCDM) methods, such as fuzzy AHP, fuzzy TOPSIS, and the fuzzy Delphi method, has proven instrumental in identifying, ranking, and addressing critical barriers to innovation and sustainable practices across various industries. By leveraging these methodologies, researchers and practitioners can navigate complex decision-making processes, prioritize solutions, and drive sustainable advancements in diverse sectors.

3. Methodology

3.1. Identification of potential barriers to sustainable manufacturing practices

In this study, we selected medium-sized garment manufacturing enterprises based on their size [1,2] and their contribution to the national economy. This contribution was measured through (i) employment generation, (ii) foreign currency earnings, and/or (iii) contract-based collaboration with larger garment enterprises. After selecting the garment factories, potential barriers to sustainable manufacturing practices in SMEs in general were identified. A two-step approach was used at this stage. Firstly, the pertaining

literature was searched out using 'barriers', 'sustainable manufacturing practices', and 'small and medium-sized enterprises (SMEs)' as keywords and then reviewed to find the potential barriers. Secondly, a brainstorming session (a group consisting of two professors of Industrial Engineering field and two directors (of production from two selected medium-sized garment factories) was conducted to identify the possible barriers in addition to those obtained from the literature review. Table 1 shows the list of barriers to adopting sustainable manufacturing practices in SMEs in general. Then, a survey-based approach was used to address two issues: (i) identifying the critical barriers to sustainable manufacturing practices in the selected medium-sized garment manufacturing enterprises and (ii) determining mitigation strategies for the selected critical barriers.

3.2. Data collection technique

This study constitutes a quantitative research endeavor involving a cohort of sixteen (16) distinguished professionals specializing in the field of garment manufacturing. The sampling methodology used in this study is characterized by a purposive sampling approach, wherein participant selection is contingent upon their extensive expertise in the aforementioned domain. The decision to enlist sixteen (16) experts aligns with the recommendation put forth by Yusoff et al. [108], advocating for a minimum of 10 experts to ensure a high level of consensus and homogeneity among participants. The criteria utilized for expert selection in this study encompass individuals who have (i) worked in garment factories for more than ten years and (ii) been actively involved in addressing sustainability issues in their respective medium-sized garment enterprises for a period of two and a half years or more as a part of their current job responsibilities.

The current study utilizes a questionnaire consisting of twenty-five (25) distinct barriers to the implementation of sustainable manufacturing practices. The fuzzy Delphi survey was conducted by distributing the afforested questionnaires to a specified panel of experts, who enthusiastically contributed their specialized knowledge and expertise to evaluate the severity of these obstacles in the context of implementing sustainable manufacturing practices. The experts were requested to use a 5-point Likert scale, extending from "strongly disagree (1)" to "strongly agree (5)," to show how much they agreed with each item on the questionnaire. Afterward, the data obtained from the Likert Scale evaluations was transformed into fuzzy numerical data and analyzed utilizing Microsoft Excel 2016.

3.3. Fuzzy Delphi Method (FDM) implementation

The Fuzzy Delphi Method, which uses fuzzy logic to handle the ambiguity and uncertainty linked to expert judgments, is a modified form of the conventional Delphi approach [109]. This method has been applied in various fields, as evidenced by its utilization in diverse domains [110–112]. Compared to the conventional Delphi approach, the Fuzzy Delphi method has a number of advantages, most notably faster response times and lower costs, which increase the overall number of survey responses [110]. As a result, this methodology becomes a useful tool that combines fuzzy set theory and the traditional Delphi approach to promote expert agreement, enhance decision-making procedures, and make it easier to identify key elements in a variety of sectors and research fields.

Table 1
The list of barriers to adopting sustainable manufacturing practices in the SMEs.

Barrier Dimensions	Adoption barriers to sustainable manufacturing practices	Sources
Financial Resources and Support	FS01: Lack of financial resources FS02: Limited access to capital and funding FS03: High costs of sustainable technology and equipment	[21,51–64]
Knowledge and Awareness	KA01: Limited knowledge and awareness KA02: Difficulty in measuring sustainability KA03: Lack of standardized sustainability measurement KA04: Lack of access to information and training	[24,64–72]
Human Resources and Skills	HS01: Limited human resources HS02: Lack of specialized skills/Limited technical expertise HS03: Limited management support HS04: Cultural barriers	[51,63,64,67,73–79]
Stakeholder Engagement and Collaboration	SE01: Lack of stakeholder engagement SE02: Limited collaboration and networking opportunities/Lack of collaboration SE03: Limited supplier commitment	[18,21,51,53,67,80–85]
Regulation and Policy	RP01: Lack of regulatory support/supportive policy frameworks RP02: Regulatory barriers RP03: Lack of enforcement RP04: Inconsistent regulatory frameworks	[18,21,24,51,63,64,67,75,82,86–92]
Market and Demand (for the sustainable product)	MD01: Limited market demand/Limited consumer demand MD02: Limited customer education MD03: Limited market access MD04: Higher prices of sustainable products	[21,67,80,93–101]
Supply Chain and Logistics	SC01: Lack of supply chain transparency/Limited supply chain visibility SC02: Complex supply chains SC03: Inefficient transportation and logistics	[67,102–107]

3.4. Data analyzing technique of FDM

3.4.1. Questionnaire for experts

In this study, the research questionnaire for the Fuzzy Delphi method was meticulously formulated following an extensive review of pertinent literature within its delineated scope. After the adaptation of the questionnaire from the existing literature, it was subjected to evaluation by a panel of experts comprising two academic and two industrial professionals, who provided their valuable feedback. The questionnaire underwent iterative modifications based on the insightful input received from the expert panel. Furthermore, rigorous assessments were conducted to ascertain the reliability of the questionnaire, culminating in the attainment of a commendable Cronbach's alpha coefficient of 0.793. A five-point rating scale, as outlined in Table 2, was given to the experts to address the research inquiry and help them reach a consensus on the various barrier items under investigation.

3.4.2. Triangular Fuzzy Number (TFN)

In this study, linguistic elements were transformed into fuzzy numbers using a triangular fuzzy number to produce a fuzzy scale that closely resembles to the Likert scale. The justification for utilizing triangular fuzzy numbers is rooted in their ability to encompass the inherent vagueness or lack of precision in expert opinions. The triangle fuzzy number recognizes and portrays the underlying uncertainty in each viewpoint, in contrast to the rigid scoring of a Likert scale.

In this study, the data analysis technique began by converting each Likert scale value into a triangular fuzzy number. The conversion was achieved by utilizing the relationship between the five-point Fuzzy scale and the Likert scale established by Alghawli et al. [113], as shown in Table 2. At this point, every recorded response was defined by three values: the mean minimum value (n_1), the most logical value (n_2), and the maximum value (n_3). Afterward, the fuzzy scores were calculated and then averaged, resulting in the numbers m_1, m_2, and m_3 used in equation (i). The numbers mentioned play a crucial role in the Defuzzification process, wherein m1 denotes the minimum value, m_2 represents the reasonable value, and m_3 signifies the maximum value. Furthermore, these fuzzy values, together with the average values of fuzzy, were utilized to establish the threshold value, the proportion of expert consensus, and the ranking of the items.

3.4.3. Defuzzification process

The Defuzzification process, denoted as A_{max}, entails the systematic ranking of individual items to discern their relative levels of significance. This methodological approach has proven to be instrumental in facilitating informed decision-making regarding the retention or elimination of specific items. The efficacy of this ranking process is underscored by its ability to provide valuable insights into the importance levels of the items under consideration. In this study, equation (1) has been used to determine the relative importance levels.

$$A_{max} = \frac{1}{3}(m_1 + m_2 + m_3) \tag{1}$$

3.4.4. Determination of item acceptability

The determination of the acceptability of constructs and their respective items necessitated the fulfillment of three prerequisites. These prerequisites encompassed: (i) the adherence to a threshold value (d-construct) with a stipulation of d-construct $\leq$0.2 [114]; (ii) the attainment of a minimum 75 % consensus among experts regarding the evaluated items [115]; and (iii) the assignment of ranking to each item based on the fuzzy score (A_{max}) provided that its value is greater than or equal to α-cut value (0.5) [108]. The threshold value, d-construct, serves as a pivotal criterion for the selection of specific constructs based on expert consensus for each construct. Prior to this, the derivation of a threshold value (d) for each item was imperative, involving the computation of the disparity between the average fuzzy number and the respective fuzzy numbers provided by each expert. This computation was executed using equation (2).

$$d(\overline{m}, \overline{n}) = \sqrt{\frac{1}{3}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]} \tag{2}$$

Following the acquisition of this value, the threshold value for constructs (d-construct) was computed using equation (3).

$$d - Construct = \frac{\sum Average\ Threshold\ Value, (d) for\ each\ item}{Total\ experts \times Total\ items\ in\ construct} \tag{3}$$

The determination of construct acceptability was contingent upon the calculated threshold value (d-construct) being less than or

Table 2
Relationship between fuzzy scale and Likert scale.

Agreement Level	Fuzzy Scale			Likert Scale
Strongly disagree	0	0	0.2	1
Disagree	0	0.2	0.4	2
Somewhat agree	0.2	0.4	0.6	3
Agree	0.4	0.6	0.8	4
Strongly agree	0.6	0.8	1	5

equal to 0.2. Similarly, the assessment of expert agreement on each evaluated item hinged upon the respective threshold value (d) for each item, with values not exceeding 0.2 deemed acceptable. Items failing to achieve a minimum expert consensus of 75 % were excluded from further consideration. Subsequent to the Defuzzification process, the ranking of items within similar constructs was ascertained. As mentioned earlier, all respondent data was meticulously inputted and analyzed using Microsoft Excel Version 2016.

4. Results and discussion

4.1. Identification of critical barriers to adopting sustainable manufacturing practices

4.1.1. Financial resources and support barriers

Table 3 displays the results of expert agreement on the obstacles associated with financial resources and support that impede the adoption of sustainable manufacturing methods in medium-sized garment manufacturing companies. As previously indicated in Table 1, the hurdles in this category encompass lack of financial resources (FS01), limited access to capital and funding (FS02), and high costs of sustainable technology and equipment (FS03). Again, based on the table, it is clear that the financial resources and support barrier category has achieved a consensus among experts, as the computed threshold (d) for this category is 0.014 ($\leq$0.2). Nevertheless, along with the threshold value (d = 0.16), the analysis of the experts' agreement and defuzzification values reveals that the barrier with the highest expenses associated with sustainable technology and equipment (expert agreement: 75 % and fuzzy score: 0.575) is the only barrier that achieved a consensus among the experts. The results obtained from multiple research studies [16, 116–118] further confirm that the high costs of sustainable technology and equipment present a more pressing obstacle, despite the lack of financial resources and limited access to capital and funding, which are unquestionably significant hurdles. Therefore, addressing the exorbitant expenses associated with sustainable technology and equipment is essential, as they directly affect the viability and scalability of sustainable manufacturing practices in medium-sized garments manufacturing enterprises (MGMEs). The lack of cost-effective access to these technologies may impede the MGMEs' ability to maintain competitiveness in marketplaces where sustainability is becoming increasingly important, thereby jeopardizing their long-term sustainability and growth.

4.1.2. Knowledge and awareness barriers

Table 4 illustrates the findings of experts' consensus on barriers related to knowledge and awareness that impede the adoption of sustainable manufacturing practices in medium-sized garment manufacturing firms. Within this category, limited knowledge and awareness (KA01), difficulty in measuring sustainability (KA02), lack of standardized sustainability measurement (KA03), and lack of access to information and training (KA04) were identified as hurdles while adopting sustainable manufacturing practices in medium-sized garment manufacturing factories. The table also reveals that the barrier category, along with each of its barrier items, has gained experts' consensus, as the assessed values of the threshold (d) are found to be less than or equal to 0.2. However, upon review of the defuzzification values and consensus among experts, it becomes evident that lack of access to information and training (KA04) and difficulty in measuring sustainability (KA02) are the critical barriers acknowledged by the experts, with an agreement and fuzzy score of at least 75 % and an α-cut value of 0.5, respectively. Previous studies [119–121] also suggest that lack of access to information and training (KA04) and difficulty in measuring sustainability (KA02) are more critical when it comes to implementing sustainable manufacturing practices in the garments manufacturing enterprises under consideration. This is for the critical evaluation of sustainability efforts and the direct influence they have on the acquisition of knowledge and skills, both of which are necessary for the effective implementation of sustainable manufacturing practices in MGMEs. Therefore, it is crucial to overcome these barriers by making focused efforts to provide MGMEs with the essential expertise, competencies, and resources to seamlessly incorporate sustainability into their activities and assess their advancement towards sustainability goals.

4.1.3. Human resources and skills barriers

Table 5 presents the findings of expert consensus on the barriers related to human resources and skills that hinder the adoption of sustainable manufacturing practices in the studied garment manufacturing enterprises. Within this category, limited human resources (HS01), lack of specialized skills or limited technical expertise (HS02), limited management support (HS03), and cultural barriers (HS04) were recognized as barriers while adopting sustainable manufacturing practices in this type of garment manufacturing company. From the table, it is clear that the human resources and skills barrier category has achieved consensus among experts. This is indicated by the computed threshold (d) for this category, which is 0.01 ($\leq$0.2). However, when considering the threshold value (d = 0.14), the analysis of the experts' agreement and defuzzification values indicates that the barrier labeled as HS02, which pertains to the lack of specialized skills or limited technical expertise, achieved a consensus among the experts. This barrier had an expert agreement

Table 3
Expert consensus on financial resources and support related barriers to adopting sustainable manufacturing practices in MGMEs.

Item (Barrier)	Threshold Values		*Experts' Consensus (%)*	Fuzzy Score (A_{max})	Overall Position Among the Barriers Considered	Experts Consensus
	For Each Barrier Item (d)	For Each Category				
FS01	0.26	0.014	38	0.475	18	Discarded
FS02	0.24		44	0.433	22	Discarded
FS03	0.16		75	0.575	3	Retained

Table 4
Expert consensus on knowledge and awareness-related barriers to adopting sustainable manufacturing practices in MGMEs.

Item (Barrier)	Threshold Values		*Experts' Consensus (%)*	Fuzzy Score (A_{max})	Overall Position Among the Barriers Considered	Experts Consensus
	For Each Barrier Item (d)	For Each Category				
KA01	0.19	0.01	50	0.542	9	Discarded
KA02	0.17		75	0.513	12	Retained
KA03	0.16		56	0.575	3	Discarded
KA04	0.12		81	0.575	3	Retained

Table 5
Expert consensus on human resources and skills related barriers to adopting sustainable manufacturing practices in MGMEs.

Item (Barrier)	Threshold Values		*Experts' Consensus (%)*	Fuzzy Score (A_{max})	Overall Position Among the Barriers Considered	Experts Consensus
	For Each Barrier Item (d)	For Each Category				
HS01	0.16	0.01	69	0.450	19	Discarded
HS02	0.14		81	0.550	7	Retained
HS03	0.21		44	0.400	25	Discarded
HS04	0.16		56	0.425	24	Discarded

rate of 81 % and a fuzzy score of 0.550. Prior studies conducted by Park et al. [122], Abdallah et al. [123], and Arif et al. [124] further reinforce the critical role of insufficient specialized skills or limited technical expertise as a significant obstacle to effectively implementing sustainable manufacturing practices in MGMEs. The reasons stem from its immediate influence on implementation, competitive edge, sustainability, and resource allocation. Hence, it is essential to prioritize efforts to address this barrier by focusing on equipping MGMEs with the requisite training, education, and assistance to develop the technical proficiencies necessary for achieving sustainable manufacturing.

4.1.4. Stakeholder engagement and collaboration barriers

Table 6 exhibits the outcomes of experts' consensus on barriers associated with stakeholder engagement and collaboration that impede the deployment of sustainable manufacturing practices in medium-sized garment manufacturing organizations. The barriers to adopting sustainable manufacturing practices in this category include lack of stakeholder engagement (SE01), limited collaboration and networking opportunities (SE02), and limited supplier commitment (SE03). In addition, the table demonstrates that experts have reached a consensus on each barrier and its corresponding category, as the evaluated threshold values (d) are determined to be less than or equal to 0.2. After assessing the defuzzification values and consensus among experts, it becomes apparent that the key obstacles identified are limited collaboration and networking opportunities (SE02) and limited supplier commitment (SE03). These barriers have been acknowledged by the experts with a consensus of at least 75 % and a fuzzy score of 0.5, respectively. The evidence from previous studies [125,126] also confirms that insufficient supplier commitment and a lack of collaboration and networking opportunities are notably more critical to adopting sustainable manufacturing practices in SMEs. This is because of their direct impact on the sustainability of supply chains, the ability to access resources, the development of innovative ideas, the management of risks, and the potential for MGMEs to adopt more sustainable manufacturing practices. Hence, it is vital to tackle these obstacles by cultivating robust relationships, establishing cooperative networks, and incentivizing supplier commitment to promote sustainable manufacturing practices in MGMEs.

4.1.5. Regulation and Policy barriers

The level of expert consensus regarding the regulatory and policy barriers hindering the implementation of sustainable manufacturing practices in the organizations under investigation is detailed in Table 7. Within this barrier category, the selected organization encounters multiple challenges in its pursuit of sustainable manufacturing practices. These obstacles encompass the lack of regulatory support or supportive policy frameworks (RP01), regulatory barriers (RP02), insufficient enforcement (RP03), and inconsistent regulatory frameworks (RP04). The estimated threshold values (d) for the stated barrier category and each of its barrier

Table 6
Expert consensus on stakeholder engagement and collaboration-related barriers to adopting sustainable manufacturing practices in MGMEs.

Item (Barrier)	Threshold Values		*Experts' Consensus (%)*	Fuzzy Score (A_{max})	Overall Position Among the Barriers Considered	Experts Consensus
	For Each Barrier Item (d)	For Each Category				
SE01	0.18	0.008	63	0.475	17	Discarded
SE02	0.10		88	0.550	8	Retained
SE03	0.10		75	0.588	2	Retained

items, as indicated in the table, are all less than 0.2, signifying consensus among experts on these issues. After analyzing the defuzzification values and expert consensus, it becomes apparent that the critical challenges identified include insufficient enforcement (RP03), inconsistent regulatory frameworks (RP04), and inadequate regulatory support or supportive policy frameworks (RP01). These barriers have been acknowledged by the experts with a consensus and fuzzy score of at least 75 % and an α-cut value of 0.5, respectively. Although regulatory barriers play a significant role, previous studies [127–129] provide evidence that insufficient enforcement, inconsistent regulatory frameworks, and inadequate regulatory support or supportive policy frameworks are even more crucial for the successful implementation of sustainable manufacturing practices in MGMEs. Due to their crucial influence on policy effectiveness, compliance costs, and burden, market confidence and investment, and government-corporate collaboration, these barriers are critical to the successful implementation of sustainable manufacturing practices within the medium-sized garments manufacturing sector. Therefore, it is essential to address these challenges by giving priority to enforcement, aligning legislation, and offering customized support mechanisms to enable MGMEs to effectively implement sustainable practices.

4.1.6. Market and demand (for the sustainable product) barriers

Table 8 shows the level of expert consensus regarding the market and demand (for sustainable products) barriers obstructing the adoption of sustainable manufacturing practices in organizations under study. Within this specific category, the chosen organization faces numerous challenges in its efforts to implement sustainable manufacturing practices. The barriers include limited market demand or consumer demand (MD01), inadequate customer education (MD02), limited market access (MD03), and higher prices of sustainable products (MD04). The table also illustrates consensus among experts regarding the barrier category related to market demand for sustainable products. The computed threshold value (d) for this category is 0.01, falling within the specified range of $\leq$0.2. Moreover, in conjunction with the threshold value (d = 0.10), the analysis of both experts' concurrence and defuzzification values suggests consensus among the experts solely concerning the barrier denoted by the higher prices of sustainable products. This barrier achieved a perfect agreement rate of 100 % among experts and a fuzzy score of 0.700. Previous studies [53,130,131] provide further evidence that while all the above-mentioned barriers are important, the higher prices of sustainable products stand out as notably more critical than other market and demand barriers when it comes to implementing sustainable manufacturing practices in MGMEs. The limited market demand for sustainable products is influenced by consumer behavior, which in turn is affected by the prices of these products. Additionally, inadequate customer education can contribute to misconceptions about the value and benefits of sustainable products, potentially leading to resistance to higher prices. Hence, these barriers are intricately associated with the issue for higher prices of sustainable products. Furthermore, limited market access can be resolved by implementing strategic partnerships, market expansion initiatives, and regulatory support. Therefore, to mitigate this challenge, organizations should prioritize strategic pricing strategies, implement cost optimization measures, and foster collaborative initiatives to align market forces with sustainability goals.

4.1.7. Supply chain and logistics barriers

Table 9 depicts the degree of expert consensus about the supply chain and logistics barriers impeding the implementation of sustainable manufacturing practices within the studied organizations. Within this distinct barrier category, the selected organizations confront many obstacles in their pursuit of implementing sustainable manufacturing practices. These hurdles encompass a lack of supply chain transparency or limited supply chain visibility (SC01), complex supply chains (SC02), and inefficient transportation and logistics (SC03). Additionally, the table elucidates consensus among experts regarding the supply chain and logistics barrier categories. The determined threshold value (d) for this category is 0.009, aligning with the stipulated range of $\leq$0.2. Furthermore, in conjunction with the threshold value (d = 0.12), an assessment of both experts' concurrence and defuzzification values signifies consensus among experts exclusively regarding the impediment denoted by a lack of supply chain transparency or limited supply chain visibility. This barrier garnered an 81 % agreement rate among experts and a fuzzy score of 0.538. Prior research [132,133] provides additional evidence reinforcing the contention that although complex supply chains and inefficient transportation and logistics are important barriers, they may not be as critical as the lack of supply chain transparency. This transparency plays a critical role in ensuring ethical sourcing, preventing unethical conduct, and enhancing traceability—all of which are essential components of sustainable manufacturing practices. Moreover, strategic simplification and optimization can be used to manage complex supply chains, and process enhancements and technology adoption can be employed to address inefficient transportation and logistics. However, in order to overcome the lack of transparency in the supply chain, there needs to be a fundamental change towards traceability and transparency, which are essential preconditions for implementing sustainable manufacturing practices. Organizations should therefore make a concentrated effort to improve supply chain transparency, traceability, and ethical sourcing practices to effectively mitigate this barrier.

Table 7
Expert consensus on regulation and policy related barriers to adopting sustainable manufacturing practices in MGMEs.

Item (Barrier)	Threshold Values		*Experts' Consensus (%)*	Fuzzy Score (A_{max})	Overall Position Among the Barriers Considered	Experts Consensus
	For Each Barrier Item (d)	For Each Category				
RP01	0.15	0.010	75	0.563	6	Retained
RP02	0.17		63	0.488	14	Discarded
RP03	0.18		75	0.500	13	Retained
RP04	0.13		81	0.538	11	Retained

Table 8
Expert consensus on market and demand (for the sustainable product) related barriers to adopting sustainable manufacturing practices in MGMEs.

Item (Barrier)	Threshold Values		*Experts' Consensus (%)*	Fuzzy Score (A_{max})	Overall Position Among the Barriers Considered	Experts Consensus
	For Each Barrier Item (d)	For Each Category				
MD01	0.20	0.010	50	0.442	20	Discarded
MD02	0.20		44	0.429	23	Discarded
MD03	0.14		75	0.438	21	Retained
MD04	0.10		100	0.700	1	Retained

Table 9
Expert consensus on supply chain and logistics-related barriers adopting sustainable manufacturing practices in MGMEs.

Item (Barrier)	Threshold Values		*Experts' Consensus (%)*	Fuzzy Score (A_{max})	Overall Position Among the Barriers Considered	Experts Consensus
	For Each Barrier Item (d)	For Each Category				
SC01	0.12	0.009	81	0.538	20	Retained
SC02	0.14		81	0.488	23	Retained
SC03	0.15		75	0.475	17	Retained

4.2. Critical barriers to adopting sustainable manufacturing practices

Table 10 displays a list of barriers deemed crucial for implementing sustainable manufacturing practices in medium-sized garment factories. The barriers were categorized and evaluated according to specific criteria, including threshold value, percentage of expert group consensus, and fuzzy score. The table clearly shows that important barriers were distributed among different barrier categories. In particular, there are three barriers categorized under 'Regulation and Policy,' two barriers each associated with 'Stakeholder Engagement and Collaboration,' and 'Knowledge and Awareness.' Furthermore, one obstacle is assigned to each of the remaining categories. However, the most significant obstacle arises from the 'Market and Demand' category.

Again, the data presented in the table underscores the prevailing agreement over the top three critical barriers that hinder the implementation of sustainable manufacturing practices. These barriers include the higher prices of sustainable products in the 'Market and Demand' category, limited supplier commitment as categorized under 'Stakeholder Engagement and Collaboration', and the lack of access to pertinent information and training within the domain of 'Knowledge and Awareness'. Conversely, the findings indicate that inconsistent regulatory frameworks and insufficient enforcement mechanisms, categorized under 'Regulation and Policy', alongside challenges in measuring sustainability within the 'Knowledge and Awareness' domain, are identified as the bottom three barriers hindering the successful implementation of sustainable manufacturing practices.

Overall, these challenges highlight the multifaceted nature of sustainability implementation, touching on aspects such as market dynamics, stakeholder engagement, regulatory environments, and resource availability. Addressing these challenges would likely require coordinated efforts across various sectors and stakeholders.

Table 10
Ranking of barriers identified critical to adopting sustainable manufacturing practices in MGMEs.

Barrier Category	Barrier Item	Threshold Value, d for Each Item	Percentage Experts Group Consensus (%)	Fuzzy Score (A_{max})	Rank
Market and Demand	Higher prices of sustainable products	0.10	100	0.700	1
Stakeholder Engagement and Collaboration	Limited supplier commitment	0.10	75	0.588	2
Knowledge and Awareness	Lack of access to information and training	0.12	81	0.575	3
Financial Resources and Support	High costs of sustainable technology and equipment	0.16	75	0.575	4
Regulation and Policy	Lack of regulatory support or supportive policy frameworks	0.15	75	0.563	5
Stakeholder Engagement and Collaboration	Limited collaboration and networking opportunities	0.10	88	0.550	6
Human Resources and Skills	Lack of specialized skills or limited technical expertise	0.14	81	0.550	7
Supply Chain and Logistics	Lack of supply chain transparency or limited supply chain visibility	0.12	81	0.538	8
Regulation and Policy	Inconsistent regulatory frameworks	0.13	81	0.538	9
Knowledge and Awareness	Difficulty in measuring sustainability	0.17	75	0.513	10
Regulation and Policy	Lack of enforcement	0.18	75	0.500	11

4.3. Mitigation strategies to overcome critical barriers to implementing sustainable manufacturing practices

To overcome the critical barriers illustrated in Table 10, the formulation of mitigation strategies has become obvious. In this regard, a focus group discussion (FGD) was convened, featuring seven industrial experts chosen from the group of sixteen participants engaged in the survey component of the study. Based on insights from the discussion and supported by relevant literature, the following strategies have been articulated:

4.3.1. MD04: Higher prices of sustainable products

While implementing sustainable manufacturing practices, several strategies can be employed to overcome the obstacle posed by the higher cost of sustainable products. To begin with, the MGMEs should consider channel selection and pricing decisions based on sustainable operations perspectives. This may entail establishing premium prices for sustainable products compared to non-sustainable alternatives, keeping in mind to capitalize the sustainability attributes to attract environmentally conscious consumers. Additionally, by emphasizing the value of sustainability initiatives in product evaluation, these enterprises can effectively convey to consumers their adoption of sustainable manufacturing practices. Moreover, the MGMEs should integrate sustainable manufacturing practices with circular economy principles. This integration can result in cost savings and improved efficiencies, which may help offset the potential impact of increased costs on sustainable products [134].

4.3.2. SEO3: Limited supplier commitment

To address the issue of inadequate supplier commitment during the implementation of sustainable manufacturing practices, the MGMEs can contemplate various strategies that offer a holistic approach to fostering and augmenting supplier commitment. Firstly, the MGMEs, particularly in emerging economies, should prioritize compliance and commitment strategies as perceived by suppliers. This approach will entail comprehending and mitigating the factors influencing supplier commitment to sustainable supply chain practices. Furthermore, these enterprises should strengthen their suppliers' commitment to sustainability by employing sustainable supplier selection models and order allocation strategies to identify and engage suppliers who are committed to environmentally sustainable, socially responsible, and economically viable practices. Moreover, they should prioritize the establishment of trust and relational commitment between buyers and suppliers through supplier collaboration and development. This can have a favorable impact on suppliers' commitment to sustainable practices, ultimately resulting in enhanced information sharing and supplier development [135]. Besides, these enterprises should leverage collaborative communication and control mechanisms to enhance supplier knowledge and affective commitment, which, in turn, promotes continuous improvement in supplier performance and strengthens supplier commitment to sustainability. In addition, the MGMEs should showcase their dedication to achieving sustainable objectives and strengthen supplier commitment to sustainability by adopting sustainable resource sharing and transforming supply chain partnerships into sustainable collaborations [84].

4.3.3. KA04: Lack of access to information and training

To address the challenge of limited access to information and training in sustainable manufacturing practices, several strategies can be recommended. Firstly, MGMEs should develop all-encompassing training programs that center on sustainable manufacturing practices to furnish employees with the essential knowledge and competencies required to seamlessly integrate sustainability into their routine activities. Sustainable supply chain management, environmental impact reduction, and resource efficacy are a few of the topics that can be addressed in these programs. Additionally, these enterprises should establish mentorship programs and knowledge-sharing platforms to promote the dissemination of information and best practices pertaining to sustainable manufacturing throughout different levels of the organization. Moreover, they should afford the staff members the chance to engage in collaborative endeavors with professionals in the field and partake in seminars and workshops. This effort can provide their employees with valuable insights and training opportunities to enhance understanding and implementation of sustainable practices within the manufacturing processes [136]. Furthermore, MGMEs should use digital technologies to develop online training modules and resources, providing employees with adaptable and easily accessible learning opportunities for employees to augment their sustainability knowledge and skills.

4.3.4. FS03: High costs of sustainable technology and equipment

To address the barrier of high costs associated with sustainable technology and equipment while advancing sustainable manufacturing practices, medium-sized garment manufacturing enterprises should adopt a multifaceted strategy. The medium-sized garment manufacturing enterprises (MGMEs) should focus on implementing green supply chain management practices to achieve cost efficiencies and environmental benefits through waste reduction and efficient resource utilization. Furthermore, these enterprises can explore available government financial incentives, grants, and subsidies aimed at promoting sustainable initiatives. These financial support mechanisms can help offset the initial high costs of sustainable technology adoption and equipment acquisition.

4.3.5. RP01: Lack of regulatory support or lack of supportive policy frameworks

To overcome the obstacle posed by the absence of regulatory backing during the adoption of sustainable manufacturing practices, several strategies can be suggested. First, the MGMEs should actively establish more explicit regulatory frameworks and government support to address the lack of effective legislation and inadequate regulatory environments. Moreover, the MGMEs should engage in stakeholder consultations, capacity development, and setting clear policy objectives to address insufficient government support and ambiguous regulatory frameworks, thereby mitigating the impact of regulatory barriers on sustainable manufacturing practices.

4.3.6. SE02: Limited collaboration and networking opportunities

To mitigate limited collaboration and networking opportunities while implementing sustainable manufacturing practices, several strategies can be considered. Firstly, the MGMEs should evaluate their collaborative capabilities concerning sustainability in inter-organizational networks. This assessment should primarily concentrate on enhancing the individual capabilities of firms to foster collaboration within the network. Moreover, to achieve sustainable interoperability in networked enterprise information systems, these enterprises should leverage knowledge and model-driven technology trends to improve networking and enterprise integration. Furthermore, these enterprises should use collaborative approaches to emphasize the importance of collaboration between actors involved in sustainable and resilient manufacturing. In addition, they should employ simulation modeling approaches to evaluate collaborative workplaces in sustainable manufacturing to explore how these spaces affect the sustainability of manufacturing systems, ultimately leading to enhanced collaboration and networking opportunities [137].

4.3.7. HS02: Lack of specialized skills or limited technical expertise

During the implementation of sustainable manufacturing processes, the following strategies can be used to collectively address the lack of specialized skills or limited technical expertise. Firstly, the MGMEs should promote the involvement of executives and workers from different departments to align lean manufacturing and sustainability efforts. This approach allows for the integration of diverse expertise and knowledge to achieve sustainable practices effectively. In addition, these enterprises should employ time-based manufacturing competence strategically to prioritize the reduction of lead times and enhancement of manufacturing skills, which, in turn, will help compensate for any limitations in technical expertise by streamlining processes and operations. Furthermore, they can adopt sustainable setup stream mapping (3SM), a systematic approach to integrating lean principles with sustainability criteria, offering a visual-analytical method to improve operations more holistically, thereby compensating for limited technical expertise by providing a structured framework for sustainable manufacturing practices [138].

4.3.8. SC01: Lack of supply chain transparency or limited supply chain visibility

Several strategies can be employed to address the challenge of a lack of supply chain transparency or limited supply chain visibility while promoting sustainable manufacturing practices. Firstly, the MGMEs should incorporate blockchain technology into their operations to augment supply chain transparency and traceability, consequently bolstering visibility and accountability. By enabling the monitoring of processes and products, this technology can guarantee that sustainable practices are maintained across the entire supply chain. In addition, these enterprises should arrange supplier engagement, and commitment to fostering strong relationships with their suppliers, thereby improving supply chain visibility and transparency. Moreover, these enterprises should adopt collaborative, coordinative, and cooperative business strategies to facilitate the sharing of information and coordination among stakeholders, ultimately leading to an improvement in supply chain visibility. Furthermore, these enterprises need to prioritize and invest in technologies and processes that can facilitate real-time monitoring and data-driven insights, contributing to enhanced supply chain visibility and sustainability [139]. Besides, they should align their activities with sustainable development goals to ensure that all manufacturing and supply chain processes are focused on sustainability, thereby enhancing visibility and accountability [140].

4.3.9. RP04: Inconsistent regulatory frameworks

Several tactics can be used to lessen the obstacles of inconsistent regulatory frameworks while implementing sustainable manufacturing practices. To bridge the sustainability indicator gap and negotiate inconsistent regulatory frameworks, the MGMEs should first concentrate on defining essential indicators in sustainable manufacturing. In addition, these enterprises should build the necessary competencies, such as assurance of information security and compliance with legislation, to adapt to and comply with varying legal frameworks. Furthermore, these enterprises should concentrate on incorporating sustainability principles into their production processes, thereby facilitating the management of regulatory discrepancies.

4.3.10. KA02: Difficulty in measuring sustainability

Several strategies can be employed to mitigate difficulties in measuring sustainability while employing sustainable manufacturing practices. The MGMEs should essentially develop suitable sustainability assessments and action plans for the implementation of sustainable manufacturing [141]. This assessment and action plan should include considering the triple bottom line – the economic, social, and environmental performance of the firm. Additionally, organizations should focus on developing sustainability metrics and benchmarking their performance based on economic, environmental, and social criteria [142]. Finally, these enterprises can develop a framework that incorporates both core and supplemental indicators to enhance how organizations measure their progress toward sustainable manufacturing systems.

4.3.11. Lack of enforcement

The subsequent strategies may be proposed to foster a culture of accountability and compliance in sustainable manufacturing practices and assist in overcoming the issue of inadequate enforcement. The MGMEs forge alliances with industry associations and regulatory entities to advocate for more robust enforcement mechanisms and legislation that support sustainable manufacturing initiatives. Through their collaboration with external stakeholders, manufacturers can foster a regulatory environment that is favorable to sustainable manufacturing practices. Moreover, these enterprises should perform routine internal audits and evaluations to ascertain adherence to sustainability regulations throughout the establishment. This approach can facilitate monitoring and enforcing sustainable manufacturing practices [143]. In addition, MGMEs should have industry-wide initiatives related to sustainable manufacturing, demonstrating their dedication to compliance and enforcement of sustainable practices.

4.4. Mitigation strategies to overcome other barriers to adopting sustainable manufacturing practices

4.4.1. KA04: Lack of standardized sustainability measurement

When implementing sustainable manufacturing processes, the following strategies can be used to address the issue of a lack of standardized sustainability measurement. First, in order to provide a foundation for standardized measurement, the MGMEs should concentrate on creating a conceptual framework for measuring the sustainability of manufacturing processes [120]. Second, by incorporating different sustainability evaluation models that are currently in use, these enterprises should use an integrated approach at the process and product levels to get beyond the drawbacks of standardized sustainability measurement. Besides, machines used in organizations can be reconfigured to attain sustainability and system flexibility, as they support standardized sustainability monitoring and are consistent with the ideas of sustainable manufacturing. Finally, since standards are crucial to sustainable manufacturing, the MGMEs should use historical insights into manufacturing standard development to establish standardized sustainability measurement practices.

4.4.2. SC02: Complex supply chain

A number of strategies can be used to help reduce the impact of a complex supply chain on the promotion of sustainable manufacturing practices. To start with, the MGMEs should address the complexity of supply chain operations by utilizing the coordination mechanism of dual-channel supply chains [144]. This mechanism can help design coordination strategies that account for the intricate interactions within the supply chain, thereby enhancing visibility and alignment with sustainable practices. In addition, these enterprises should give priority to the establishment of an adaptable framework that integrates sustainable manufacturing practices into both strategic and operational decision-making processes. This will ensure that the implementation of sustainability initiatives remains unimpeded by the intricacy of the supply chain. Furthermore, by employing blockchain technology, they can augment transparency and traceability, thus reducing the intricacy of the supply chain. Moreover, the MGMEs can reduce the impacts of a complex supply chain by implementing Industry 4.0 enablers that improve supply chain agility, ensure responsiveness to sustainability demands, and alleviate disruptions [145].

4.4.3. SC03: Inefficient transportation and logistics

To address the obstacle posed by inefficient transportation and logistics and facilitate the adoption of sustainable manufacturing practices, the following strategies can be suggested. In the first place, the MGMEs should prioritize the planning and development of sustainable logistics systems at the micro-level. This will enable them to rectify inefficiencies in urban logistics that have detrimental impacts on sustainability. This approach entails the optimization of logistical operations within urban environments to reduce environmental impact and augment overall sustainability. Furthermore, through the evaluation of Radio Frequency Identification (RFID) technology's application in transport logistics, these enterprises can make a positive impact on supply chain sustainability by enhancing traceability and operational efficiency [146]. In addition, they should focus on the abilities of logistics operators to optimize external costs associated with freight logistics solutions. This can offer valuable insights into ways to decrease transportation expenses and externalities throughout the logistic supply chain, thereby making a positive contribution to sustainable transportation practices. Furthermore, to improve the sustainability of urban freight transport, the MGMEs should incorporate emerging modes of transport and infrastructure.

4.4.4. MD03: Limited market access

Several strategies can be used to address the challenge of limited market access for sustainable products during the implementation of sustainable manufacturing practices. To start with, MGMEs can overcome limited market access barriers by implementing sustainable marketing strategies that increase the visibility and market acceptability of their sustainable products [147]. This involves leveraging sustainability as a fundamental value proposition in marketing strategies to appeal to consumers who are environmentally conscious. Furthermore, these enterprises should prioritize the development of inter-cluster linkages among medium-sized garment manufacturing enterprises to promote collaborative business strategies, enhancing market access and visibility for sustainable products. In addition, they should incorporate circular economy principles into their sustainable manufacturing practices to achieve cost reductions and operational efficiencies. This could potentially alleviate the impact of higher prices on sustainable products, consequently bolstering market competitiveness and accessibility.

5. Conclusion, implications, and future research

This study aimed to identify the critical barriers to adopting sustainable manufacturing practices in medium-sized garment manufacturing enterprises (MGMEs). Through a comprehensive literature review and brainstorming sessions, followed by a survey-based approach, eleven critical barriers were identified. Among these, 'higher prices of sustainable products', 'insufficient supplier commitment', and 'lack of access to pertinent information and training' emerged as the top three barriers to adopting sustainable manufacturing practices in MGMEs. The present study employs the Fuzzy Delphi method due to its diverse acceptance in such research domains. This tool helped us to manage uncertainty and ambiguity in expert opinions to identify and prioritize critical barriers effectively. The second purpose of the current study was to gain a better understanding of the critical barriers in the context of medium-sized export-oriented manufacturing enterprises. The most obvious finding to emerge from the second part of this study was the formulation of mitigation strategies for overcoming the identified critical barriers. In this regard, current research employed focus group discussions with industrial experts. The proposed mitigation strategy is directed towards an understanding of the question of

how medium-sized garment manufacturing enterprises can overcome their sustainability barriers.

5.1. Practical and theoretical implications

The authors envision that the findings of this study will contribute significantly to addressing adoption barriers within both the industry and the academic discourse. These findings hold the potential to facilitate a more profound scholarly understanding of the underlying mechanisms governing these barriers, thereby providing managers with indispensable insights for formulating corporate strategies aimed at overcoming such barriers. Besides, by addressing the critical barriers to sustainable manufacturing practices through a combination of strategic initiatives, technology investments, collaborative approaches, and emphasis on sustainability value, managers in medium-sized garment manufacturing enterprises can drive positive change towards more environmentally friendly and socially responsible operations. Moreover, the insights gained from this research are poised to assist decision-makers in outlining priority areas for the adoption of sustainable manufacturing practices within medium-sized export-oriented garment manufacturing enterprises. Additionally, the strategies described in this study are anticipated to offer practical guidance to industry professionals engaged in the implementation of sustainable manufacturing practices. Prior to this study, it was difficult to make predictions about how companies can set strategies for mitigating barriers. In some issues, the findings of this investigation complement those of earlier studies. Thus, this study adds to the growing body of research that indicates specific barriers for specific manufacturing enterprises, as well as proposes the direction in strategy formulation. Finally, this study enhances both academic and practitioner understanding by providing crucial insights into barriers to implementing sustainable manufacturing practices in medium-sized export-oriented garment manufacturing enterprises.

5.2. Limitations and future research

Notwithstanding the relatively limited sample, this work offers valuable insights due to the suitability of the method selected with the scope of the study scope. However, more research using controlled trials is needed for more deduction of indications. Next, the mitigation strategies proposed in this study provide some insights for further research. Due the limitation of time and scope of this research, it was not possible to assess linkage between performance objectives and mitigation strategies on hand. What is now needed is a study to assess the long-term effect of the proposed mitigation strategies on business performance. Last but not least, more information on strategy formulation would help us to establish a greater degree of accuracy on this matter.

CRediT authorship contribution statement

Mohammad Muhshin Aziz Khan: Writing – review & editing, Writing – original draft, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Md. Jahedul Alam:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **Shanta Saha:** Writing – original draft, Data curation, Conceptualization. **Ahmed Sayem:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization.

Data availability statement

The data are not publicly available due to the confidential agreement with the funding Institution. However, the data will be provided on request.

Declaration of competing interest

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

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Appendix A. Supplementary data

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