



# A mixed-method approach to develop an eco-robust supply chain management framework for Bangladeshi RMG industries

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## ABSTRACT

The Bangladeshi Readymade Garment (RMG) industry plays a pivotal role in the national economy, yet it faces significant sustainability challenges due to high resource consumption, environmental impact, and vulnerability to supply chain disruptions. This study adopts a mixed-method approach with a QFD-based Optimization Model to develop an Eco-Robust Supply Chain Management (ERSCM) framework. By integrating sustainability and resilience into a unified model, the research provides a strategic approach to enhancing environmental performance while improving resilience against supply chain disruptions. The methodology employs a mixed-method approach: expert insights were collected and prioritized using the Analytical Hierarchy Process to rank ERSCM strategies, which were then mapped to sustainability and resilience goals through Quality Function Deployment. This relationship analysis was followed by a Mixed-Integer Linear Programming optimization to select cost-effective strategies that maximize eco-robust performance under budget constraints. The results reveal that Technology Integration, Continuous Improvement and Innovation, Supply Chain Transparency, and Stakeholder Collaboration are among the most impactful ERSCM strategies, demonstrating strong alignment with Sustainable Development Goals. The findings underscore that, even within budgetary limits, high-impact, cost-efficient strategies can be implemented to advance both sustainability and resilience. This research contributes to Sustainable Supply Chain Management literature by developing a novel QFD-based optimization model that systematically integrates sustainability and resilience. Methodologically, it combines AHP for strategic prioritization, QFD for mapping interdependencies, and MILP for cost-effective decision-making. This research also offers actionable insights for RMG industry managers aiming to transition toward eco-robust practices that support sustainable and resilient development.

## 1. Introduction

The growing demand for sustainable practices in global industries has brought Sustainable Supply Chain Management (SSCM) to the forefront, emphasizing environmental responsibility alongside operational efficiency. SSCM aims to integrate sustainable principles into the entire supply chain, from raw material sourcing to final product delivery, with a focus on reducing environmental impact and promoting social responsibility [1,2]. This research introduces the concept of Eco-Robust Supply Chain Management (ERSCM), which combines environmental sustainability with resilience to create adaptable, eco-friendly supply chains that can withstand market and environmental disruptions. This approach is particularly relevant for the RMG industry in Bangladesh, a sector critical to the country's economy, accounting for over 80 % of export earnings and providing employment to millions [3,

4]. However, the industry faces significant sustainability and resilience challenges, making it essential to explore cost-effective, eco-robust strategies that align with Sustainable Development Goals (SDGs) to ensure long-term viability and environmental compliance [5].

Despite extensive research on SSCM, there is still a significant gap in addressing both sustainability and resilience objectives within the RMG industry, particularly in emerging economies like Bangladesh [6]. Many studies tend to address sustainability and resilience as separate goals, often missing the interconnected challenges industries face when striving to achieve both simultaneously. This research addresses the gap by exploring how an Optimization Model can achieve eco-robust performance by balancing sustainability and resilience objectives within budget constraints. This approach highlights the need for research focused on optimizing ERSCM strategies in resource-limited settings, providing adaptive and cost-effective solutions for the RMG sector. The

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primary research questions guiding this study are:

**RQ1:** What are the strategies can enhance eco-robust performance in the Bangladeshi RMG industry?

**RQ2:** How can these strategies be prioritized based on their performance and cost efficiency?

**RQ3:** How do budget constraints impact the implementation of eco-robust practices?

To achieve the goals of eco-robust performance, we employed a mixed-method approach, combining qualitative and quantitative techniques. By integrating qualitative insights with a quantitative model, we could more accurately capture the complexities of implementing green practices and green technologies in the RMG industry, where both economic and environmental factors are interdependent. This approach ensures robust, data-driven decision-making that captures both practical industry insights and precise, cost-effective solutions [7,8]. First, we prioritized the weight of various ERSCM strategies using the Analytical Hierarchy Process (AHP). This step helped us systematically rank the importance of different strategies based on expert input. The AHP was chosen for its ability to capture expert insights and systematically prioritize strategies based on their impact on sustainability and resilience. AHP provides a structured methodology to rank complex criteria, making it particularly suitable for contexts requiring a clear ranking of priorities [9,10]. This choice reflects our focus on developing a methodologically robust and time-efficient model for practical use in the fast-paced RMG industry. Following the prioritization of strategies through AHP, we applied Quality Function Deployment (QFD) to map the relationships between prioritized ERSCM strategies and the specific sustainability and resilience goals they address. This QFD framework allows for a detailed analysis of how each strategy contributes to achieving ERSCM objectives and provides additional insights into the synergies and interactions among strategies [11]. With these relationships established, we then developed an optimization model to identify the most cost-effective strategies within budget constraints. This model considers both sustainability and resilience, ensuring that the selected solutions are adaptable, financially feasible, and aligned with the overarching goals of ERSCM.

This research makes a distinct contribution to the field by introducing an Optimization Model specifically designed for the unique challenges of the Bangladeshi RMG sector. Unlike traditional SSCM models that primarily target environmental impact reduction, this model fully integrates resilience, recognizing that adaptability is essential for long-term stability in volatile markets [12–14]. This dual focus on sustainability and resilience is particularly critical for the RMG sector in developing countries, where supply chains are often susceptible to external disruptions [15,16]. By combining expert-driven prioritization through AHP with optimization techniques, the model provides RMG managers with actionable insights, enabling them to select strategies that balance these dual objectives within limited resource constraints. The model emphasizes practicality and accessibility for small and medium-sized RMG industry, offering a viable solution for managers committed to sustainable practices despite financial limitations. This integrated approach fosters a resilient and sustainable transition for the RMG sector.

This study is organized as follows: [Section 2](#) reviews the literature on SSCM and resilience frameworks. [Section 3](#) details the methodology, covering AHP for priority weight calculation, QFD methodology and QFD-based optimization model formulation. [Section 4](#) describes the model's implementation in Bangladeshi RMG across four phases: Identification and Prioritization, Strategy Impact Evaluation, Goal Setting, and Optimization with Sensitivity Analysis. [Section 5](#) presents results, including sensitivity analysis, strategic action plan, Implementation Roadmap for adopting eco-robust strategies and discusses the model's alignment with SDGs. [Section 6](#) concludes with key findings, implications, and future research directions.

## 2. Literature review

The literature on sustainable supply chain management and its integration with resilience is rich, yet there remain gaps in addressing these within the context of emerging markets like Bangladeshi RMG industry. This section reviews foundational concepts in SSCM, explores frameworks integrating resilience, and discusses key methods like AHP, QFD, and optimization models. The alignment of these concepts with the Sustainable Development Goals is also explored, establishing a basis for the contributions of this study. Finally, the research gap is identified highlighting the need for an integrated framework that balances sustainability and resilience within the resource-constrained settings typical of Bangladeshi RMG sector.

SSCM is a strategic approach that integrates environmental, social, and economic sustainability into supply chain processes, from sourcing to end-of-life product management [17]. The primary goals of SSCM include reducing environmental impacts, promoting social responsibility, and achieving economic viability. In emerging markets, SSCM can be transformative, helping companies navigate environmental and social demands while fostering economic growth. However, many industries in these regions face resource limitations and weak regulatory frameworks, inhibiting SSCM adoption [1,2]. The Bangladeshi RMG industry, one of the world's largest garment exporters, faces similar challenges. As a major contributor to employment and GDP, the industry is under increasing pressure to adopt SSCM practices that align with global standards while addressing local limitations [3]. An emerging trend within SSCM literature is the integration of resilience to create eco-robust SCM frameworks that support both environmental sustainability and adaptability. Resilience in SCM refers to the ability of supply chains to recover from disruptions and maintain operations [18, 19]. While sustainability focuses on resource efficiency and environmental protection, resilience emphasizes flexibility and risk management [20,21]. Balancing these objectives can be challenging, as strategies that improve resilience may not always align with sustainability goals. This study aims to adapt such frameworks for the RMG industry, where both environmental impact and supply chain vulnerabilities are critical issues.

Eco-robust supply chain management strategies are vital for enhancing both sustainability and resilience in the RMG industry. As one of the largest garment exporters globally, the Bangladeshi RMG sector faces myriad challenges, including resource constraints, regulatory pressures, disruptions and environmental impacts, which necessitate a dual focus on sustainable practices and resilience-building measures. These strategies aim to reduce environmental footprints and address the industry's vulnerabilities, enabling it to adapt to changing market conditions and unforeseen disruptions [22,23]. By integrating practices that promote environmental responsibility and social accountability, eco-robust SCM strategies help ensure that the RMG industry can navigate the complexities of modern supply chains while maintaining operational flexibility. [Table 1](#) below outlines key eco-robust SCM strategies aimed at achieving sustainability and resilience goals.

In addition to the core eco-robust SCM strategies, several supplementary strategies further enhance sustainability and resilience within the RMG industry. Supplier Development Programs focus on building long-term, sustainable partnerships with suppliers through capacity-building and knowledge-sharing initiatives, thereby strengthening resilience and embedding sustainable practices throughout the supply chain [41,42]. Eco-Friendly Packaging Solutions leverage biodegradable or recyclable materials to reduce waste and pollution, aligning with sustainability goals by decreasing environmental impact and supporting resilience by reducing dependency on traditional packaging supplies that may face shortages [43]. Circular Economy Practices encourage product and packaging designs that emphasize recyclability, reusability, and waste reduction, implementing principles that extend product life cycles and reduce reliance on natural resources [44,45]. Additionally, Green Logistics strategies focus on optimizing transportation and

**Table 1**  
Eco-robust SCM strategies.

ERSCM Strategies	Description	References
S1: Supply Chain Transparency	Enhancing visibility throughout the supply chain to track sustainability practices.	[24,6]
S2: Technology Integration	Utilizing advanced technologies like IoT and AI to optimize supply chain operations.	[25,26]
S3: Collaboration with Stakeholders	Engaging suppliers, customers, and other stakeholders in sustainability initiatives.	[27,28]
S4: Continuous Improvement and Innovation	Fostering a culture of ongoing assessment and adoption of best practices.	[29,30]
S5: SC Resilience and Risk Management	Developing strategies to identify and mitigate risks within the supply chain.	[31,16]
S6: Education and Training Programs	Providing training on sustainable practices to employees and stakeholders.	[32,33]
S7: Energy-Efficient Technology	Investing in technologies that improve energy efficiency and reduce the carbon footprint.	[34]
S8: Waste and Pollution Management	Implementing measures to minimize waste and manage pollution effectively.	[35,36]
S9: Life Cycle Assessment	Assessing environmental impacts across the product life cycle to inform decision-making.	[37,38]
S10: Certifications and Standards	Adhering to recognized sustainability certifications to enhance credibility and compliance.	[39,40]

logistics processes to minimize carbon emissions and enhance overall supply chain efficiency, contributing directly to eco-robust performance [46].

The AHP is a multi-criteria decision-making tool widely used in SSCM to prioritize factors and strategies [9]. AHP enables complex decisions to be broken down into a hierarchy, with criteria and alternatives systematically ranked [10]. Its application in SSCM is valuable in resource-constrained settings, where decision-makers must carefully allocate resources to high-priority initiatives. AHP’s reliance on expert input makes it especially suitable for sectors like RMG, where insights from industry professionals are critical for identifying impactful strategies. Other MCDM tools like TOPSIS, ELECTRE, or Best-Worst Method (BWM) were not chosen as they focus more on ranking alternatives or pairwise comparisons without providing the hierarchical structure and weighting mechanism that AHP offers. While BWM reduces the number of comparisons required and can improve consistency, it may be less intuitive for Bangladeshi RMG sector experts unfamiliar with complex mathematical models [47,48]. On the other hand, QFD is a structured approach that translates customer needs (WHATs) into design requirements (HOWs), making it an effective tool for aligning SSCM strategies with sustainability and resilience goals [49,15]. In SCM, QFD enables a clear mapping of strategic goals to actionable requirements. In emerging markets, QFD has proven effective in resource-limited industries where targeted, high-impact actions are prioritized [11]. For the RMG sector, which requires both sustainable practices and adaptability, QFD offers a structured method to evaluate and align SSCM strategies with goals in eco-robust SCM. Alternatives like Kano or DEMATEL methods could have been used for analyzing relationships, but they do not provide the same level of detail in linking strategies to goals. Additionally, QFD’s ability to integrate seamlessly with optimization models strengthens its relevance to this study [5,50].

Optimization models, especially MILP, have become essential in SSCM to maximize goal attainment under constraints. MILP allows for complex optimization and handling of multiple objectives, constraints, and priorities in SSCM. Optimization models in contexts with budget limitations help ensure that selected strategies provide maximum impact within financial constraints [5,51]. Optimization provides a cost-effective approach to achieving sustainability and resilience for the RMG sector, where financial resources are often limited. Studies

applying MILP in similar sectors demonstrate how budget-constrained optimization models can be used to prioritize high-impact SSCM strategies effectively [5]. This study leverages MILP to select a combination of eco-robust SCM strategies that achieve sustainability and resilience within set budget limits, ensuring practicality and maximum impact. Additionally, SSCM practices that align with SDGs play a crucial role in achieving sustainable development, addressing global challenges related to work conditions, resource efficiency, and climate change [52]. Studies on SDG alignment highlight how companies benefit from integrating these goals, as they meet consumer demands and regulatory standards while contributing to global sustainability [5]. This study emphasizes these SDGs, demonstrating how an eco-robust SCM framework for the RMG sector can drive positive socio-economic and environmental change in Bangladesh.

The existing research on SSCM predominantly addresses sustainability or resilience in isolation, lacking an integrated approach that combines these essential objectives, particularly for resource-limited sectors [12–14]. Although SSCM frameworks generally focus on reducing environmental impacts, they often neglect resilience factors, which are critical for industries facing regular disruptions, such as Bangladeshi RMG sector. This gap is particularly significant for small and medium-sized enterprises (SMEs) within emerging economies, where financial constraints and limited access to advanced technologies pose considerable barriers to achieving both sustainability and resilience. Existing studies often lack a comprehensive mixed-method approach that integrates expert-driven prioritization with quantitative optimization, which is essential for dynamic, high-impact industries like RMG [5,16,53]. This gap reveals an urgent need for research that provides decision-makers with clear, data-driven guidance to implement eco-robust SCM strategies effectively, maximizing both social and environmental outcomes. Studies show that by identifying and measuring these relationships, companies can maximize both their social and environmental impacts, thereby improving strategic alignment with SDGs. This study addresses these gaps by developing an eco-robust SCM framework that utilizes AHP, QFD, and optimization modeling to balance sustainability and resilience within budget constraints, providing actionable insights that align with SDGs for emerging markets.

### 3. Methodology

This section outlines the multi-step methodology used to develop an ERSCM framework for the RMG industry in Bangladesh. Fig. 1 illustrates the proposed methodology, which integrates AHP, QFD, and MILP to develop an eco-robust supply chain management framework. The

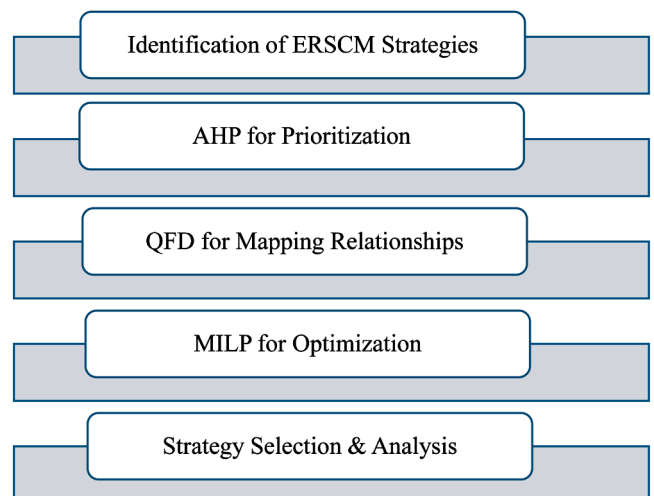


Fig. 1. Research Framework.

process begins with identifying key ERSCM strategies, followed by prioritization using AHP, mapping relationships through QFD, and optimization via MILP for cost-effective strategy selection. This integrated approach facilitates a balanced focus on sustainability and resilience, aligning with the SDGs and addressing the specific needs of SMEs in the Bangladeshi RMG sector.

### 3.1. Priority weight calculation using AHP

The AHP is a widely used multi-criteria decision-making technique developed by Thomas L. Saaty, which helps in making complex decisions by breaking down the decision problem into a hierarchical structure and prioritizing options based on multiple criteria [54]. AHP is instrumental in sustainability and supply chain management for selecting strategies and evaluating alternatives, especially within resource-constrained environments like the RMG industry in Bangladesh, where both eco-friendly and resilient strategies are crucial. The AHP process involves four main steps:

#### Step 1: Problem Definition and Hierarchical Structuring

The first step is defining the problem and structuring it hierarchically. The top level represents the goal. The intermediate levels consist of criteria and sub-criteria that influence the decision, while the bottom level includes the alternatives or options (e.g., ERSCM strategies) being evaluated. In this research, the hierarchy was designed to prioritize strategies that enhance eco-robust performance, considering factors like sustainability, resilience, and cost-efficiency.

#### Step 2: Pairwise Comparison and Priority Setting

In this step, decision-makers perform pairwise comparisons of criteria and alternatives to evaluate their relative importance. This is usually done using a 1-to-9 scale, where 1 indicates equal importance, and 9 indicates extreme importance. For example, if "supply chain transparency" is deemed more critical than "technology integration," it would receive a higher score. These comparisons are recorded in a matrix for each level of the hierarchy. Expert inputs from the RMG industry were used to ensure the relevance and accuracy of these comparisons in the context of Bangladesh.

#### Step 3: Calculation of Weights and Consistency Check

The pairwise comparison matrix is used to calculate the relative weight of each criterion and alternative. The weights are derived by normalizing the eigenvector of the comparison matrix, giving each criterion or alternative a priority value that reflects its importance. The consistency of judgments is then checked using the Consistency Ratio (CR). A CR below 0.1 generally indicates acceptable consistency; if it is higher, the judgments may need revision. Ensuring consistency is crucial in the context of this study to avoid biased or inaccurate prioritization of eco-robust SCM strategies.

#### Step 4: Synthesis of Priorities and Decision-Making

The final step involves synthesizing the weights obtained for criteria and alternatives to compute a final score for each alternative. This is done by multiplying the weight of each criterion by the weights of its corresponding alternatives and summing the results. The alternative with the highest final score is considered the optimal choice, as it best aligns with the decision goal. This synthesized score provides a systematic ranking of ERSCM strategies, supporting the selection of cost-effective, high-impact strategies for enhancing eco-robust performance in the RMG industry.

### 3.2. QFD methodology

In this study, the QFD methodology is employed to systematically link eco-robust SCM strategies (the "HOWs") with specific sustainability and resilience goals (the "WHATs"). As illustrated in Fig. 2, the QFD matrix contains two sets of relationships: one linking eco-robust SCM strategies with sustainability goals and another linking them with resilience goals. In both cases, the relationship matrix values,  $R_{ij}$  and  $R_{ik}$ , denote the impact level of each strategy (HOW) on achieving each

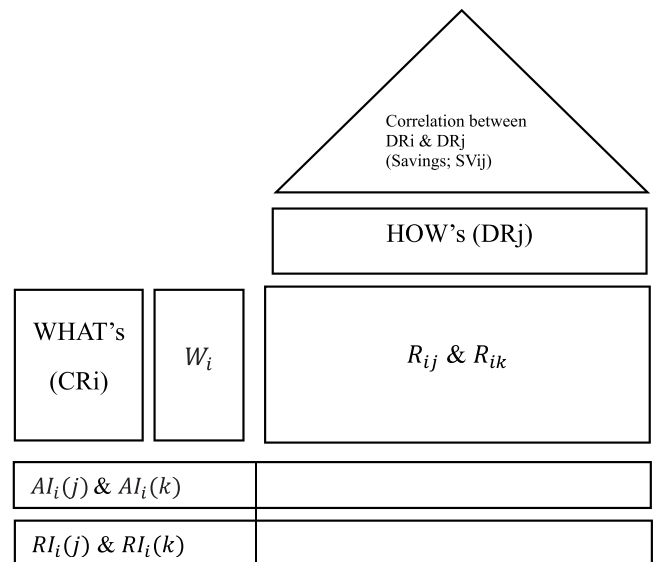


Fig. 2. QFD framework.

specific sustainability or resilience goal (WHAT). Consistent with QFD practices, these impacts are rated on a scale of 9 (strong impact), 3 (moderate impact), 1 (little impact), and 0 (no impact), reflecting each strategy's relevance and effectiveness in achieving sustainability and resilience in the RMG supply chain [49,55,56]. To quantify these relationships, the Absolute Importance (AI) and Relative Importance (RI) of each strategy are calculated separately for sustainability and resilience goals, following the method described by Park and Kim [57].

The absolute importance for sustainability goals and resilience goals is calculated as follows:

$$AI_i(j) = \sum_{j=1}^m W_i * R_{ij} \text{ for } i = 1, \dots, n. \quad (1)$$

$$AI_i(k) = \sum_{k=1}^K W_i * R_{ik} \text{ for } i = 1, \dots, n. \quad (2)$$

Here,  $AI_i(j)$  represents the total impact of the  $j$ th sustainability goal, and  $AI_i(k)$  denotes the total impact of the  $k$ th resilience goal across all ERSCM strategies.  $W_i$  is the weight of the  $i$ th strategy in terms of its contribution to the sustainability and resilience goals. The relationship values  $R_{ij}$  &  $R_{ik}$  represent the impact between the  $i$ th strategy and the  $j$ th sustainability goal, and between the  $i$ th strategy and the  $k$ th resilience goal, respectively.

The relative importance of each strategy  $RI_i(j)$  &  $RI_i(k)$  is then determined by normalizing the absolute importance values for sustainability and resilience goals, allowing for prioritized focus on strategies based on their effectiveness in achieving specific goals. The relative importance of sustainability goals ( $j$ ) and Resilience goals ( $k$ ) is expressed as:

$$RI_i(j) = \frac{AI_i(j)}{\sum_{i=1}^n AI_i(j)}. \quad (3)$$

$$RI_i(k) = \frac{AI_i(k)}{\sum_{i=1}^n AI_i(k)}. \quad (4)$$

Additionally, Fig. 2 includes a correlation matrix highlighting interdependencies between strategies, revealing potential cost savings (SVij) when implemented together. These synergies support cost-effective and resource-efficient implementation by capitalizing on inter-strategy compatibility [57,58]. Decision-makers estimate these savings, facilitating a more cohesive and efficient approach to eco-robust SCM in the RMG industry.

### 3.3. QFD-based optimization model formulation

This optimization model is formulated using the priority weights derived from AHP and the relationships established through QFD. The primary objective is to identify cost-effective strategies that maximize eco-robust performance while staying within budget constraints. By integrating these prioritized relationships, the model ensures a balanced approach, enhancing both sustainability and resilience in the supply chain for the RMG sector.

#### Parameters

- $n$  is the number of ERSCM strategies indexed by  $i$ ;
- $m$  is the number of sustainability goals indexed by  $j$ ;
- $K$  is the number of resilience goals indexed by  $k$ ;
- $SP_i$ : sustainability performance of ERSCM strategy  $i$ ;
- $RP_i$ : Resilience performance of ERSCM strategy  $i$ ;
- $w_s$  is the weight for sustainability performance.
- $w_r$  is the weight for resilience performance.
- $IC_i$ : Expected implementation cost of ERSCM strategy  $i$ ;
- $sv_{ij}$ : savings cost (if ERSCM strategies  $i$  and  $j$  are implemented together);
- $B$ : Budget.
- $s_{ij}$ : The impact of strategy  $i$  on sustainability goal  $j$ . This could come from expert opinions, using a scale like (0: no impact, 1: low, 3: moderate, 9: high).
- $r_{ik}$ : The impact of strategy  $i$  on resilience goal  $k$ . This could come from expert opinions, using a scale like (0: no impact, 1: low, 3: moderate, 9: high).
- minimum threshold  $G_j$  for each sustainability goal  $j$  that the selected ERSCM strategies must be achieved. These  $G_j$  values represent the minimum sustainability level required and can be adapted based on industry standards, expert insights, or specific case requirements.
- minimum threshold  $R_k$  for each resilience goal  $k$  that the selected ERSCM strategies must be achieved. These  $R_k$  values represent the minimum resilience level required and can be adapted based on industry standards, expert insights, or specific case requirements.

#### Decision Variables:

Let  $x_i$  be a binary variable that equals 1 if strategy  $i$  is selected, and 0 if not.

#### Objective:

Maximize eco-robust performance by considering both sustainability and resilience goals.

$$Max f(x) = w_s * \sum_{i=1}^n SP_i * x_i + w_r * \sum_{i=1}^n RP_i * x_i \tag{5}$$

$$or, Max f(x) = \left( w_s * \sum_i^n SP_i + w_r * \sum_i^n RP_i \right) * x_i$$

#### Subject to,

$$\sum_{i=1}^n IC_i x_i - \sum_{i=1}^n \sum_{j=i+1}^n sv_{ij} (x_i x_j) \leq B \tag{6}$$

$$\sum_i^n s_{ij} * x_i \geq G_j \forall j = 1 \dots m \tag{7}$$

$$\sum_i^n r_{ik} * x_i \geq R_k \forall k = 1 \dots K \tag{8}$$

$$x_i \in \{0, 1\} \forall i = 1 \dots n \tag{9}$$

To linearize constraint (6), for strategies  $i$  and  $j, j > i$ , this research introduces a new binary variable  $z_{ij}$ , which is set to 1 if strategies  $i$  and  $j$  are implemented together and 0 otherwise [59]:

$$\sum_{i=1}^n IC_i x_i - \sum_{i=1}^n \sum_{j=i+1}^n sv_{ij} z_{ij} \leq B \tag{10}$$

$$z_{ij} \leq x_i \quad i = 1, \dots, n-1, \quad j = i+1, \dots, n \tag{11}$$

$$z_{ij} \leq x_j \quad i = 1, \dots, n-1, \quad j = i+1, \dots, n \tag{12}$$

$$z_{ij} \geq x_i + x_j - 1 \quad i = 1, \dots, n-1, \quad j = i+1, \dots, n \tag{13}$$

$$x_j \in \{0, 1\} \quad j = 1, \dots, n \tag{14}$$

$$z_{ij} \in \{0, 1\} \quad i = 1, \dots, n-1, \quad j = i+1, \dots, n \tag{15}$$

### 4. Implementation of the model in small and medium-sized Bangladeshi RMG industries

Our focus on small and medium-sized RMG industries in Bangladesh stems from their crucial role in the national economy. They are particularly vital in the Bangladeshi economy, providing jobs to millions of workers and serving as the backbone of the country's export sector [3, 4]. However, these enterprises often face constraints in adopting sustainability and resilience practices due to limited financial and technical resources. Despite their significant economic contribution, the RMG sector typically operates under tighter budgetary constraints, making it essential to develop cost-efficient solutions to ensure their long-term sustainability.

The implementation costs for each eco-robust SCM strategy in the Bangladeshi RMG industry are crucial for determining the financial feasibility of achieving sustainability and resilience goals. These costs were estimated using insights gathered from five independent experts within the small and medium-sized RMG sector. Although their individual assessments varied, a clear range of potential costs was identified. To ensure the accuracy of these estimates, a three-point estimation approach (beta distribution) was employed, considering optimistic, pessimistic, and most likely scenarios. This method helps capture the full spectrum of potential financial requirements, ensuring that implementation costs and budget constraints are realistically accounted for. The estimated budgetary range for implementing sustainable and resilient practices in these industries can vary between \$500,000 to \$1,000,000 USD, depending on the size of the enterprise and the scope of technological integration required. This budget range accounts for investments in energy-efficient technology, waste management systems, stakeholder collaboration platforms and other sustainability and resilience measures.

The model implementation in Bangladeshi small and medium-sized RMG industries is carried out in four phases, as outlined below:

#### Phase I: Identification and Prioritization

Initially, a thorough literature review was conducted to identify potential eco-robust SCM strategies relevant to the Bangladeshi RMG sector. This review yielded 14 initial strategies focusing on both sustainability and resilience, which were then evaluated with a panel of 7 experts to ensure relevance and practicality. Based on their feedback, we refined and reduced the list to 10 key eco-robust SCM strategies (as shown in Table 1) for subsequent analysis. The excluded strategies either had overlapping benefits with other strategies or were deemed less critical in the specific context of the Bangladeshi RMG industry. After narrowing down the strategies, we designed a survey questionnaire to assign priority weights to the 10 key ERSCM strategies. The questionnaire was distributed to 30 experts, including industry professionals and academic specialists in supply chain management and sustainability. From these, 20 responses were successfully collected, providing the data necessary to calculate average priority weights and rank the strategies accordingly. Based on expert feedback, the finalized priority ranking of these 10 strategies (as shown in Table 2) forms the foundation for further analysis in our ERSCM model.

**Table 2**  
Pairwise comparisons and resulting weights for the ERSCM strategies.

ERSCM Strategies	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Priority Weight	Rank
S1	1	1/2	3	1/3	5	7	9	7	9	9	17.1 %	3
S2	2	1	7	2	7	9	9	9	9	9	29.6 %	1
S3	1/3	1/7	1	1/5	3	5	7	5	7	9	10.1 %	4
S4	3	1/2	5	1	7	9	9	7	9	9	25.1 %	2
S5	1/5	1/7	1/3	1/7	1	3	5	3	7	7	6.3 %	5
S6	1/7	1/9	1/5	1/9	1/3	1	3	1	5	3	3.3 %	7
S7	1/9	1/9	1/7	1/9	1/5	1/3	1	1/3	1	2	1.7 %	8
S8	1/7	1/9	1/5	1/7	1/3	1	3	1	5	7	3.8 %	6
S9	1/9	1/9	1/7	1/9	1/7	1/5	1	1/5	1	3	1.7 %	9
S10	1/9	1/9	1/9	1/9	1/7	1/3	1/2	1/7	1/3	1	1.3 %	10

**Phase II: Rating and Evaluation of ERSCM Strategy Impacts**

In this phase, we applied the strategies to two different sets of goals: sustainability goals and resilience goals. For this, we developed two matrices. In Table 3, we fitted the ERSCM strategies as "How's" and sustainability goals as "What's." Similarly, in Table 4, we fitted ERSCM strategies as "How's" and resilience goals as "What's." Five expert respondents were asked to rate the impact of each strategy on the sustainability and resilience goals using 0,1,3,9 scales. The relationship values  $R_{ij}$  between strategies and sustainability goals and  $R_{ik}$  between strategies and resilience goals were averaged across the five experts. The central part of the matrix in Tables 3 and 4 displays the calculated  $W_i * R_{ij}$  and  $W_i * R_{ik}$  values, which represent the weighted impact of each strategy.

For sustainability goals, the Eco-robust SCM strategies S2 (Technology Integration), S4 (Continuous Improvement and Innovation), and S1 (Supply Chain Transparency) showed the highest Absolute Importance (AI) and Relative Importance (RI) scores, with AI values of 7.87, 6.07, and 4.48, and corresponding RI values of 0.312, 0.241, and 0.177, respectively. For resilience goals, S2 (Technology Integration), S4 (Continuous Improvement and Innovation), and S5 (Supply Chain Resilience and Risk Management) demonstrated the highest AI and RI scores, with AI values of 5.86, 5.57, and 1.39, and RI values of 0.366, 0.348, and 0.087, respectively. This study sets an average budget projection for implementing ERSCM strategies within small and medium-sized RMG industries in Bangladesh. Implementation costs ( $IC_i$ ) for each strategy were evaluated using a three-point estimation method, gathering expert estimates for optimistic, most likely, and pessimistic scenarios. The expected cost ( $C_e$ ) was calculated using the formula:  $C_e = (C_o + 4C_m + C_p)/6$ , where  $C_e$ ,  $C_o$ ,  $C_m$ , and  $C_p$  represent the expected,

optimistic, most likely, and pessimistic cost estimates respectively, as recommended by approaches in cost estimation [16,60]. Cost figures were averaged across five expert respondents, and results are presented in Tables 3 and 4, alongside performance indicators for sustainability (SPi) and resilience (RPI), with amounts in thousands of dollars. Additionally, to quantify potential savings (SVij), experts provided input on the possible cost benefits of implementing certain ERSCM strategies together. The left side of the Tables displays these savings insights, such as an estimated 15,000 USD savings achieved by jointly adopting strategies 1 and 3.

**Phase III: Sustainability and Resilience Goals**

The sustainability goals in supply chain management target a balanced approach to economic efficiency, environmental responsibility, and social accountability. These goals include reducing costs to enhance operational efficiency while maintaining a moderate threshold to ensure cost-saving efforts do not undermine other sustainability priorities [11]. Enhancing stakeholder satisfaction emphasizes building trust and strong relationships, supporting long-term industry viability and social responsibility [61]. Additionally, increasing the adoption of green technologies fosters innovation within budget constraints, and reducing environmental impact is prioritized to minimize the industry's carbon footprint, aligning with global standards for sustainable operations [62]. Promoting social compliance further ensures adherence to ethical labor practices, emphasizing fair treatment, worker rights, and social responsibility [63]. In parallel, the resilience goals focus on strengthening supply chains' ability to withstand and recover from disruptions [64,65]. Flexibility enables the supply chain to adapt to changing conditions by adjusting resources and processes as needed, which is vital for navigating market volatility [66]. Risk mitigation

**Table 3**  
QFD Model for sustainability performance.

	Si	Wi	G1	G2	G3	G4	G5	AI <sub>i</sub> (j)	RI <sub>i</sub> (j)	IC <sub>i</sub>	SP <sub>i</sub>
	S1	0.171	0.4446	1.539	0.4446	0.7182	1.3338	4.4802	0.177941	61.67	0.0726
	S2	0.296	1.2432	1.5984	2.3088	1.9536	0.7696	7.8736	0.312717	148.33	0.0530
	S3	0.101	0.2626	0.909	0.303	0.2222	0.7878	2.4846	0.098681	46.67	0.0532
	S4	0.251	0.753	0.6526	2.259	1.6566	0.753	6.0742	0.24125	85	0.0715
	S5	0.063	0.4914	0.2646	0.189	0.3402	0.189	1.4742	0.058551	85	0.0173
	S6	0.033	0.0858	0.2574	0.1386	0.099	0.1782	0.759	0.030145	42.5	0.0178
	S7	0.017	0.1054	0.051	0.1326	0.1122	0.0442	0.4454	0.01769	101.67	0.0043
	S8	0.038	0.114	0.0988	0.2508	0.342	0.114	0.9196	0.036524	68.33	0.0134
	S9	0.017	0.0442	0.051	0.085	0.0918	0.0442	0.3162	0.012559	64.17	0.0049
	S10	0.013	0.039	0.0702	0.0702	0.0702	0.1014	0.351	0.013941	48.33	0.0072

**Table 4**  
QFD Model for resilience performance.

	Si	Wi	R1	R2	R3	AI <sub>i</sub> (k)	RI <sub>i</sub> (k)	IC <sub>i</sub>	RP <sub>i</sub>
S1	0.171	0.513	0.4446	0.2394	1.197	0.0748	61.67	0.0194	
S2	0.296	1.9536	2.3088	1.5984	5.8608	0.3664	148.33	0.0395	
S3	0.101	0.303	0.2222	0.303	0.8282	0.0517	46.67	0.0177	
S4	0.251	1.9578	1.6566	1.9578	5.5722	0.3483	85	0.0655	
S5	0.063	0.4914	0.3402	0.567	1.3986	0.0874	85	0.0164	
S6	0.033	0.0726	0.099	0.0858	0.2574	0.0160	42.5	0.0060	
S7	0.017	0.1122	0.1122	0.1326	0.357	0.0223	101.67	0.0035	
S8	0.038	0.114	0.0988	0.0836	0.2964	0.0185	68.33	0.0043	
S9	0.017	0.0306	0.0442	0.0306	0.1054	0.0065	64.17	0.0016	
S10	0.013	0.0338	0.0546	0.0338	0.1222	0.00763	48.33	0.0025	

involves proactive strategies to assess and manage risks, minimizing the potential impact of disruptions [67]. Lastly, redundancy establishes backup resources and systems to ensure continuity even if primary resources fail, balancing preparedness with cost considerations [68].

The threshold values for each sustainability and resilience goal were determined based on expert opinions and industry benchmarks. A panel of five experts from the Bangladeshi RMG sector, comprising professionals from academia and industry, was consulted to define these thresholds. Experts provided their assessments through a structured survey, evaluating the minimum level of achievement required for each goal. A three-point estimation method (optimistic, most likely, and pessimistic values) was used to refine and standardize these thresholds, ensuring alignment with industry best practices and financial feasibility. The thresholds for sustainability and resilience goals are expressed as percentages (Tables 5 and 6). Each threshold represents the minimum percentage of fulfillment required for the selected ERSCM strategies to ensure meaningful contributions toward sustainability and resilience. These threshold values act as constraints in the optimization model, ensuring that the selected strategies maximize eco-robust performance and meet the essential sustainability and resilience criteria.

**Phase IV: Optimization and Sensitivity Analysis**

In the final phase, the optimization model was implemented using OPL CPLEX software. The model aimed to eco robust performance while remaining within budget constraints. Input data from Tables 3–6 were used, and the model was solved using Eqs. (5) to (15), with an initial budget set at USD 500,000. After solving the model, we conducted a sensitivity analysis [Section 5.1 for more details] to determine how changes in various parameters, such as budget or strategy impact scores,

**Table 5**  
Sustainability Goals.

Sustainability Goals	Description	Threshold (S <sub>j</sub> )
G1: Reducing Costs	Lowering operational expenses through efficient practices.	20
G2: Enhancing Stakeholder Satisfaction	Improving relationships and trust among stakeholders.	30
G3: Increasing Adoption of Green Technologies	Encouraging the use of environmentally friendly technologies.	25
G4: Reducing Environmental Impact	Minimizing negative effects on the environment.	30
G5: Promoting Social Compliance	Ensuring adherence to social and ethical standards.	25

**Table 6**  
Resilience Goals.

Resilience Goals	Description	Threshold (R <sub>k</sub> )
R1: Flexibility	Ability to adapt to changes	40
R2: Redundancy	Availability of backup resources	35
R3: Risk Mitigation	Ability to manage risks and disruptions	40

would affect the overall solution. This phase provided insights into the most cost-effective strategies and how the balance between sustainability and resilience can be optimized.

**5. Results and discussion**

In our research, Eco-Robust SCM is introduced as an integrated framework that combines sustainability and resilience within the RMG industry. This concept emphasizes creating a supply chain that is environmentally sustainable (eco-friendly) and robust enough to withstand disruptions. By establishing eco-robust SCM, the framework prioritizes strategies that reduce environmental impacts while ensuring adaptability to market and environmental fluctuations, particularly in the context of resource-limited settings like small and medium-sized enterprises in Bangladesh. Following this, we define Eco-Robust Performance as a measure of the combined effectiveness of selected ERSCM strategies in achieving both sustainability and resilience goals.

The prioritized ERSCM strategies, such as Technology Integration, Continuous Improvement, and Supply Chain Transparency, achieved the highest relative importance, highlighting their critical role in balancing sustainability and resilience for the Bangladeshi RMG industry. These strategies address core challenges, including operational inefficiencies and supply chain vulnerabilities, while aligning with Sustainable Development Goals. By focusing on high-priority strategies, the industry can optimize resource allocation, enhance environmental performance, and improve resilience to disruptions, ultimately ensuring long-term competitiveness and sustainability in global markets.

The optimization model was developed to design a sustainable and resilient RMG industry for Bangladesh, focusing particularly on small and medium-sized industries. Using an expected budget of \$500,000 USD, the model selected seven out of the ten strategies, with S7 (Energy-Efficient Technology and Renewable Energy) and S9 (Life Cycle Assessment) remaining unselected. The eco robust performance score achieved under this budget is 0.4773, which represents the combined sustainability and resilience performance of the chosen strategies. In this

model, the sustainability performance weight is set to 1 and the resilience performance weight is set to 1, ensuring equal importance is assigned to sustainability and resilience goals. This balanced weighting avoids favoring one objective over the other, allowing the selected strategies to contribute effectively to both dimensions. The selected strategies, including those focused on SC transparency, technology integration, collaboration with stakeholders, continuous improvement and innovation, SC resilience and risk management, education and training programs, and certifications and standards collectively provide an optimal trade-off between cost and performance across sustainability and resilience.

Moreover, the model incorporates a savings cost mechanism, which accounts for cost reductions when strategies (i and j) are implemented together. This feature enhances the efficiency of the selected strategies, although it was insufficient at the \$500,000 budget level to justify the inclusion of S7 and S9. These strategies likely remained unselected due to their higher costs or a lack of synergy with the other chosen strategies. However, further exploration could focus on integrating or merging unselected strategies. For example, energy-efficient technology (S7) could potentially be bundled with continuous improvement efforts (S4), creating a more cost-effective solution that might be feasible within the given budget. The model also ensures that each selected strategy meets the minimum thresholds for sustainability and resilience goals, serving as constraints to guarantee that essential requirements for both objectives are satisfied. These thresholds ensure that the model doesn't merely aim to maximize the performance score but also ensures that critical sustainability and resilience outcomes are met.

5.1. Sensitivity analysis

The sensitivity analysis (as shown in Table 7 and Fig. 3) explores how variations in the budget affect strategy selection and eco-robust performance. At a higher budget level of \$650,000 USD, all ten strategies are selected, resulting in an eco-robust performance score of 0.4916, reflecting better alignment with both sustainability and resilience goals. As the budget decreases, the selection of strategies becomes more limited, and the eco-robust performance score decreases accordingly. For instance, with a budget of \$300,000 USD, the eco robust performance score drops to 0.3924, as key strategies like S5 (Supply Chain Resilience and Risk Management) and S10 (Certifications and Standards) are not selected. This decline in score underlines these strategies' significant role in enhancing sustainability and resilience when larger budgets are available.

The eco-robust performance score of 0.4773 reflects how effectively the selected strategies meet the sustainability and resilience objectives within the allocated budget. While this score doesn't reach 1 (or 100 %), it still reflects a reasonable balance, considering the budget constraints and the inherent complexity of aligning multiple strategies with diverse sustainability and resilience goals. The score doesn't reach 100 % because, despite increasing the budget, the model prioritizes strategies

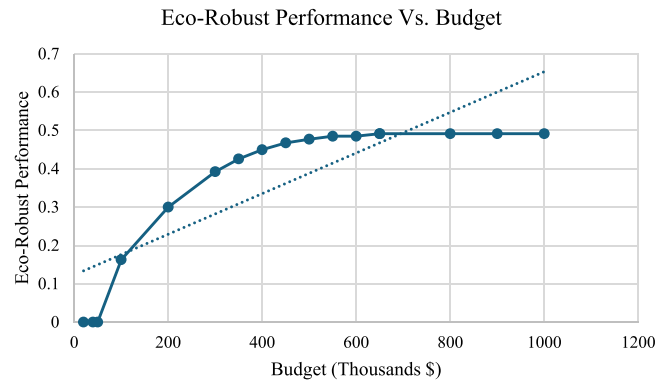


Fig. 3. Sensitivity Analysis.

based on their performance-to-cost ratio. Additionally, certain trade-offs between sustainability and resilience goals and the interactions between strategies make it challenging to achieve a perfect alignment.

A critical insight from the sensitivity analysis is the role of the savings cost mechanism. When certain strategies are implemented together for example, S3 (Collaboration with Stakeholders) and S4 (Continuous Improvement and Innovation) the total implementation cost decreases, increasing the likelihood of selection within a limited budget. Despite this mechanism, however, the combined savings at the budget level of \$500,000 USD were not sufficient to include S7 and S9. This suggests that, in future scenarios, decision-makers could consider integrating higher-cost strategies, such as energy-efficient technology (S7), with other strategies to make them more feasible. Also, merging lower-cost strategies with complementary goals could enhance performance under budget constraints.

Finally, the sensitivity analysis highlights the importance of ensuring that the selected strategies meet the minimum thresholds for sustainability and resilience goals. These thresholds add another layer of complexity to the decision-making process, ensuring that cost-effective strategies alone are not sufficient they must also meaningfully contribute to achieving these critical goals. This means that, even if a strategy is less expensive or efficient, it may be omitted if it fails to adequately address these minimum thresholds.

5.2. Comparison with similar studies

This research presents a QFD-based optimization model designed specifically for eco-robust SCM in the Bangladeshi RMG industry, contributing a novel approach that addresses the dual objectives of sustainability and resilience. Previous research by Al Amin and Baldacci [5] focused on overcoming SSCM adoption challenges within the RMG sector using a similar QFD-based optimization model. However, this research uniquely integrates sustainability and resilience within a

Table 7 Sensitivity Analysis.

Budget (B) *10 <sup>3</sup> USD	Eco-Robust Performance score	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
>650	No change	All selected									
650	0.4916	1	1	1	1	1	1	1	1	1	1
600	0.4851	1	1	1	1	1	1	1	1	0	1
550	0.4851	1	1	1	1	1	1	1	1	0	1
500	0.4773	1	1	1	1	1	1	0	1	0	1
450	0.4676	1	1	1	1	1	1	0	1	0	0
400	0.4499	1	1	1	1	1	1	0	0	0	0
350	0.4259	1	1	1	1	0	1	0	0	0	1
300	0.3924	1	1	1	1	0	0	0	0	0	0
200	0.2999	1	0	1	1	0	0	0	0	0	0
100	0.1629	1	0	1	0	0	0	0	0	0	0
<50	No results	None of them selected									

unified decision-making model. The addition of resilience goals enhances the framework's ability to address supply chain disruptions alongside sustainability concerns. This dual focus differentiates our model, which aligns more closely with the resilience-based approaches advocated by Chowdhury and Quaddus [16] in managing vulnerabilities specific to the Bangladeshi garment industry.

Our single-objective MILP model contrasts with the multi-objective formulations found in prior studies, such as Chowdhury et al. [15], who used multi-objective methods to balance resilience and sustainability goals. Unlike these studies, which explore a range of solutions, our approach seeks an optimal strategy mix that balances eco-robust performance within a strict budget, targeting specific sustainability and resilience metrics. The single-objective MILP structure enables decision-makers to achieve targeted goals with greater precision in budget-constrained settings, a feature emphasized by similar approaches in Gunduz et al. [53]. Furthermore, our study's emphasis on technology integration within an eco-robust framework supports the findings of Durga Prasad et al. [69], who demonstrated the importance of advanced decision-making tools for effective supply chain design. In alignment with Gunduz et al. [53], we incorporate QFD not only to prioritize eco-robust strategies but also to identify synergistic relationships between strategies, providing a framework that supports resilience-building initiatives. Unlike earlier research that primarily considers sustainability measures [5], our model addresses critical challenges such as cost constraints, an element also noted by Durga Prasad et al. [69] as crucial in high-impact industrial settings. By focusing on dual goals of sustainability and resilience within a budget, this study addresses a significant gap in existing SSCM literature and provides actionable insights for supply chain decision-makers in resource-limited settings.

### 5.3. Strategic action plan and implementation roadmap

Achieving sustainability and resilience in the Bangladeshi RMG industry requires a structured approach that integrates strategic planning with phased implementation. The findings highlight key challenges, such as financial constraints, regulatory barriers, and limited technological resources, that must be addressed to enable a transition towards an ERSCM framework. By prioritizing targeted strategies, firms can align with sustainability goals while ensuring operational resilience in a competitive market.

A critical first step involves securing financial resources and fostering collaborations with government agencies and international organizations to facilitate access to funding. The allocation of an initial budget for high-cost green technologies such as blockchain, IoT, and renewable energy systems can ensure long-term cost savings while reducing environmental impacts. Regulatory support, including tax incentives and subsidies, plays a vital role in mitigating financial barriers and encouraging industry-wide adoption of sustainable practices. Additionally, enhancing supply chain transparency through blockchain and IoT can improve compliance with global sustainability standards, increase visibility by up to 70 %, and build consumer trust. Stakeholder collaboration is another essential component of the ERSCM framework. Strengthening digital platforms to engage supply chain actors can foster accountability, align sustainability efforts, and support informed decision-making. The goal is to integrate at least 60 % of supply chain stakeholders within three years, ensuring broader industry participation. Concurrently, resilience-building measures including contingency planning, alternative supplier networks, and flexible production systems can reduce disruptions by 50 % over a five-year period. Technological advancements, such as AI, Big Data, and IoT, further enhance operational efficiency by optimizing production, inventory, and logistics, contributing to a projected 20 % improvement in overall efficiency within four years.

The roadmap for implementing these strategies follows a structured three-phase approach. **Phase I (Year 1–2)** focuses on capacity building,

stakeholder engagement, and pilot projects that introduce blockchain-enabled supply chain transparency and IoT-driven efficiency improvements. **Phase II (Year 3–4)** involves scaling technology adoption, developing infrastructure for waste and pollution management, and integrating resilience-focused supply chain frameworks. **Phase III (Year 5 and beyond)** emphasizes long-term sustainability by expanding renewable energy use, embedding life cycle assessment practices, and fostering continuous improvement through industry-academia partnerships. These phased strategies create a pathway for achieving eco-robust performance, balancing cost-effectiveness with environmental and social responsibilities.

### 5.4. Contribution to the sustainable development goals

The eco-robust SCM strategies developed for the Bangladeshi RMG industry align with key Sustainable Development Goals (SDGs), ensuring both sustainability and resilience. SDG 8 (Decent Work and Economic Growth) is supported through Education and Training (S6) and Stakeholder Collaboration (S3, S5), enhancing labor rights, social responsibility, and productivity. SDG 9 (Industry, Innovation, and Infrastructure) is advanced via Technology Integration (S2) and Continuous Improvement (S4), enabling modernization through IoT, AI, and automation. In line with SDG 12 (Responsible Consumption and Production), Supply Chain Transparency (S1), Waste and Pollution Management (S8), and Life Cycle Assessment (S9) foster responsible resource use and minimize environmental impact across the product lifecycle. SDG 13 (Climate Action) is addressed through Energy-Efficient Technologies and Renewable Energy (S7), reducing emissions and promoting sustainable energy adoption. These strategies collectively enhance sustainability within the RMG industry, reinforcing Bangladesh's progress toward global socio-economic and environmental objectives.

## 6. Conclusion

This research develops an Optimization Model for eco-robust SCM to address the unique sustainability and resilience challenges in the Bangladeshi RMG industry, particularly among small and medium-sized enterprises. By addressing the primary research questions, this study provides targeted insights into identifying, prioritizing, and implementing eco-robust strategies under budget constraints, supporting the industry's transition toward sustainable development.

To answer RQ1 (What strategies can enhance eco-robust performance in Bangladesh's RMG industry?), the study identifies and prioritizes key strategies, including Technology Integration, Continuous Improvement and Innovation, Supply Chain Transparency, and Collaboration with Stakeholders. These strategies collectively enhance environmental performance while building resilience against industry disruptions. In response to RQ2 (How can these strategies be prioritized based on their performance and cost efficiency?), the AHP was employed to assign priority weights to each strategy, reflecting their impact on sustainability and resilience goals. The QFD framework then facilitated a deeper evaluation, revealing the relationships between strategies and goals, and allowing for a cost-effective prioritization of high-impact strategies. To address RQ3 (What is the impact of budget constraints on implementing eco-robust practices?), the study formulates an MILP optimization model to maximize eco-robust performance within defined budgetary limits. Results indicate that while budget constraints restrict the selection of all potential strategies, the model helps identify the most impactful, cost-efficient strategies. This ensures that resource allocation maximizes sustainability and resilience objectives within financial limitations.

### 6.1. Research contributions

This study makes several key contributions to the advancement of

eco-robust Supply Chain Management for the Bangladeshi RMG industry, bridging both theoretical and practical gaps. First, this research introduces a unique eco-robust SCM framework that balances sustainability and resilience goals. This framework is particularly valuable for resource-constrained environments like the Bangladeshi RMG sector, where industries must simultaneously address environmental impact and supply chain adaptability to disruptions. Second, the study applies a mixed-method approach integrating AHP, QFD, and optimization modeling. The AHP method prioritizes strategies based on expert input, while the QFD framework establishes relationships between ERSCM strategies and sustainability/resilience goals. This integrated methodology addresses a critical gap in Sustainable Supply Chain Management (SSCM) literature by tackling the multidimensional complexities of supply chain challenges. Third, an MILP-based optimization model was developed to facilitate cost-effective strategy selection for eco-robust SCM. By maximizing ERSCM performance under budget constraints, this model serves as a practical decision-making tool for RMG managers, ensuring that impactful strategies can be implemented even under financial limitations. Furthermore, this study aligns eco-robust SCM strategies with Sustainable Development Goals (SDGs), particularly those related to decent work, responsible consumption, climate action, and innovation. By linking ERSCM strategies to global sustainability objectives, this research enhances the relevance and applicability of sustainable supply chain practices within the RMG sector. Finally, the study provides both theoretical and managerial insights. Theoretically, it advances SSCM literature by integrating resilience and sustainability within a unified SCM framework. From a managerial perspective, it offers a strategic roadmap for RMG practitioners, guiding small and medium-sized enterprises (SMEs) in Bangladesh to adopt and implement eco-robust SCM strategies effectively.

### 6.2. Implications (theoretical and managerial)

This study provides both theoretical and managerial implications for eco-robust SCM within the RMG industry. Theoretically, this research contributes to the growing literature on SSCM by integrating resilience and sustainability into a unified framework that is specific to emerging economies. This model fills a significant gap in existing frameworks by employing a mixed-method approach utilizing both expert opinions through the AHP and quantitative optimization. Furthermore, the inclusion of context-specific challenges and budgetary constraints provides a nuanced understanding that can serve as a reference for future studies in sectors with similar structural and financial limitations.

From a managerial perspective, the study offers actionable insights into adopting eco-robust practices within budget constraints and addresses specific challenges in the Bangladeshi RMG sector. Managers are provided with a clear, phased roadmap that prioritizes high-impact, cost-effective strategies, enabling them to achieve both sustainability and resilience. Additionally, the study's focus on stakeholder collaboration and transparency as key components helps RMG managers build stronger supply chain relationships and meet rising consumer expectations for sustainable practices. The optimization model and strategic action plan also provide managers with risk management and cost-efficiency tools, allowing them to address disruptions effectively while advancing toward sustainable development goals.

### 6.3. Limitations and future directions

While the Optimization Model provides a valuable framework for advancing eco-robust SCM, several limitations must be acknowledged. First, the model relies on expert input and assumptions that may vary in different contexts, potentially limiting generalizability. Future studies could expand this work by incorporating data from additional sectors or regions, enabling broader application. Additionally, the cost estimations in this study were based on a three-point estimation approach, but actual costs can fluctuate depending on market dynamics, requiring ongoing

updates for accuracy. Furthermore, while the model emphasizes both environmental sustainability and resilience, it may not capture all dimensions of supply chain complexity, such as social factors beyond compliance or regional regulatory variations.

Future research could refine the model by integrating real-time data from supply chain operations, allowing for dynamic adjustments in strategy selection based on emerging conditions. Exploring machine learning and data analytics could enhance the model's adaptability, enabling more precise cost and performance predictions under variable conditions. Another direction for future research involves developing industry-specific adaptations of the Optimization Model, which could support other sectors in managing their unique sustainability and resilience challenges. By expanding the model's scope and adaptability, these future directions would provide deeper insights and greater flexibility in supporting eco-robust supply chains globally.

### CRedit authorship contribution statement

**Md Al Amin:** Writing – original draft, Writing – review & editing, Validation, Software, Methodology, Investigation, Data curation, Conceptualization. **Roberto Baldacci:** Writing – review & editing, Supervision.

### Declaration of competing interest

We have no conflict of interest to disclose.

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### Supplementary materials

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### Data availability

No data was used for the research described in the article.

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