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A Machine Learning-Based Analysis of Barriers and Mitigation Strategies for Sustainable Supply Chain in the RMG Sector of Bangladesh

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ABSTRACT

This study investigates the key barriers hindering the implementation of Sustainable Supply Chain Management (SSCM) in Bangladesh's Ready-Made Garment (RMG) sector and proposes practical mitigation strategies through a machine learning (ML)-based approach. The RMG industry, a cornerstone of Bangladesh's economy, continues to face pressing sustainability challenges across economic, environmental, managerial, societal, technological and inbound supply dimensions. Following a comprehensive literature review, 12 critical barriers and 8 potential mitigation strategies were identified. To analyze and prioritize these barriers, the study employs the Random Forest Regressor (RFR) model, a robust ML technique capable of capturing complex interactions among factors. Based on the ranking results, appropriate mitigation strategies are mapped to individual barriers, providing a data-driven framework for addressing sustainability challenges. This research contributes to both theory and practice by integrating machine learning with supply chain sustainability studies. The findings yield actionable insights for policymakers, industry practitioners and researchers, offering practical pathways to enhance SSCM practices in the RMG sector of Bangladesh while contributing to the broader discourse on sustainable supply chain management.

Keywords: Ready-Made garment, Sustainable supply chain management, Machine learning, Random Forest regressor

1. Introduction

The RMG industry is a key contributor to Bangladesh's economy, helping to grow the country, provide jobs and raise its earnings from exports. Over recent years, Bangladesh has built a strong reputation for producing clothes and becoming one of the world's largest exporters of ready-made garments (RMG). In 2022, Bangladesh secured the second position in global garment exports as a single country[1].

While the manufacturing sector has grown fast, it has raised problems of sustainability and highlighted the problems societal, economic and environmental issues. Due to the high costs in materials, the textile sector causes a lot of pollution, drains water resources and produces hazardous wastes. However, this industry has serious sustainability problems and it has been indicated to be the 2nd most polluting industry in the world, after the oil industry[2].

Bangladeshi RMG industry has significantly faces Hazardous materials, water pollution, greenhouse gas emissions and poor waste management are causing significant environmental changes. Sustainable Supply Chain Management (SSCM) challenges in the Supply Chain (SC) network, together with SSCM adoption, influence all the players involved[1]. So, sustainability is becoming a global issue, many progressive organizations[3]. There are many researches on SSCM. The majority of the research focuses on SC economic, social and environmental factors separately.

The sector in Bangladesh's RMG industry requires everyone to adopt sustainable solutions to tackle ongoing issues and challenges. This research aims to make useful and practical suggestions for using sustainable practices in organizations by developing special models[1]. The term sustainability, which refers to an integration of economic, social and environmental responsibilities that already mentioned has started to arise in the literature of business disciplines such as operations and management[4]. Sustainability in SCM performance has become very important for the survival of the business firms because customers judge the effectiveness of the firms based on their SC performance[5]. The contribution of this research is that it successfully fits SSCM adoption challenges and mitigation strategies within Machine Learning (ML) framework. This research employs an approach to determine the priorities and challenges by the ML methodology. Sorting out these problems in priority helps build an effective plan for protection.

2. Literature Review

The Bangladeshi RMG business has faced several barriers, which has led to ongoing improvement and transformation to increase resilience[1]. With the increasing importance of sustainability, SCM researchers are integrating sustainability into SCM to boost the development of the field of SSCM[6]. An SSC refers to a system that handles the flow of materials, information and finances in a way that encourages collaboration among all involved parties. The goal is to meet environmental, economic and social objectives all while addressing the needs of customers and other stakeholders[7].

There are 4 barriers categories are identified likes financial, information-related, managerial and organizational, socio-cultural barriers[8]. Each barriers categories contain several barriers in SSCM. Green Supply Chain Management (GSCM) is of particular significance to the RMG industry in Bangladesh for sustainable development. Here, GSCM becomes a strategic approach within supply chains to mitigate environmental risks that are often substantial in textile production[9]. There is a close relationship between GSCM and SSCM.

These countries often face challenges such as lower income levels, limited industrial activity and underdeveloped infrastructure[10]. On top of that, the business environment is often unpredictable and rapidly changing and the absence of strong institutional support makes it difficult for supply chains to adapt, grow and work toward sustainability. As a result, many companies in these regions tend to take only minimal steps when it comes to engaging in sustainable practices[11]. Bangladesh, an emerging economy of Asia, is one of the largest manufacturers and exporters in the global textile industry[3]. The textile industry plays a vital role in the national economy, generating around 78.6% of export earnings and employing over 4 million people. In 2011, the country ranked as the world's second-largest clothing exporter with $19.9 billion in apparel exports. The study creates a QFD-driven optimization model where AHP and MILP are coined to resolve 25 challenges of SSCM adoption and 16 mitigation measures with a score of sustainability performance of 0.4511 in the context of the Bangladeshi RMG industries in an optimized budget[1].

Yet another survey highlights Collaboration, whether internally within firms or with the suppliers and the business rivals, the major role in the overall potential of allowing the SSC of a sustainable nature in the textile industry, by lowering the plasters and supporting the policy execution[12]. Another paper was able to come up with 23 supply-side challenges in the supply chain of apparel in Bangladesh, which are organized into six categories. The research roomed on 11 mitigation strategies that relate to these obstacles[13].

We also find from another research that drive at the problems that occurred during implementation of SSCM in India amid fastener manufacturing industries listed 13 of the most important obstacles. The study demonstrates the interconnection of these barriers by using the Interpretive Structural Modeling (ISM)[14]. Anther paper researches the obstacles affecting the adoption of SSCM through the ISM approach ranked 15 barriers. These barriers are analyzed and ranked through ISM and MICMAC analysis. The results underline the view that whereas factors such as high costs represent important stimulants, another factor such as the absence of meaningful measures to SSCM implementation[15].

The paper examines key drivers like budget, infrastructure, technology and regulations as crucial for implementing sustainable supply chain management at a palm oil company using the TOPSIS method[16]. The Chinese companies highlight that external pressures (government, customers, competition) and internal strengths (leadership, technical skills) significantly influence SSCM adoption. It uses institutional theory and resource-based view to provide deeper insights into these driving forces[17].

On South India's textile industry identifies 13 key enablers of SSCM adoption using the ISM technique, including green practices and government regulations. It highlights that these two factors play a central role in promoting sustainable practices and enhancing industry-wide sustainability integration[18].

Another research explores the problem of sustainable supply chain practices (SSCP) in the Indian automobile industry explores the adoption of sustainability practices, positively affects the supply chain performance (SCP), inhibitors like cost uncertainty, market inhibitors on the other hand negatively affect the effectiveness of the practices and advantages of such enabling conditions as technological innovation and collaborations with supplier in promoting a better relationship between SSCP and SCP[19].We also find from research paper conducts a review of the way Canadian corporations blend SSCM practices with reference to governance, performance measures and cooperation with the suppliers. It concludes that though several firms have sustainability strategies, majority of them have strategies on environmental and economic aspects[20]. Another study finds that internal cooperation, strong management and a clear sustainability path support SSCM adoption in the textile industry. However, inadequate resources, low supplier motivation and poor regulations hinder progress, suggesting improved collaboration and resource sharing as solutions[21]. Another review is a systematic examination of the concept of SSCM and the necessity of its application in the automobile sector, which will bring closer attention to three fundamental procedures: supplier selection, production and post-use management[22]. Green Supply Chain Practice (GSCP) impacts on sustainability in the pharmaceutical sector in Jordan. Findings reveal that sustainability performance significantly improves due to the use of eco-design, green purchasing and green manufacturing[23]. The analysis investigates the key barriers to the implementation of Green Supply Chain Management (GSCM) in Karachi pharmaceutical industry. Evidence shows that high capital expenditures, inadequate training, poor awareness and limited resources are the most evident stumbling blocks[24]. The present study examines the role of GSCM functioning in India automobile sector and identifies three practices as its basis green product design, green purchasing and cleaner production technologies. The evidence of practice shows that the creative adaptation of these practices substantially improves measures of environmental, economic, social and operational performance across the industry[25].

The study examines the factors influencing the adoption of GSCM practices in the Indian mining industry. The research used the DEMATEL method to analyze the interconnections between these factors and suggests strategic steps to enhance GSCM adoption[26]. Another study shows an obstacle to implementation of SSCM in hospitals and applies a hybrid multiple-criteria decision analysis (MCDA) models to identify those restrictions that should receive the most thorough consideration[27]. RMG supply chain sustainability is the guarantee of a long-term feasibility in the economy, environment, technology, management and social structures.

3. Methodology

This section outlines the research methodology employed to investigate the barriers and mitigation strategies for implementing a sustainable supply chain in Bangladesh's RMG sector using a machine learning approach.

3.1. Research approach

This study follows a machine learning–based quantitative approach to identify and analyze barriers to sustainable supply chain management (SSCM) in the RMG sector. Twelve critical barriers, grouped under six categories and eight mitigation strategies were selected from literature review. Data were collected from industry professionals through structured surveys and validated before analysis. The Random Forest Regressor (RFR) model was then applied to rank barriers and map them with suitable mitigation strategies, ensuring both data-driven insights and practical relevance for the RMG industry.

3.2. Identification of barriers

After a critical review, we selected 12 barriers for analysis. In previous work, MCDM integrated QFD was used to identify the most critical barriers. Instead of this model, we will use an updated data driven approach "Random Forest Regressor" which is a ML model. **(Table 1)** represents the identification of 12 barriers through a strong literature review.

Table 1: List of Barriers.

Barriers Type	Barriers Name	Reference
Economical	High cost of sustainability adoption	1,2
	High cost of disposing hazardous wastes	1,14
Environmental Regulations	Compliance with certifications and standards	1
	Complexity in monitoring the environmental practice	1
Technological	Lack of advanced technology	2
	Lack of collaboration with research institute	1,3
Managerial	Lack of top management commitment	1,8,14
	Lack of supply chain integration	1
Societal	Absence of Govt. support and policies	1-3,8
	Lack of corporate social responsibility	1,8,28
Inbound Supply	Longer lead time	13
	Raw material price fluctuation	13

(Table 1) presents the 12 critical barriers hindering the implementation of sustainable supply chain management (SSCM) in the Ready-Made Garment (RMG) sector of Bangladesh. These barriers are categorized into six major types: economical, environmental regulations, technological, managerial, societal and inbound supply. Each barrier type contains 2 critical barriers which we found by reviewing various research paper. These barriers illustrate the multifaceted challenges faced by the RMG sector in its journey toward sustainable supply chain practices.

3.3. Identification of mitigation strategies

To overcome the SSC barriers identified in the RMG sector of Bangladesh, eight mitigation strategies were selected through an extensive review of existing literature. Various peer-reviewed journal articles, case studies and academic reports were examined to identify strategies that have been widely recognized and recommended in the context of SC sustainability. The selection focused on those strategies that appeared frequently across multiple studies and demonstrated strong relevance to the operational and environmental challenges of the RMG sector **(Table 2)**.

Table 2: Mitigation Strategies.

SSC Strategies	References
Supply Chain Transparency (M1)	1
Integration of Energy-Efficient Technology (M2)	1,10
Training and Education Programs (M3)	1,10,13
Assuring governmental support (M4)	8
Standards and Certifications (M5)	1
Ethical Labour Practices and Efficient planning (M6)	1,13
Recycling and Waste Reduction (M7)	1
Enhancing Collaboration and Information Sharing with SC partners (M8)	1,8,10,13

(Table 2) outlines the 8 mitigation strategies proposed to address the 12 critical barriers to sustainable supply chain management (SSCM) in Bangladesh's RMG sector. These strategies provide a practical framework for overcoming the identified barriers, enabling the RMG industry to move toward more sustainable and resilient supply chain practices.

3.4. Method selection

The Random Forest Regressor (RFR) was chosen to prioritize barriers and mitigation strategies. RFR constructs multiple decision trees and aggregates results, which reduces over fitting and enhances prediction accuracy. It is particularly effective for feature importance analysis and performs well with smaller datasets, offering robustness against noise and multi-collinearity. These strengths make RFR more suitable than traditional statistical or decision-making models for identifying the most critical SSCM challenges in this study.

3.5. Comparison with previous research

Previous studies addressing SSCM challenges in the RMG sector often relied on multi-criteria decision-making (MCDM) techniques such as AHP, TOPSIS, ISM and QFD-based hybrid models. While these approaches provided valuable insights, they mostly focused on hierarchical relationships and subjective weight assignments, which can limit generalizability. In contrast, the present study applies a machine learning-based model (RFR) that captures nonlinear dependencies among variables and provides data-driven prioritization without relying solely on expert subjectivity. The results are therefore more adaptive, replicable and robust compared to traditional MCDM-based frameworks. This integration of machine learning into SSCM research extends the methodological frontier and strengthens the reliability of barrier and mitigation strategy identification.

3.6. Sensitivity analysis

Sensitivity analysis is a key validation technique in machine learning studies, applied to assess the robustness and reliability of model outcomes. It examines how small changes in input data or model parameters influence results, thereby ensuring consistency in predictions. In Random Forest, methods such as cross-validation and bootstrapping are commonly used to test stability. Although the detailed sensitivity results are presented in Section 7, its theoretical inclusion here highlights its importance for validating the reliability of findings in barrier ranking and mitigation strategy selection.

This section outlined the theoretical foundation and methodological choices underpinning the study. It first introduced the machine learning–based research approach, emphasizing the suitability of the Random Forest Regressor (RFR) for analyzing complex, nonlinear interactions among barriers and mitigation strategies. The rationale for selecting RFR over traditional models was discussed, highlighting its robustness with small datasets and ability to provide feature importance for ranking. A brief comparison with prior research demonstrated how this approach extends beyond conventional MCDM methods, offering a more objective and adaptive framework. Finally, the theoretical basis of sensitivity analysis was presented to underline its role in validating the stability and reliability of model outcomes. Together, these elements establish a comprehensive methodological framework for analyzing sustainable supply chain challenges in Bangladesh's RMG sector.

4. Data Collection

Primary data were collected using structured questionnaires. Two surveys were administered:

- One for evaluating the importance of 12 selected barriers, completed by 40 supply chain professionals from various RMG organizations.
- Another for assessing the effectiveness of 8 pre-identified mitigation strategies, completed by 20 industry professionals.

A purposive sampling method (a non-probability sampling technique where participants are deliberately selected based on their expertise or relevance to the research problem) was applied to select professionals actively working in the supply chain departments of major RMG companies (Gildan, Standard Group, Q Collection Pte. Ltd, Square Fashion Ltd, Comfit Composite Knit Ltd, Noman Composite Textile Ltd, Croyodon Kowloon Designs Ltd). The goal was to ensure the inclusion of informed respondents capable of providing expert input on SSCM issues.

4.1. Validation of the dataset for random forest regressor model

'K-Fold Cross Validation' method is used to check that how much valid our prepared data set is for 'Random Forest Regressor' method. Cross-validation is a robust method to validate the performance of our ML model. The most common type is k-fold cross-validation, where the dataset is split into k subsets (k=5). The model is trained on k-1 subsets and tested on the remaining subset. This process is repeated k times, with each subset being used as the test set once. This helps in evaluating the model's stability and generalizability.

We have gotten the validation result of 'Barrier Type' dataset below;

Cross-Validation Scores (MSE): [-106.3856875, -65.9284375, -147.219175, -48.8292125, -39.0455]

Mean MSE: -81.48160250000001

Standard Deviation of MSE: 40.126161534589414

The results showed varying MSE scores with a mean of -81.48 and a standard deviation of 40.12, reflecting some instability due to the small dataset size. Although MSE values vary, they remain within an acceptable range, confirming the dataset's validity. Since MSE has no universal standard value and depends on the data scale, values closer to zero indicate better accuracy. Thus, the dataset is suitable for the model, though future studies with larger samples could improve stability and precision. The high standard deviation (around 40%) is a common issue in models trained on small datasets. If a larger dataset were available, the model would likely show more stable and reliable results, with lower variation across folds. Therefore, in future studies, increasing the sample size can help improve the precision and consistency of the model's predictions.

5. Result Analysis

We have 6 types of barriers and we collected data for barrier type also to find out the most actionable barrier. At first, collected data were uploaded in excel file according to the RFR model. Then the file was uploaded on the Google Colab platform, where our RFR model's python code has been run. After uploading the file, we have run the code step by step to get the values of Feature Importance (prioritizing value of the factors) for every six barrier types. Finally, we got the ranking of barrier types according to its feature importance (FI) values.

(Figure 1) presents the feature importance scores of six barrier categories as derived from the RFR model. Among them, economical barriers recorded the highest contribution (26.77%), showing that cost-related issues such as high adoption expenses and waste disposal costs are the most critical obstacles to SSCM adoption in the RMG sector. This is followed by technological barriers (22.72%) and managerial barriers (14.88%), which emphasize the importance of advanced technology, collaboration and strong managerial commitment. Societal barriers (12.84%) and inbound supply barriers (12.48%) appear moderately significant, indicating challenges in government support, CSR and supply chain reliability. By contrast, environmental regulatory barriers obtained the lowest score (10.32%), suggesting that compliance and monitoring issues are relatively less influential in this context. Overall, the ranking highlights that overcoming financial and technological constraints should be prioritized to foster sustainable supply chain practices in the RMG sector.

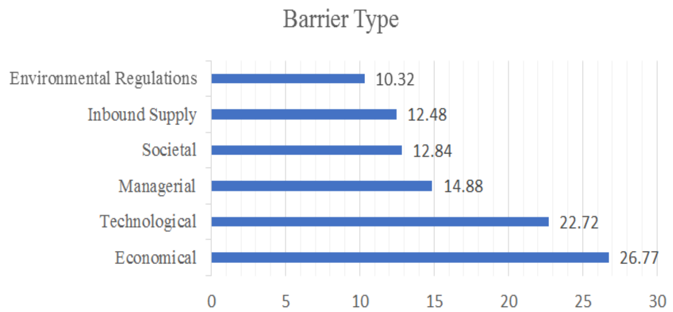


Figure 1: Feature Importance of Barrier Type.

(Table 3) depicts the feature importance score (in %) of different types of barriers hindering the implementation of a sustainable supply chain in the RMG sector, as obtained from the Random Forest Regressor model. Feature importance reflects how much each barrier contributes to predicting the outcome (supply chain sustainability performance); hence, a higher score indicates a stronger influence.

Here, RFR model shows highest importance score for Economical barrier is "High cost of sustainability adoption" and that is 28.04%. So, it is ranked as 1. Similarly feature importance score is calculated for other barrier type in same way.

Finally, under Environmental Regulatory barriers, compliance with certifications & standards (B11) ranks highest (56.03%), indicating that strict regulations and certifications act as the most dominant barrier overall. Complexity in monitoring environmental practice (B12) carries a lower importance of 22.61%.

Now our 2nd objective is to find out the appropriate mitigation strategy for each of 12 barriers. We collected data from 20 responses and applied RFR model.

(Table 4) presents the feature importance scores (in %) of eight mitigation strategies (M1-M8) against the twelve identified supply chain barriers (B1–B12). The importance scores are generated using a RFR model and reflect how effectively each mitigation strategy contributes to reducing the respective barrier a higher score indicating a stronger mitigation impact. Overall, the table helps identify which mitigation strategy is most suitable for tackling each specific barrier;

- **For Economical barriers (B1–B2):** Supply Chain Transparency (46.33%) shows the strongest effectiveness in mitigating high cost of sustainability adoption (B1), whereas Recycling and Waste Reduction (47.19%) and Integration of Energy-Efficient Technology (14.23%) are more relevant for high cost of disposing hazardous wastes (B2).
- **Technological barriers (B3–B4):** Integration of Energy-Efficient Technology (84.56%) has the highest contribution in mitigating lack of advanced technology (B3), while Training and Education Programs (74.20%) and Ethical Labor Practices and Efficient planning (5.52%) appear most influential for lack of collaboration with research institutes (B4).

Table 3: Feature Importance of type wise barriers.

Barrier Types	Barriers	Feature Importance (%)	Rank
Economical	High cost of sustainability adoption (B1)	28.04	1
	High cost of disposing hazardous wastes (B2)	25.03	2
Technological	Lack of advanced technology (B3)	42.57	1
	Lack of collaboration with research institute (B4)	32.38	2
Managerial	Lack of supply chain integration (B5)	36.40	1
	Lack of top management commitment (B6)	33.37	2
Societal	Lack of corporate social responsibility (B7)	34.58	1
	Absence of Govt. support and policies (B8)	33.93	2
Inbound Supply	Raw materials price fluctuation (B9)	43.77	1
	Longer lead time (B10)	33.5	2
Environmental Regulations	Compliance with certifications & standards (B11)	56.03	1
	Complexity in monitoring the environmental practice (B12)	22.61	2

Table 4: Feature importance score of mitigation strategies for 12 barriers.

Mitigation Strategies	Feature Importance											
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
M1	46.33	6.05	4.18	4.24	81.44	1.38	0.44	0.79	8.34	12.63	14.53	9.73
M2	11.67	14.23	84.56	6.24	4.88	11.18	1.00	1.47	10.38	10.96	16.32	17.92
M3	7.27	4.91	2.65	74.20	4.52	2.02	91.22	0.52	5.53	10.31	9.39	11.85
M4	4.16	7.37	1.07	5.04	2.51	0.80	0.46	87.53	12.81	4.26	14.18	6.57
M5	4.02	7.57	1.75	0.88	2.30	4.36	2.57	1.08	9.92	1.67	18.10	9.30
M6	12.91	3.73	2.50	5.52	2.13	0.81	1.71	1.41	5.50	3.02	11.59	33.48

Mitigation Strategies	Feature Importance											
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
M7	7.36	47.19	2.53	2.15	1.32	1.03	0.85	1.33	16.61	7.87	3.62	8.37
M8	6.29	8.95	0.76	1.74	0.90	78.43	1.85	5.87	30.89	49.27	12.27	2.78

- **Managerial barriers (B5-B6):** Supply Chain Transparency (81.44%) and Enhancing Collaboration and Information Sharing with SC partners (78.43%) stand out as the foremost strategies to overcome lack of supply chain integration (B5) and lack of top management commitment (B6), respectively. Integration of Energy-Efficient Technology (11.18%) and Standards and Certifications (4.36%) also show some relevance in addressing managerial concerns.
- **Societal barriers (B7-B8):** Training and Education Programs (91.22%) is highly effective for mitigating lack of corporate social responsibility (B7), whereas Assuring Governmental Support (87.53%) provides the strongest response to absence of government support and policies (B8).
- **Inbound supply barriers (B9-B10):** Enhancing Collaboration and Information Sharing with SC partners (30.89%) is most important for raw material price fluctuation (B9), while Enhancing Collaboration and Information Sharing with SC partners (49.27%) again shows outstanding importance for longer lead time (B10) indicating its strong capability to strengthen inbound supply efficiency.
- **Environmental barriers (B11-B12):** For compliance with standards/certifications (B11), Standards and Certifications (18.10%) and Integration of Energy-Efficient Technology (16.32%) are most influential mitigation strategies. Ethical Labor Practices and Efficient planning (33.48%) is highly significant for addressing complexity in monitoring environmental practices (B12).

This part enables practitioners to strategically select the most suitable mitigation option based on the most pressing barrier in their supply chain.

So, appropriate mitigation strategies to overcome each barrier are **(Table 5)**;

Table 5: Appropriate Mitigation for each barrier.

Barrier	Mitigation Strategy
High cost of sustainability adoption	Supply Chain Transparency
High cost of disposing hazardous wastes	Recycling and Waste Management
Lack of advanced technology	Integration of Energy-Efficient Technology
Lack of collaboration with research institute	Training and Education Programs
Lack of supply chain integration	Supply Chain Transparency
Lack of top management commitment	Enhancing Collaboration and Information Sharing with SC partners
Lack of corporate social responsibility	Training and Education Programs
Absence of Govt. support and policies	Assuring governmental support
Raw materials price fluctuation	Enhancing Collaboration and Information Sharing with SC partners
Longer lead time	Enhancing Collaboration and Information Sharing with SC partners
Compliance with certifications & standards	Standards and Certifications
Complexity in monitoring the environmental practice	Ethical Labour Practices and Efficient Planning

To overcome the sustainability challenges within the RMG supply chain in Bangladesh, several strategic mitigation approaches have been identified which is identified in **(Table 5)**. Enhancing supply chain transparency plays a vital role in addressing issues related to cost and integration, enabling more efficient and accountable operations. Recycling and waste management strategies support environmentally responsible disposal practices. The integration of energy-efficient technologies promotes cleaner production and reduces dependence on outdated systems.

Training and education programs are essential for strengthening institutional collaboration and fostering a culture of corporate social responsibility. Moreover, improved collaboration and information sharing among SC partners can significantly enhance coordination, reduce lead times and improve responsiveness to market dynamics. Ensuring governmental support through appropriate policies and incentives is also critical in promoting sustainability initiatives. In addition, compliance with established standards and certifications enhances global competitiveness, while the adoption of ethical labor practices and efficient planning improves monitoring and implementation of environmental measures.

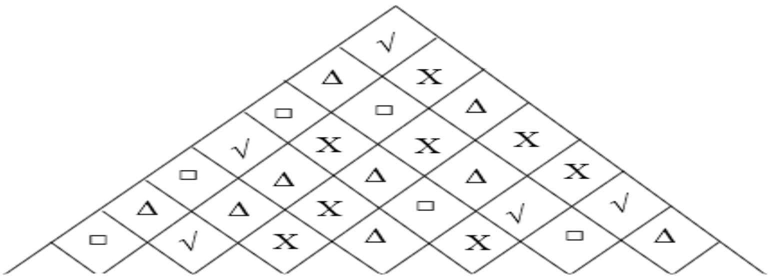
6. Comparison of Result with Previous Researches

The integration of QFD and TOPSIS enabled a structured evaluation and prioritization of key barriers within the SC system. Using QFD, critical relationships between barriers and mitigation strategies were identified and quantified. The relative importance weights derived from the QFD matrix were then used as input criteria for the TOPSIS analysis. This hybrid approach provided a robust decision-support framework for strategic barrier mitigation. The degree of relationship among the barrier mitigation strategies is illustrated in the roof matrix of the House of Barrier Mitigation (HoBM). From the roof matrix, **(Table 6)** reveals that quick response is related with most of the strategies. It is also identified that the relationship between forecasting and preparedness and quick response is very strong. From the relationships between the strategies, managers can make important decisions on simultaneous implementation of mitigation strategies.

Table 6: Symbol of Correlations.

Symbol	Meaning
√	Strong
Δ	Medium
□	Weak
X	No Relationship

(Figure 2) represents the relationships between the barriers and the corresponding mitigation strategies with the help of TOPSIS weighted factor. The lower part of **(Figure 2)** shows the absolute importance (A.I.) and relative importance (R.I.) values of each strategy. The upper triangle of the HoBM represents correlation among 8 mitigation strategies. The mathematical values of the barriers vs mitigations are calculated by using TOPSIS method **(Table 7)**.



B.T.	Barrier	M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8	A.I.
Economical	B1	0.102	0.07	0.137	0.04	0.05	0.221	0.2040	0.177	1
	B2	0.054	0.206	0.138	0.049	0.095	0.027	0.263	0.168	1
Technological	B3	0.099	0.247	0.133	0.047	0.065	0.161	0.036	0.211	1
	B4	0.126	0.054	0.232	0.074	0.094	0.168	0.049	0.202	1
Managerial	B5	0.213	0.056	0.127	0.078	0.100	0.159	0.034	0.228	1
	B6	0.133	0.05	0.206	0.07	0.103	0.163	0.038	0.241	1
Societal	B7	0.127	0.06	0.225	0.091	0.108	0.194	0.031	0.163	1
	B8	0.159	0.051	0.123	0.248	0.21	0.077	0.033	0.097	1
Inbound Supply	B9	0.105	0.052	0.136	0.17	0.186	0.073	0.037	0.241	1
	B10	0.087	0.073	0.131	0.102	0.16	0.11	0.052	0.285	1
Environmental Regulations	B11	0.113	0.05	0.133	0.163	0.238	0.18	0.03	0.095	1
	B12	0.163	0.048	0.131	0.111	0.121	0.185	0.171	0.07	1
A.I.		1.481	1.017	1.852	1.243	1.53	1.718	0.978	2.178	12
R.I.		0.123	0.085	0.154	0.104	0.128	0.143	0.082	0.182	

Figure 2: House of Barrier & Mitigation (HoBM).

Here, Absolute Importance (A.I.) = Row wise sum and Column wise sum

Relative Importance (R.I.) = $\frac{A.I._i}{\sum_{i=1}^{12} A.I.}$

Table 7: Result Comparison.

Barrier	Mitigation (RFR)	Mitigation (QFD)
B1	M1 (46.33%)	M6 (22.10%)
B2	M7 (47.19%)	M7 (26.30%)
B3	M2 (84.56%)	M2 (24.70%)
B4	M3 (74.20%)	M3 (23.20%)
B5	M1 (81.44%)	M8 (22.80%)
B6	M8 (78.43%)	M8 (24.10%)
B7	M3 (91.22%)	M3 (22.50%)
B8	M4 (87.53%)	M4 (24.80%)
B9	M8 (30.89%)	M8 (24.10%)
B10	M8 (49.27%)	M8 (28.50%)
B11	M5 (18.10%)	M5 (23.80%)
B12	M6 (33.48%)	M6 (18.50%)

Both models show the prediction of appropriate mitigation strategy for each barrier. Around 83.33% result of most appropriate strategy finding is same in both models. In **(Table 7)** we can see the mitigation strategies of B1& B5 show different result. Though TOPSIS integrated QFD model is based on manual calculation process, it has some calculation errors. On the other hand, RFR model is a ML method which predicts the result by training the dataset properly. We also can see that in Table 8, RFR model predicts the mitigation strategies with high percentage. It means the model is sure about its predictions. So, we have selected the RFR model's predictions to find out appropriate mitigation strategy for the most actionable 12 barriers.

7. Sensitivity Analysis

To test the robustness of the barrier type ranking, a sensitivity analysis was conducted using bootstrapping. Bootstrapping is a statistical method used to understand how sensitive your model's results are to variations in the input data. It is a resampling technique. The dataset was repeatedly resampled (100 iterations) and RFR was applied each time to capture the variation in feature importance scores **(Figure 3)**.

(Figure 3) presents the results of the sensitivity analysis for different types of barriers. The findings highlight that economic barriers were consistently identified as the most significant, showing the highest average importance. Technological and managerial barriers also showed strong importance but with less variation, indicating their steady and dependable role in the model. These categories not only had lower average importance but also displayed greater sensitivity to changes in the data, suggesting their impact may be more situational or dependent on specific conditions within the RMG sector.

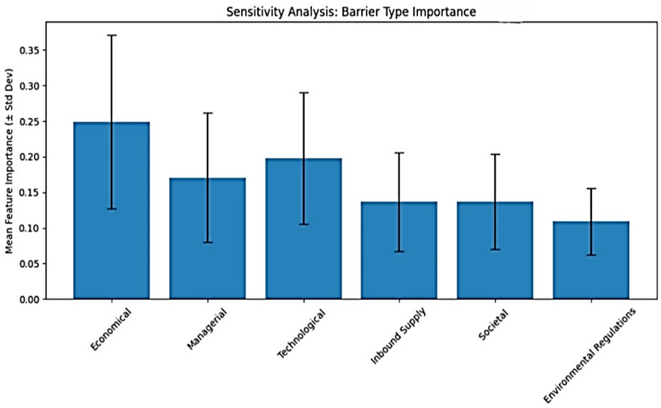


Figure 3: Sensitivity Analysis of Barrier Type.

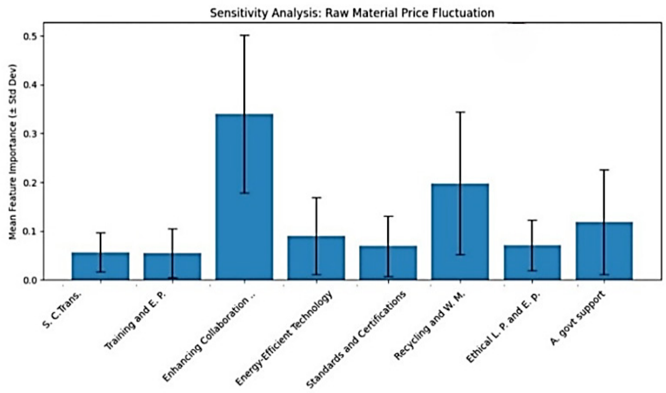


Figure 4: Sensitivity Analysis of Raw Materials Price Fluctuation.

(Figure 4) represents the results of the sensitivity analysis for raw materials price fluctuation. The sensitivity analysis shows that Enhancing Collaboration is the most influential factor in raw material price fluctuation, though its impact varies widely. The results highlight the need for data-driven decisions, as the effect of key barriers depends on context. The vertical black lines in the sensitivity analysis plot represent ±1 standard deviation from the mean feature importance, indicating how much each barrier type's importance varies across different data samples. A longer error bar signifies greater sensitivity to data variation, whereas shorter bars reflect robust and stable rankings.

8. Key Findings & Managerial Implications

The key finding of this paper is the significance of RFR model's result. The ML model identifies clearly the appropriate strategies to mitigate the barriers with high percentage of FI value, where TOPSIS integrated QFD shows the less predictions. The model's results were also validated through sensitivity analysis, confirming the robustness of the model by using bootstrapping method. The findings of this study offer significant managerial insights for decision-makers in the Bangladeshi RMG sector. By identifying and ranking the most critical barriers to SSC implementation using a data-driven RFR model, managers can make informed decisions based on empirical evidence rather than assumptions. This approach allows for strategic prioritization, enabling firms to allocate resources efficiently toward high-impact areas such as high sustainability costs, lack of advanced technology and raw material price volatility. Managers should tailor sustainability efforts based on the specific challenges their organizations face. For instance, enhancing supply chain transparency and integrating energy-efficient technologies are shown to be highly effective for key barriers and should be prioritized accordingly.

9. Conclusion and Future Work

This study explored sustainable supply chain (SSC) challenges in Bangladesh's Ready-Made Garment (RMG) sector and identified 8 effective mitigation strategies. An initial list of 25 barriers was narrowed down to 19 after expert consultation. Using survey data and the Random Forest Regressor (RFR) machine learning method, 12 key barriers were identified based on their impact. A second survey round matched these barriers with suitable strategies, again using RFR for optimal results. The study also compared RFR with TOPSIS-QFD, where RFR performed better, offering valuable academic and industrial insights. The future work could expand the dataset by including a broader range of industries within the textile sector, both within Bangladesh and globally, to validate the findings across different contexts and integrate more advanced ML techniques, such as SVM, ANN to enhance the accuracy and precision of barrier identification and ranking. Additionally, incorporating a multi-objective optimization approach could enable a more nuanced analysis of how different mitigation strategies interact and their collective impact on sustainability performance. Lastly, the practical application of these mitigation strategies within the RMG sector warrants further investigation.

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