

An Empirical Analysis of Bangladesh's Textile and Ready-Made Garment (RMG) Sector: Export Trends, Sustainability Indicators, Gendered Labor Dynamics, and Global Value Chain Upgrading

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Abstract

Bangladesh's textile and ready-made garment (RMG) industry has transformed from a small export-oriented sector in the late 1970s into the world's second-largest apparel exporter, contributing about 81% of national export earnings on a fiscal year basis and employing approximately four million workers. This study provides an original mixed-methods secondary-data analysis of the industry's evolution by integrating quantitative trend analysis with qualitative thematic interpretation. Drawing on selected calendar-year RMG export observations from 2000 to 2025, the study applies compound annual growth rate, year-on-year growth analysis, and a linear time-trend forecasting model to assess export performance and possible trajectories for 2026–2030. The analysis is further interpreted through the Triple Bottom Line and Global Value Chain frameworks, focusing on four interconnected dimensions: economic growth, sustainability, gendered labor dynamics, and global value chain integration. The findings show that RMG exports increased from USD 4.8 billion in 2000 to USD 38.82 billion in 2025, representing a long-term CAGR of approximately 8.72%. However, the sharp post-2022 decline and modest recovery in 2024–2025 indicate growing vulnerability to global demand shocks. The baseline forecast suggests that exports may reach approximately USD 48.61 billion by 2030, while scenario analysis shows that stronger upgrading could raise performance above USD 53 billion. Despite progress in LEED-certified green factories and post-Rana Plaza safety reforms, sustainability gains remain uneven, wage gaps persist, women's workforce participation has declined, and functional upgrading remains limited. The study argues that Bangladesh's future competitiveness depends on moving beyond low-cost assembly toward higher-value production, technical textiles, stronger labor governance, sustainability integration, and deeper GVC upgrading.

Keywords: Ready-Made Garment (RMG); Bangladesh; Global Value Chains; Gendered Labor; Triple Bottom Line; Industrial Upgrading; Green Manufacturing

1. Introduction

The textile and ready-made garment (RMG) sector is the central pillar of Bangladesh's export-oriented industrialization and one of the most significant cases of labor-intensive manufacturing growth in the Global South. From a modest beginning in the late 1970s, the sector has expanded into the world's second-largest apparel export industry after China. RMG exports reached USD 38.48 billion in calendar year 2024 and USD 38.82 billion in 2025, while fiscal-year exports stood at USD 36.15 billion in FY2023–24 [1,2]. The sector accounts for about 81% of Bangladesh's total export earnings on a fiscal-year basis and directly employs approximately four million workers, with millions more indirectly dependent on related activities such as textiles, accessories, logistics, packaging, and services [3].

This growth has played a transformative role in Bangladesh's economic development. The RMG sector has contributed to export diversification, poverty reduction, female labor-force participation, industrial entrepreneurship, and the

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development of backward and forward linkages. However, the sector's success has also been accompanied by major structural contradictions. Its competitiveness has historically depended on low-cost, high-volume production, while value addition, technological upgrading, design capability, branding, and research and development remain limited. Bangladesh continues to specialize largely in basic garments, leaving the industry vulnerable to buyer pressure, global demand fluctuations, and competition from countries with stronger logistics, deeper trade agreements, and more diversified production systems [4].

The sustainability challenge is equally significant. Bangladesh has made visible progress in green manufacturing, particularly through the growth of LEED-certified garment factories and post-Rana Plaza safety reforms [5]. Nevertheless, these improvements remain unevenly distributed across the sector. Large export-oriented factories serving global brands have adopted stronger environmental and safety standards, while many small and medium enterprises continue to face gaps in effluent treatment, chemical management, waste recycling, and regulatory compliance [6,7]. At the same time, social sustainability remains constrained by low wages, excessive overtime, limited worker representation, and persistent gaps between minimum wage levels and estimated living wages.

Gendered labor dynamics represent another central dimension of the sector's development. The expansion of garment employment created unprecedented income opportunities for rural women and contributed to shifts in household bargaining, mobility, and social recognition [8]. Yet these gains remain fragile. Women are still concentrated in low-paid and low-skilled positions, while managerial and technical roles are dominated by men. Recent automation and technological upgrading have also contributed to a decline in women's employment share, raising concerns that the sector's earlier gender-equity gains may be partially reversed unless women are included in skills development, supervisory pathways, and higher-value production roles.

Bangladesh's position within global value chains further shapes these economic, social, and environmental outcomes. The apparel industry is a buyer-driven global value chain in which lead firms control design, branding, marketing, sourcing decisions, prices, and compliance requirements [9]. Although Bangladesh has progressed from basic cut-make-trim production toward original equipment manufacturing in some segments, functional upgrading into original design manufacturing, own branding, technical textiles, and higher-value fashion remains limited. This creates a strategic challenge as Bangladesh approaches Least Developed Country graduation, which may reduce preferential trade advantages and intensify the need for productivity improvement, sustainability integration, and value-chain upgrading [9].

Although Bangladesh's RMG sector has been widely studied, much of the existing literature remains fragmented. Economic studies focus mainly on export growth and trade performance, sustainability studies examine environmental and social compliance, gender studies analyze women's employment and empowerment, and global value chain studies focus on upgrading constraints. Fewer studies integrate these dimensions within a single empirical framework that connects export trends, sustainability indicators, gendered labor dynamics, and GVC upgrading. Moreover, limited attention has been given to combining qualitative thematic interpretation with quantitative trend analysis and export forecasting [10].

This study addresses this gap by providing a mixed-methods secondary-data analysis of Bangladesh's textile and RMG sector. It combines descriptive statistics, compound annual growth rate, year-on-year growth analysis, selected calendar-year export observations, and a linear time-trend forecasting model for 2026–2030. These quantitative results are interpreted through the Triple Bottom Line and Global Value Chain frameworks to examine how economic growth, sustainability performance, labor dynamics, and upgrading constraints are interconnected. The paper argues that Bangladesh's future competitiveness will depend not only on maintaining export growth but also on moving beyond low-cost assembly toward higher-value production, technical textiles, stronger labor governance, inclusive skills development, environmental compliance, and deeper value-chain upgrading [11].

The paper makes four contributions. First, it provides an empirical secondary-data analysis of Bangladesh's RMG export performance using trend and forecasting tools. Second, it links export growth with sustainability, gendered labor, and GVC upgrading rather than treating these issues separately. Third, it identifies structural contradictions that limit the sector's long-term competitiveness and inclusive development. Fourth, it proposes strategic pathways for sustainable transformation as Bangladesh prepares for LDC graduation and faces stronger global competition.

The remainder of the paper is organized as follows. Section 2 reviews the literature on the historical evolution, sustainability challenges, gendered labor dynamics, and global value chain integration of Bangladesh's RMG sector. Section 3 presents the theoretical framework. Section 4 explains the research design, data sources, variables, statistical methods, and forecasting approach. Section 5 presents the empirical and thematic findings. Section 6 discusses

structural contradictions and policy implications. Section 7 concludes with recommendations for sustainable and inclusive upgrading.

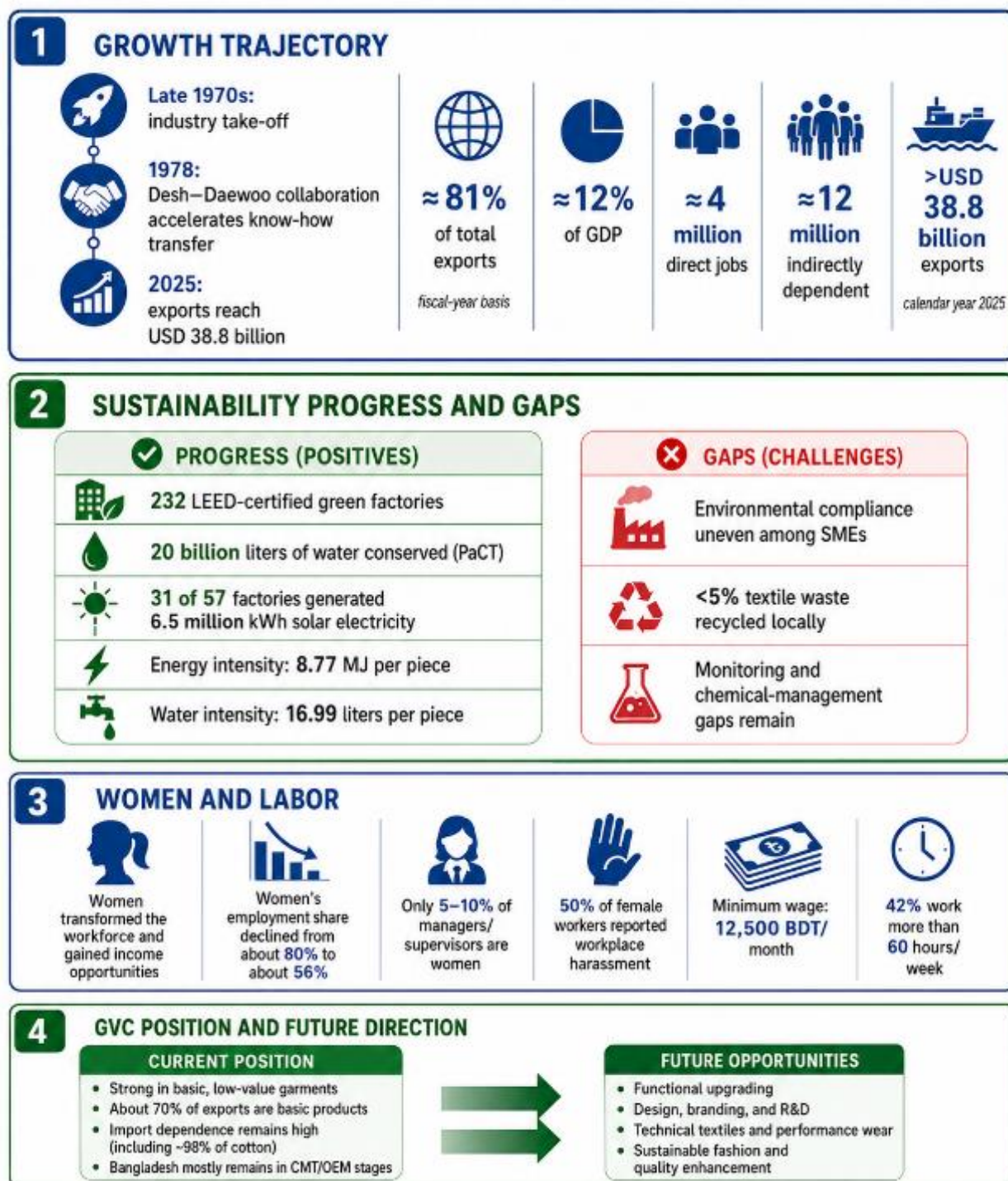


Figure 1 Overview of the evolution, sustainability progress, gendered labor dynamics, and GVC position of Bangladesh's textile and RMG industry.

This figure provides a visual overview of the paper's main argument. It summarizes the industry's historical growth, sustainability achievements and gaps, gendered labor issues, and GVC position. It prepares readers for the four analytical pillars developed in the literature review, findings, and discussion sections.

2. Literature Review

2.1. Historical Evolution of the RMG Industry in Bangladesh

The emergence of Bangladesh's RMG industry has been extensively documented in development economics literature. Ahmed et al. [10] traced the sector's origins to the confluence of global trade policies and domestic economic reforms in the late 1970s. The Multi-Fibre Arrangement (MFA), established in 1974 under GATT, imposed quotas on textile and apparel exports from established Asian manufacturers to developed country markets, creating opportunities for quota-free nations like Bangladesh [10]. Simultaneously, the Bangladeshi state, under pressure from international financial institutions, pursued economic liberalization policies that included export incentives, bonded warehouse facilities, and duty-free import regimes for export-oriented industries.



Figure 2 Major milestones in the evolution of Bangladesh's ready-made garment industry.

Figure 2 contextualizes the literature review by mapping the major turning points in Bangladesh's RMG development, from early export-oriented factories to MFA phase-out, Rana Plaza, safety reforms, COVID-19 disruption, and LDC graduation preparation. It helps explain why the paper treats growth, compliance, competitiveness, and upgrading as historically connected rather than separate issues.

A pivotal moment was the 1978 collaboration between South Korea's Daewoo Group and Bangladesh's Desh Garments. Bhattacharya and Rahman [12] documented how this partnership facilitated technology transfer and trained Bangladeshi workers in modern apparel production techniques. Easterly [13] analyzed this as a classic case of "knowledge leakage" and "increasing returns," describing how within a year, 115 of the 130 trained workers had left to establish their own export firms, catalyzing the industry's entrepreneurial expansion. This knowledge diffusion created cascading benefits throughout the economy, demonstrating how human capital development can generate development dividends beyond initial intentions [13].

The sector's growth trajectory has been extraordinary. Rashid [14] documented that in 1983-84, apparel accounted for less than 4% of total exports; within a decade, this share had grown to 60%, and by 2022-23, it had reached 84%. The number of garment factories expanded from approximately 50 in the early 1980s to over 5,000 by 2023, with knitwear and woven segments contributing roughly equally to export earnings. This expansion was facilitated by the Generalized System of Preference (GSP), which provided duty-free access to European markets, while the US market remained accessible through quota arrangements [14].

The MFA's phase-out in 2005, which many analysts predicted would devastate Bangladesh's RMG sector, paradoxically accelerated growth. Rahman et al. [16] documented that between 2005 and 2009, both export values and market share increased, due to the industry's ability to contain costs by squeezing wages and profits. This resilience reflected the sector's deep integration into global supply chains and its established reputation as a reliable supplier of low-cost, basic garments. Mondal et al. [15] found that the sector's contribution to export earnings grew from 75% in 2004-05 to over 84% by 2022-23, demonstrating the industry's continued dominance of Bangladesh's export basket.

However, scholars have noted significant structural limitations. The Asia Foundation [18] found that Bangladesh continues to specialize in low-value, basic products such as T-shirts, trousers, sweaters, and woven shirts, which account for approximately 70% of exports. Value addition remains low, estimated at 25-30% for woven garments compared to 50-60% for knitwear, reflecting weak backward linkages and heavy dependence on imported raw materials [19]. Moazzem and Sehrin [19] documented that while Bangladesh had achieved significant process upgrading through automation and efficiency improvements, functional upgrading into design, branding, and marketing remained limited, constraining the sector's ability to capture higher value in global markets.

2.2. Sustainability in the Textile Sector: Environmental and Social Dimensions

The sustainability literature on Bangladesh's RMG industry has expanded dramatically following the Rana Plaza disaster in 2013. Hossain and Mahmud [5] applied the Triple Bottom Line framework to analyze the sector's sustainability performance, finding that while Bangladesh leads globally in LEED-certified green factories, social sustainability lags significantly behind environmental achievements. BGMEA [23] documented that Bangladesh hosts the highest number of LEED-certified garment facilities worldwide, with 232 certified factories adopting energy-efficient technologies, renewable energy sources, and sustainable waste management practices.

The Partnership for Cleaner Textile (PaCT) project, implemented with IFC support, has contributed to significant resource savings. Sakamoto et al. [24] documented that water recycling and zero-liquid-discharge technologies have reduced freshwater consumption substantially in participating factories, with approximately 20 billion liters of water conserved. The BGMEA Sustainability Report 2023 [23] indicates that reporting factories achieved energy intensity of 8.77 MJ per piece and water intensity of 16.99 liters per piece, with 31 of 57 factories generating 6.5 million kWh of solar electricity, avoiding an estimated 14,564 tCO₂e.

However, scholars have identified significant implementation gaps. Sarker et al. [20] analyzed the environmental impacts of textile dyeing industries, finding that despite technological improvements in some factories, regulatory enforcement remains weak, with monitoring gaps and corruption undermining environmental governance. Nabi et al. [26] investigated social sustainability challenges, finding that waste management infrastructure remains inadequate across the sector, with less than 5% of textile waste recycled locally. Environmental compliance is concentrated among large exporting factories serving prominent international brands, while small and medium enterprises, particularly subcontractors, often lack adequate effluent treatment, chemical management, and waste disposal systems [26]. Regulatory enforcement remains weak, with monitoring gaps and corruption undermining environmental governance [24].

Social sustainability presents even more profound challenges. Chaudhury and Akpinar [4] found that despite contributing 80% of export earnings, garment workers earn wages that remain among the lowest globally. The minimum monthly wage, revised in December 2023 to 12,500 taka (approximately USD 113), remains far below the estimated living wage of USD 460 per month and is substantially lower than competitors such as China (USD 300), Vietnam (USD 200), and India (USD 170) [27]. Working conditions are characterized by excessive overtime, with 42% of workers exceeding 60 hours per week [4]. Occupational health and safety remain inadequate, with 67% of workers lacking access to first-aid facilities or on-site medical professionals [4].

The post-Rana Plaza safety reforms have been extensively analyzed in the literature. Alamgir and Banerjee [6] critically examined the contested compliance regimes in global production networks, arguing that global brands' compliance audits paradoxically reinforce the state's disciplinary power. They found that international standards have been substituted for collective bargaining rights that local laws nominally guarantee, enabling employers to use compliance requirements to suppress genuine worker organization. Anner [27] analyzed purchasing practices in the Bangladesh garment export sector, documenting how buyers' price pressures squeeze workers' rights and undermine sustainability initiatives. Despite safety improvements in inspected factories, nearly 3,000 factories serving subcontractors and smaller customers remain outside inspection coverage.

2.3. Gendered Labor Dynamics and Women's Employment

The feminization of Bangladesh's RMG workforce has been a central theme in development literature. Kabeer and Mahmud [11] provided comprehensive analysis of women's employment in the sector, finding that garment work provided higher wages than alternatives such as domestic service, but was not a sustainable long-term livelihood option. They documented that most women could not continue factory work beyond five years due to physical strain and the incompatibility of factory hours with domestic responsibilities. Despite these limitations, the garment industry has been widely celebrated as an engine of women's empowerment, enabling workers to contribute to household incomes, delay marriage, exercise greater choice in partners, and gain recognition as economic actors [11].

Arizpe and Aranda's [28] concept of the "comparative advantage of women's disadvantage" has been influential in explaining why global capital exploits pre-existing gender inequalities. Bhattacharya and Rahman [12] analyzed female employment under export-propelled industrialization, documenting the transformation in gender relations brought about by women's entry into industrial wage labor. They found that women's entry into factory work challenged patriarchal norms, normalized female mobility in urban spaces, and provided millions of rural women with economic independence. However, this transformation was fundamentally shaped by structural inequalities. Employers' revealed preference for female labor reflected women's willingness to accept lower wages, their perceived docility, and their position outside established trade union structures [29].

Research consistently finds that women have limited prospects for advancement. Dannecker [2] examined the contradictions of empowerment, finding that while garment employment provided economic independence, it did not fundamentally challenge patriarchal structures. Women remain concentrated in low-paid, low-skilled positions, with only 5-10% of managers and supervisors being women [4]. Gender-based violence and harassment are prevalent, with 50% of female garment workers reporting workplace harassment in 2022 [4]. The sector's "glass ceiling" significantly inhibits women's job advancement, reinforced by employers' assumptions about women's capabilities and patriarchal norms that limit career aspirations [4].

Recent technological changes have intensified gender inequalities. Siddiqi and Ashraf [1] documented that automation and the introduction of advanced technologies have led to a "re-masculinization" of garment production, with male workers being specifically recruited for more technical roles. They estimated that women's share of garment employment has declined from 80% to approximately 60%, suggesting that approximately half a million women have left the sector [1]. This trend threatens to reverse the gender equality gains of previous decades, with automation creating new barriers to women's employment and advancement.

Women workers' capacity to improve their conditions through collective action remains severely constrained. The RMG industry is largely non-unionized, with employers using strong-arm tactics to intimidate workers attempting to organize [11]. Trade unions, where they exist, are typically dominated by men and affiliated with political parties, often more interested in political alliances than workers' welfare. The Export Processing Zones (EPZs) represent an extreme case of labor suppression, where trade union activities have been banned [12]. Despite these constraints, there have been notable instances of worker mobilization, particularly around wage demands. Six revisions of the minimum wage have occurred since 1994, each following massive labor protests and each accompanied by confrontational labor unrest of workers and trade unionists [1].

2.4. Global Value Chain Integration and Industrial Upgrading

The governance of global apparel value chains has been extensively theorized in the literature. Gereffi et al. [9] developed the influential framework distinguishing producer-driven and buyer-driven chains, identifying the apparel industry as a classic case of buyer-driven governance where lead firms wield enormous power over suppliers. They identified five governance types—market, modular, relational, captive, and hierarchy—and traced the evolution of apparel GVCs from captive to relational governance structures. However, Bangladesh's position remains largely captive, with manufacturers having limited ability to negotiate better terms [18].

Humphrey and Schmitz [30] developed the upgrading framework distinguishing process, product, functional, and chain upgrading. Moazzem and Sehrin [19] applied this framework to Bangladesh, finding that while process and product upgrading had occurred, functional upgrading remained limited due to supply-side constraints and buyer preferences. The shift from cut-make-trim (CMT) to original equipment manufacturing (OEM) represented progress, but the transition toward original design manufacturing (ODM) and original brand manufacturing (OBM) has been slow [19].

Gereffi and Frederick [31] analyzed how high-value activities in apparel GVCs are concentrated in the post-production stage, involving marketing, branding, and after-sales service, activities that remain largely controlled by lead firms. Fernandez-Stark and Gereffi [32] provided comprehensive analysis of the global apparel value chain, identifying the pre-production, production, and post-production stages and the distribution of value added across these stages. They found that developed countries preside over high-value activities such as research and development, design, and branding, while developing countries focus on lower-value assembly operations.

Raihan [8] analyzed Bangladesh's position in global value chains, finding that the country is heavily embedded in the apparel chain but largely confined to the lowest-value stages. Much of the value is created elsewhere—in fiber development, design, branding, logistics, and retail intelligence—with Bangladesh exercising little influence over how

the chain is organized [8]. The erosion of preferential access following LDC graduation will further intensify competitive pressures, making industrial upgrading imperative [8].

Diversification opportunities exist in technical textiles, performance fabrics, sportswear, outerwear, medical textiles, and sustainable fashion [9]. However, capturing these opportunities requires significant investments in skills, technology, design capabilities, and quality assurance [19]. Bangladesh must develop a more diversified industrial base, moving beyond RMG to sectors such as pharmaceuticals, agro-processing, leather goods, electronics, and digital services [8]. The policy environment must support this diversification through institutional reform, infrastructure development, and human capital investment.

2.5. Research Gap

Despite the extensive literature on Bangladesh's RMG industry, existing research is fragmented across disciplinary boundaries. Economic analyses focus on growth trajectories and trade performance [16]; sustainability research examines environmental and social dimensions [23]; gender studies analyze women's employment and empowerment [12]; and GVC scholarship explores industrial upgrading and chain governance [19]. Few studies have attempted comprehensive multi-dimensional synthesis that connects these dimensions to reveal the interconnections and contradictions that shape the industry's development trajectory.

This paper addresses this gap by providing an integrated analysis that examines the evolution of Bangladesh's textile and RMG industry through four interconnected pillars: economic growth and structural transformation, sustainability challenges and responses, gendered labor dynamics, and global value chain integration. By synthesizing fragmented research across disciplines and identifying the structural contradictions that shape the sector's development, the paper contributes to a more holistic understanding of the industry's challenges and opportunities.

3. Theoretical Framework

This study is grounded in two complementary theoretical frameworks: the Triple Bottom Line (TBL) framework and Global Value Chain (GVC) theory. These frameworks provide analytical lenses for examining the economic, environmental, social, and governance dimensions of Bangladesh's RMG industry and their interconnections.

3.1. Triple Bottom Line Framework

The Triple Bottom Line framework, developed by Elkington [33], posits that organizational performance should be evaluated across three dimensions: economic, environmental, and social. The economic dimension encompasses financial performance, profitability, and value creation. The environmental dimension includes ecological impacts, resource consumption, pollution, and sustainability practices. The social dimension covers labor rights, working conditions, community engagement, and social equity [33].

The TBL framework is particularly relevant for analyzing Bangladesh's RMG industry, which has generated significant economic benefits while imposing substantial environmental and social costs. The framework enables systematic examination of trade-offs and synergies between dimensions. For instance, while the industry has contributed to economic growth and women's employment, these benefits have been achieved at the cost of low wages, labor rights violations, and environmental degradation [5].

3.2. Global Value Chain Theory

Global Value Chain theory, developed by Gereffi and colleagues [9], analyzes how value is created and distributed across geographically dispersed production networks. GVC theory distinguishes between producer-driven and buyer-driven chains, identifies different governance structures (market, modular, relational, captive, hierarchy), and provides frameworks for analyzing industrial upgrading [30].

For Bangladesh's RMG industry, GVC theory illuminates how power asymmetries between lead firms and suppliers shape opportunities and constraints. The buyer-driven nature of apparel GVCs means that decisions made by global retailers and brands determine production locations, prices, and standards [9]. Bangladesh's position in low-value segments reflects its limited bargaining power and the concentration of high-value activities in developed countries [8].

3.3. Integrated Conceptual Framework

This study integrates the TBL and GVC frameworks to examine the interconnections between economic performance, sustainability outcomes, and power dynamics in Bangladesh's RMG industry. The integrated framework posits that:

Economic outcomes (exports, employment, growth) are shaped by the industry's position in GVCs and governance structures. Environmental outcomes (resource consumption, pollution, green practices) reflect both regulatory frameworks and buyer requirements. Social outcomes (labor rights, wages, working conditions) are influenced by power asymmetries between buyers and suppliers and the institutional and governance context of labor. Structural contradictions arise from the tensions between these dimensions, creating challenges for sustainable upgrading.

The framework enables systematic analysis of how GVC governance shapes sustainability outcomes and how upgrading strategies can address structural contradictions.

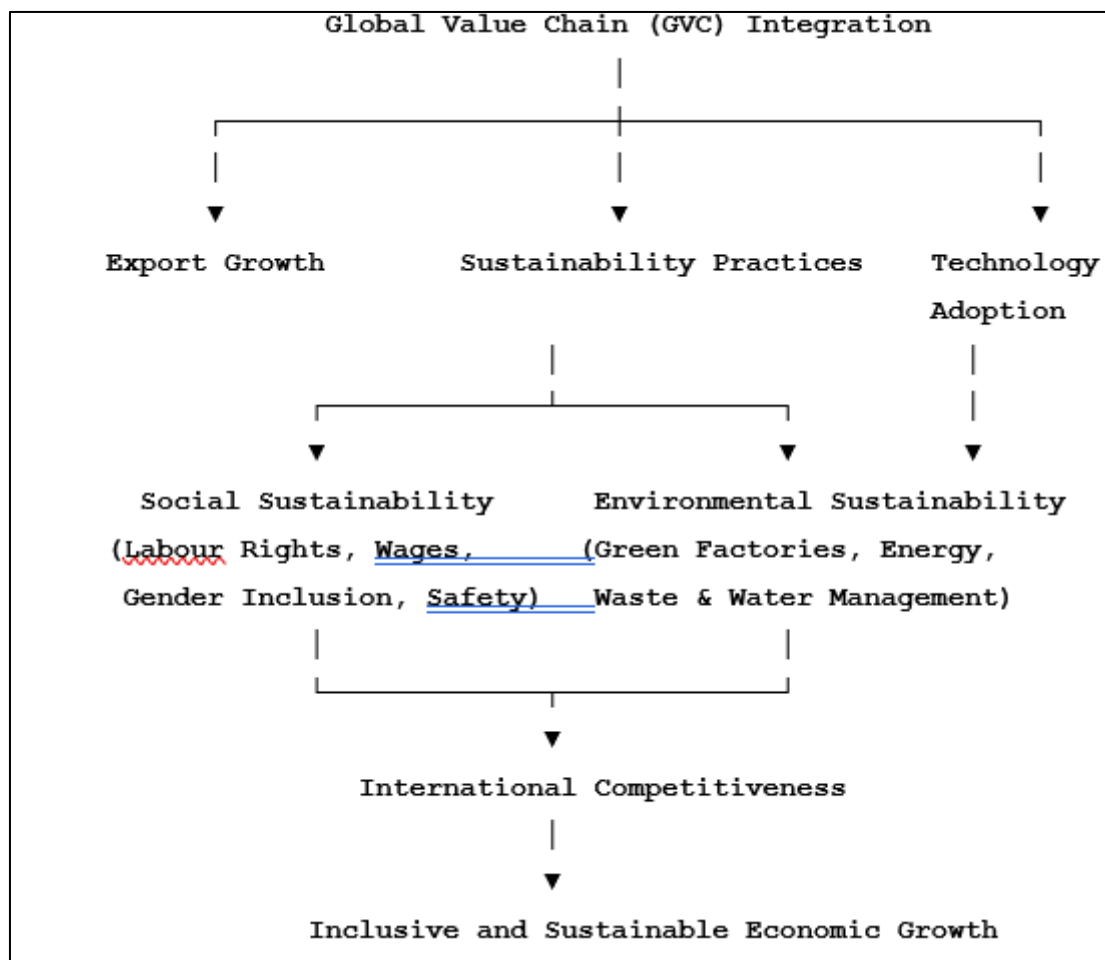


Figure 3 Integrated conceptual framework linking GVC integration, sustainability practices, technology adoption, competitiveness, and inclusive growth in Bangladesh's RMG industry.

Figure 3 operationalizes the paper's integrated TBL–GVC lens by showing how GVC integration shapes export growth, technology adoption, and sustainability practices. It links economic, environmental, and social outcomes to international competitiveness and inclusive growth, providing the analytical bridge between the theoretical framework and the later findings on contradictions and upgrading constraints.

4. Methodology

4.1. Research Design

This study adopts a mixed-methods secondary-data research design combining quantitative trend analysis, comparative indicator analysis, and qualitative thematic interpretation. The quantitative component examines export growth, value addition, wage gaps, women's employment trends, and sustainability indicators, while the qualitative component interprets these findings through the Triple Bottom Line and Global Value Chain frameworks.

4.2. Data Sources and Variables

The study uses secondary data from BGMEA, EPB, Bangladesh Bank, ILO, IFC, published journal articles, industry reports, and policy documents. The main quantitative variables include RMG export value, RMG share of national exports, women's employment share, LEED-certified factory numbers, minimum wage, estimated living wage, value addition in woven and knitwear, and selected sustainability indicators.

Table 1 Variables, measurements, data sources, and analytical uses for the secondary-data analysis.

Variable	Measurement	Source type	Analytical use
RMG export value	USD billion, annual	BGMEA/EPB	Trend and prediction model
RMG share of exports	Percentage	BGMEA/EPB	Export-dependence analysis
LEED-certified factories	Number of factories	BGMEA/industry reports	Sustainability trend
Women's employment share	Percentage	Literature/industry reports	Gendered labor trend
Minimum wage	BDT/month	Wage board/literature	Social sustainability gap
Value addition	Percentage	Literature/industry reports	GVC upgrading analysis

This table clarifies the empirical foundation of the study by identifying the key variables used in the secondary-data analysis. It shows how export performance, sustainability indicators, wage gaps, women's employment, and value addition are measured and connected to the paper's four analytical pillars: economic growth, sustainability, gendered labor, and GVC integration.

4.3. Statistical Analysis

The export trend and forecasting analysis used selected calendar-year observations from 2000 to 2025, based on available BGMEA export-performance data points used in Figure 5. Therefore, the forecast should be interpreted as an indicative trend-based projection rather than a full annual time-series model. Year-on-year export growth was calculated to identify periods of expansion, contraction, and recovery. Compound annual growth rate was used to measure long-term export growth across selected periods. Comparative bar and line charts were used to examine differences in value addition, wage gaps, women's employment trends, and sustainability performance.

Year-on-year growth:

$$YoY Growth = \frac{X_t - X_{t-1}}{X_{t-1}} \times 100$$

Compound annual growth rate:

$$CAGR = \left(\frac{X_n}{X_0} \right)^{1/n} - 1$$

Where X_t is export value in the current year, X_{t-1} is export value in the previous year, X_0 is the starting value, X_n is the ending value, and n is the number of years.

4.4. Prediction Model

To strengthen the empirical contribution, this study estimates a simple export prediction model using selected calendar-year RMG export observations from 2000 to 2025. Because the dataset is limited and does not represent a complete annual time series, the study applies a parsimonious linear time-trend model rather than a complex forecasting technique such as ARIMA or machine learning. Because the available dataset is annual and relatively small, the study applies a parsimonious time-trend forecasting model rather than a complex machine-learning model. The baseline model estimates export performance as a function of time:

$$Export_t = \alpha + \beta Year_t + \epsilon_t$$

A log-linear specification may also be used to capture proportional growth:

$$\ln(Export_t) = \alpha + \beta Year_t + \epsilon_t$$

For robustness, a moving-average or exponential smoothing forecast can be added to compare short-term predicted export values. Forecast accuracy may be evaluated using mean absolute percentage error:

$$MAPE = \frac{1}{n} \sum \left| \frac{Actual - Forecast}{Actual} \right| \times 100$$

4.5. Scenario-Based Forecasting

Scenario-based forecasting was used to interpret future competitiveness under three possible trajectories: baseline, optimistic, and pessimistic. The baseline scenario assumes continuation of recent export trends; the optimistic scenario assumes improvements in logistics, product diversification, sustainability compliance, and value addition; while the pessimistic scenario assumes weaker global demand, slower upgrading, and preference erosion after LDC graduation.

Table 2 Scenario-Based Forecasting

Scenario	Assumption	Expected implication
Baseline scenario	Continuation of recent export trend	Moderate export recovery
Optimistic scenario	Faster upgrading, better logistics, sustainability compliance	Higher export growth
Pessimistic scenario	Demand shocks, LDC graduation pressure, weak upgrading	Slower growth or stagnation

4.6. Qualitative Thematic Interpretation

The qualitative component was used to interpret the statistical findings and provide deeper contextual understanding of the quantitative trends. Following the six-phase thematic analysis approach outlined by Braun and Clarke [34], thematic coding was organized around four analytical pillars: economic growth, sustainability, gendered labor, and GVC integration. This helped explain not only the direction of numerical trends but also the structural contradictions behind them.

The thematic analysis process proceeded through systematic phases. First, the research team familiarized itself with the data by thoroughly reading and re-reading the collected secondary sources, including BGMEA reports, EPB export statistics, ILO publications, IFC impact assessments, and peer-reviewed journal articles. Initial codes were generated by identifying recurring patterns, concepts, and issues relevant to the four analytical pillars. These codes were then organized into broader themes through an iterative process of reviewing, refining, and defining thematic categories. The themes were reviewed against the original data to ensure internal consistency and analytical rigor. Finally, the thematic structure was refined and defined, with clear descriptions of each theme's scope, boundaries, and interconnections [34].

This systematic approach ensured that the qualitative interpretation was grounded in the data while remaining transparent and replicable. The qualitative thematic interpretation complemented the quantitative analysis by revealing the underlying mechanisms, power dynamics, and structural constraints that shape Bangladesh's RMG sector development. While the statistical analysis documented *what* happened in terms of export growth, sustainability performance, and employment trends, the qualitative interpretation helped explain *why* these patterns emerged and *how* they are interconnected. For instance, the statistical finding of declining women's employment share was interpreted through thematic analysis of labor dynamics, automation trends, and gender-based occupational segregation. Similarly, the quantitative gap between minimum wage and living wage estimates was contextualized through thematic examination of buyer-supplier power asymmetries, global value chain governance, and the political economy of labor regulation in Bangladesh. This integrated approach enabled the study to move beyond description toward explanation, identifying the structural contradictions that both enable and constrain the sector's sustainable transformation [34].

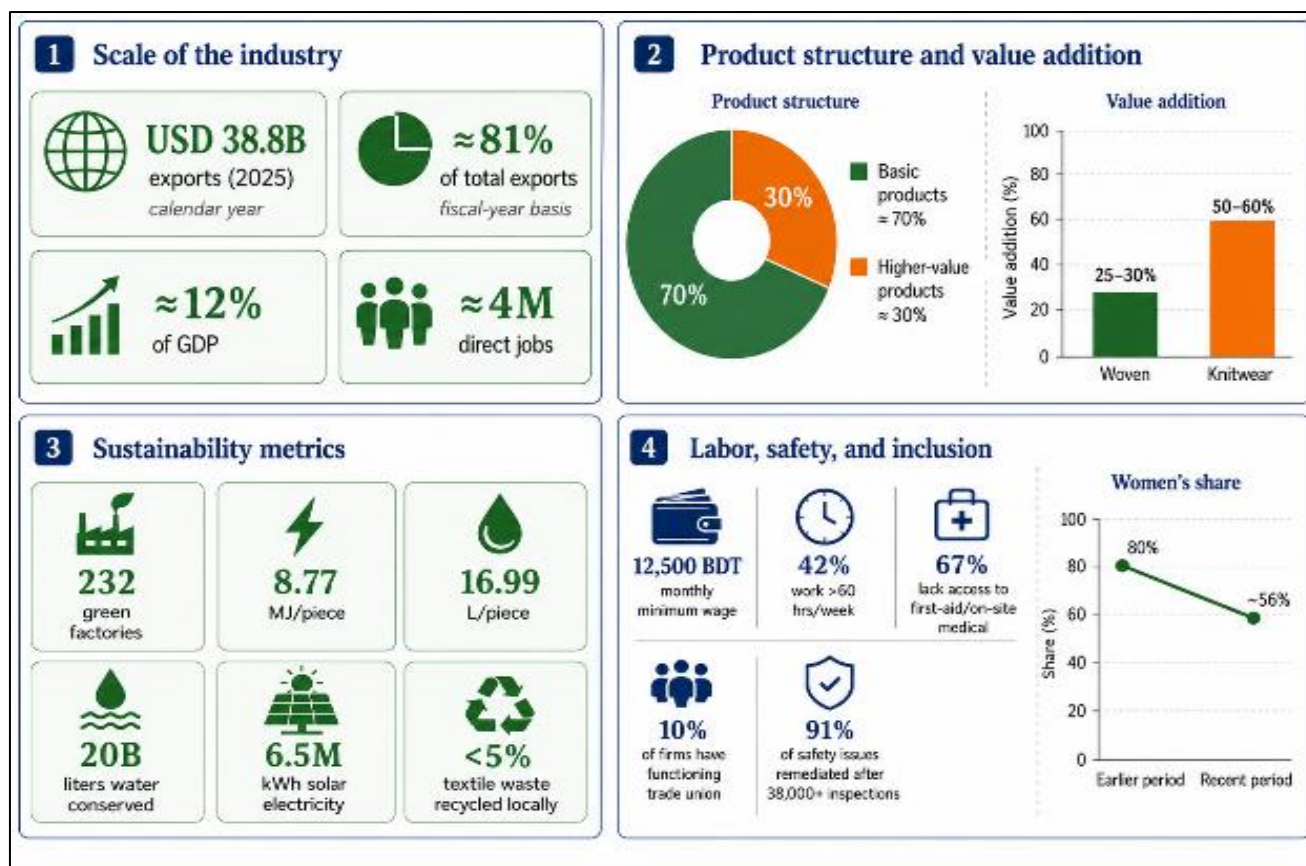


Figure 4 Key indicators of Bangladesh's textile and RMG industry across economic, sustainability, labor, and value-chain dimensions.

Figure 4 depicts the core evidence used in the findings section. By combining export, employment, sustainability, wage, safety, and value-addition indicators, it gives readers a quick statistical snapshot before the detailed thematic analysis of growth, sustainability, gendered labor, and GVC upgrading.

5. Findings

5.1. Economic Growth and Structural Transformation

The findings confirm that Bangladesh's RMG industry has experienced extraordinary growth since its inception. Export earnings increased from negligible levels in the late 1970s to USD 36.15 billion in FY2023–24 and USD 38.82 billion in calendar year 2025, accounting for about 81% of Bangladesh's total export earnings on a fiscal-year basis.

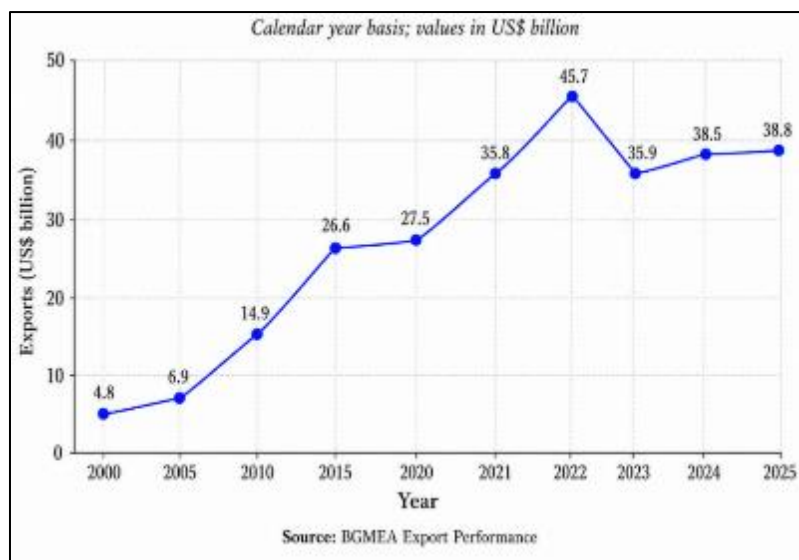


Figure 5 Bangladesh RMG export growth based on selected calendar-year observations, 2000–2025 [35].

This graph shows the long-term expansion of Bangladesh's RMG exports from USD 4.8 billion in 2000 to USD 38.8 billion in 2025 on a calendar-year basis. Exports grew strongly after 2010, peaked at USD 45.7 billion in 2022, declined in 2023, and partially recovered in 2024–2025. This pattern highlights both the sector's growth strength and its vulnerability to global demand shocks.

The industry has been instrumental in poverty reduction, women's labor force participation, and the growth of ancillary industries including textiles, packaging, logistics, and chemicals [17]. Bhattacharya and Rahman [12] estimated that 80% of garment accessories were locally produced, generating substantial backward linkages. Export performance has remained resilient despite global challenges. Calendar-year RMG exports rose to USD 38.48 billion in 2024 and further increased slightly to USD 38.82 billion in 2025, following a sharp decline from the 2022 peak. This recovery suggests resilience, but also shows the sector's exposure to fluctuations in global apparel demand.

However, growth has been primarily horizontal—an expansion in volume rather than value. Bangladesh continues to specialize in low-value, basic products such as T-shirts, trousers, sweaters, and woven shirts, which account for approximately 70% of exports [18]. Value addition remains low, estimated at 25–30% for woven garments compared to 50–60% for knitwear [19]. The industry remains heavily import-dependent, with approximately 98% of cotton, most woven fabrics, synthetic fibers, chemicals, dyes, and machinery imported [20].

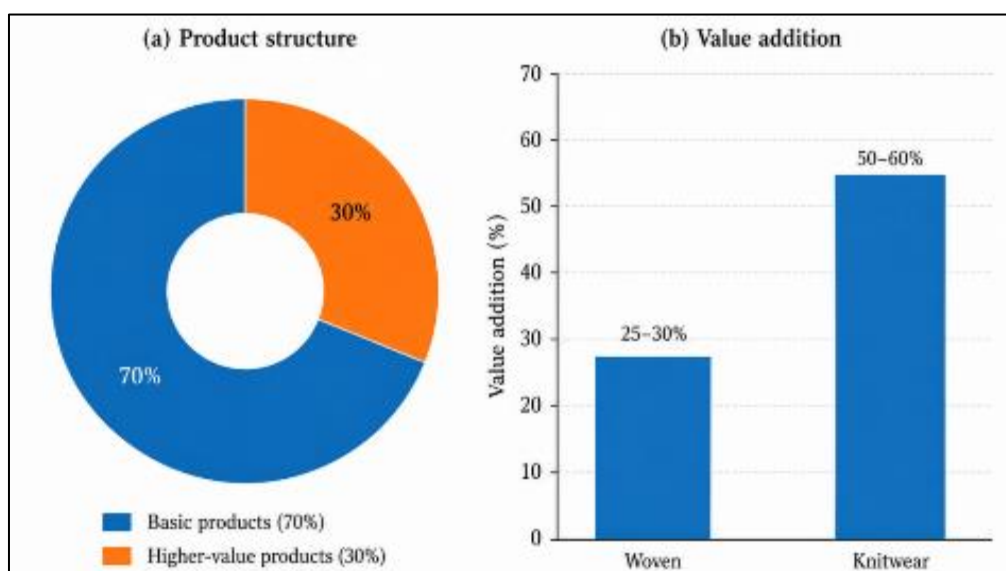


Figure 6 Product structure and value addition in Bangladesh's RMG industry.

This figure links the growth discussion with the paper's upgrading argument. It shows that Bangladesh remains concentrated in basic garments, while value addition differs between woven and knitwear products. The chart therefore supports the claim that export growth has been largely volume-driven rather than based on higher-value functional upgrading.

Structural constraints include infrastructure deficiencies, with Chittagong Port having average container dwell times of 7-11 days compared to 3-4 days in Vietnam and 2-3 days in China. Logistics costs account for 15-18% of export value, significantly eroding competitiveness [21]. Energy shortages, particularly chronic gas supply deficits, further constrain production capacity and increase costs [22]. The institutional structure of the industry, including close coordination between industry associations and public authorities, has shaped labor governance and slowed some reform processes.

5.2. Sustainability: Environmental and Social Dimensions

Bangladesh has emerged as a global leader in green garment manufacturing, with 232 LEED-certified factories adopting energy-efficient technologies and sustainable practices [23]. Reporting factories achieved energy intensity of 8.77 MJ per piece and water intensity of 16.99 liters per piece, with 31 of 57 factories generating 6.5 million kWh of solar electricity, avoiding an estimated 14,564 tCO₂e [23]. The Partnership for Cleaner Textile (PaCT) project contributed to approximately 20 billion liters of water conserved [25].

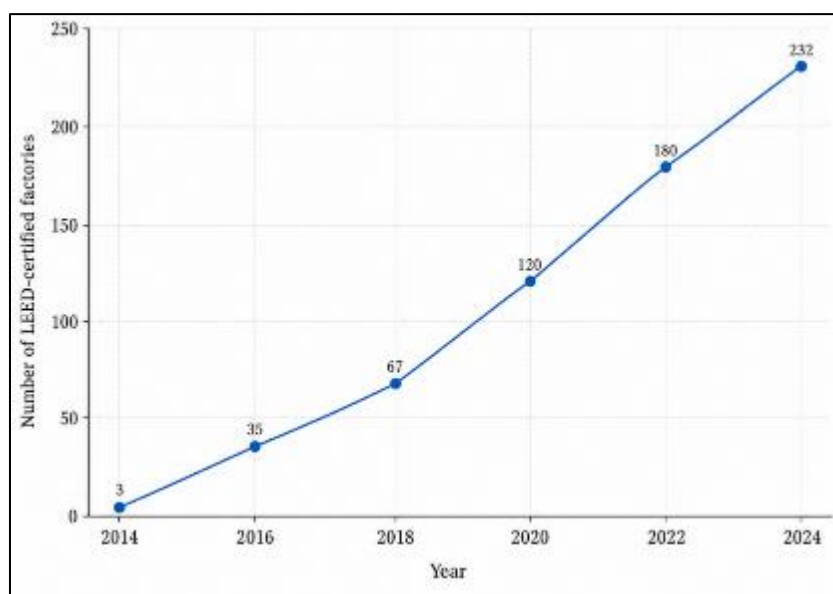


Figure 7 Growth of LEED-certified green garment factories in Bangladesh.

This graph visually supports the paper's sustainability discussion by showing the rapid increase in LEED-certified garment factories. It highlights Bangladesh's progress in green manufacturing and environmental compliance, while also preparing readers for the following discussion on uneven sustainability performance between large export-oriented factories and smaller subcontracting firms.

However, environmental compliance is concentrated among large exporting factories serving international brands, while SMEs often lack adequate effluent treatment, chemical management, and waste disposal systems [26]. Regulatory enforcement remains weak, with monitoring gaps and corruption undermining environmental governance. Waste management infrastructure remains inadequate, with less than 5% of textile waste recycled locally [26].

Social sustainability presents profound challenges. Minimum monthly wages (12,500 taka, approximately USD 113) remain far below living wage estimates and substantially lower than competitors [27]. Working conditions are characterized by excessive overtime, with 42% of workers exceeding 60 hours per week [4]. Occupational health and safety remain inadequate, with 67% of workers lacking access to first-aid facilities or on-site medical professionals [4]. Trade union representation is minimal, with only 10% of garment firms belonging to a functioning trade union [7].

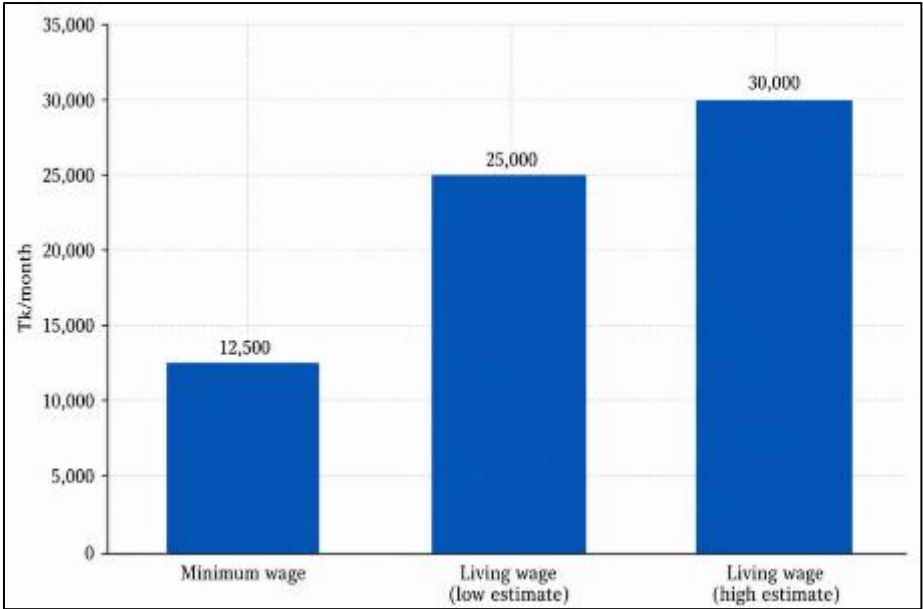


Figure 8 Monthly minimum wage versus estimated living wage in Bangladesh’s RMG sector.

This chart bridges the environmental sustainability discussion with social sustainability concerns. By comparing the legal minimum wage with estimated living wage levels, it visually demonstrates the gap between compliance and worker well-being. It strengthens the paper’s argument that economic competitiveness has been maintained partly through persistent wage suppression.

Post-Rana Plaza safety reforms have improved structural safety in inspected factories. The Accord completed more than 38,000 inspections until 2021, remediating 91% of identified safety issues [5]. However, nearly 3,000 factories serving subcontractors and smaller customers remain outside inspection coverage [4]. Compliance with labor standards beyond building safety remains inadequate, with Bangladesh making progress in "compliance" but not in "rights" [6].

5.3. Gendered Labor Dynamics and Women's Employment

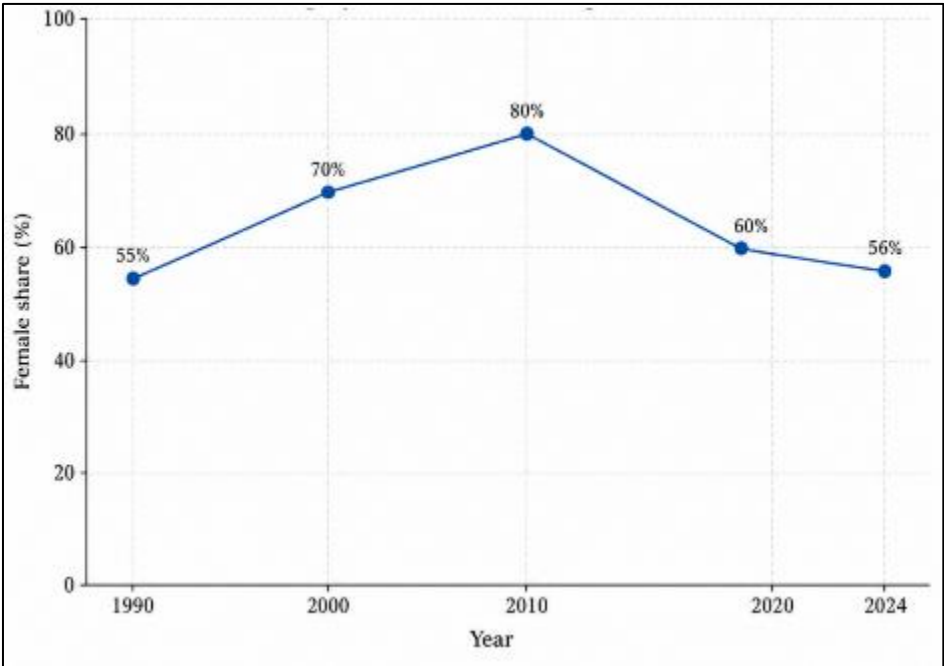


Figure 9 Women’s employment share in Bangladesh’s RMG industry over time

Women's entry into industrial wage labor has transformed gender relations in Bangladesh, challenging patriarchal norms and providing millions of rural women with economic independence [11]. However, this transformation was fundamentally shaped by structural inequalities, with employers' preference for female labor reflecting women's willingness to accept lower wages and their position outside established trade union structures [12].

Women remain concentrated in low-paid, low-skilled positions, with only 5-10% of managers and supervisors being women [4]. Gender-based violence and harassment are prevalent, with 50% of female garment workers reporting workplace harassment in 2022 [4]. Most women cannot continue factory work beyond five years due to physical strain and incompatibility with domestic responsibilities [11].

This graph supports the gendered labor analysis by showing the rise and later decline of women's employment share in the RMG workforce. It helps connect earlier empowerment through industrial employment with recent concerns about automation, masculinization of technical roles, and the potential reversal of women's labor-market gains.

Recent technological changes have intensified gender inequalities. Automation has led to a "re-masculinization" of garment production, with male workers being specifically recruited for more technical roles [1]. Women's share of garment employment has declined from about 80% to approximately 56–60%, indicating a substantial reduction in women's participation in the RMG workforce.

Women workers' capacity for collective action remains severely constrained. The RMG industry is largely non-unionized, with employers using strong-arm tactics to intimidate workers. Trade unions are typically male-dominated and politically affiliated, often prioritizing political alliances over workers' welfare. Despite constraints, six revisions of the minimum wage have occurred since 1994, each following massive labor protests and confrontational labor unrest [1].

5.4. Global Value Chain Integration and Industrial Upgrading

Bangladesh is heavily embedded in apparel GVCs but largely confined to the lowest-value stages (cutting, making, trimming, and shipping) [8]. The buyer-driven nature of apparel GVCs means lead firms (Walmart, H&M, Zara, Marks & Spencer) wield enormous power over suppliers [9]. Bangladesh's manufacturers have limited ability to negotiate better terms, particularly in the basic scheduled-response segment [18].

Progress in upgrading has been uneven. Process upgrading through automation and efficiency improvements has occurred [19]. There has been a shift from CMT to OEM, where suppliers source raw materials independently. However, functional upgrading into design and branding remains limited, with Bangladesh depending on foreign buyers for research and development, design, branding, and marketing. The transition toward ODM and OBM has been slow, reflecting supply-side constraints and buyer preferences [19].

Intensifying competition from Vietnam, India, and Cambodia threatens Bangladesh's traditional cost advantage [4]. LDC graduation will erode preferential trade access, further pressuring competitiveness [8]. Diversification opportunities exist in technical textiles, performance fabrics, sportswear, and sustainable fashion [9], but capturing these opportunities requires investments in skills, technology, design capabilities, and quality assurance [19].

Table 3 Multi-dimensional summary of Bangladesh's textile and RMG industry: achievements, contradictions, and strategic responses.

Dimension	Key achievements	Key contradictions / challenges	Strategic response
Economic growth	World's second-largest apparel exporter; RMG exports reached USD 38.8 billion in calendar year 2025; about 81% of total export earnings on a fiscal-year basis; large employment generation and backward linkages.	Growth remains mainly volume-driven; concentration in low-value basic products; high import dependence; logistics costs remain high; port dwell time and energy constraints reduce competitiveness.	Infrastructure modernization, customs digitalization, energy reliability, product diversification, and movement toward higher-value product segments.
Sustainability	232 LEED-certified green factories; water and energy	Environmental compliance remains uneven among SMEs; weak	Stronger regulation, wider inspection coverage,

	efficiency gains; post-Rana Plaza safety improvements; growing attention to cleaner production.	enforcement; less than 5% of textile waste is recycled locally; chemical-management gaps remain; many factories remain outside full inspection coverage.	improved waste-management systems, national chemical guidelines, and support for SME compliance.
Gendered labor	Mass female employment; income opportunities for rural women; contribution to social change, poverty reduction, and women's economic participation.	Women remain concentrated in low-skilled jobs; only 5–10% of managers/supervisors are women; workplace harassment persists; automation is reducing women's employment share from about 80% to about 56%.	Skills upgrading, promotion pathways for women, anti-harassment enforcement, childcare and workplace support, and inclusion of women in technical and supervisory roles.
GVC integration	Deep integration into global apparel trade; gradual shift from CMT toward OEM in some firms; established reputation as a reliable apparel supplier.	Buyer-driven power asymmetry; limited ODM/OBM capability; weak design, branding, and R&D capacity; LDC graduation may reduce preference-based competitiveness.	Functional upgrading, investment in design and branding capability, technical textiles, innovation, quality assurance, and stronger supplier bargaining capacity.

Source: Author synthesis based on the paper's findings and updated BGMEA export data.

This table synthesizes the paper's key findings across four dimensions: economic growth, sustainability, gendered labor, and GVC integration. It shows that Bangladesh's RMG success is accompanied by unresolved structural contradictions, including low-value production, uneven compliance, gender inequality, and limited upgrading. The table also links these challenges to strategic responses discussed in the policy section.

5.5. Statistical Trend and Forecasting Results

To strengthen the empirical dimension of the study, this section presents statistical trend analysis and a simple export forecasting model using selected calendar-year RMG export observations for 2000–2025. The selected observations include 2000, 2005, 2010, 2015, 2020, 2021, 2022, 2023, 2024, and 2025; therefore, the results are treated as indicative trend estimates rather than precise annual time-series forecasts. The analysis includes compound annual growth rate, year-on-year growth, and a time-trend forecast for 2026–2030. Since the available dataset is annual and limited, the forecast is interpreted as an indicative projection rather than an official prediction.

5.5.1. CAGR analysis

The compound annual growth rate was calculated using the following formula:

$$CAGR = \left(\frac{X_n}{X_0} \right)^{1/n} - 1$$

where X_0 is the export value in the base year, X_n is the export value in the final year, and n is the number of years.

Based on the calendar-year export series, Bangladesh's RMG exports increased from USD 4.8 billion in 2000 to USD 38.82 billion in 2025. This represents a long-term CAGR of approximately 8.72% over the 25-year period. The result confirms the sector's strong long-run export expansion, although recent fluctuations indicate rising exposure to global demand shocks.

Table 4 Historical RMG export growth indicators, 2000–2025

Indicator	Period	Starting value	Ending value	Result
Long-term CAGR	2000–2025	USD 4.8 billion	USD 38.82 billion	8.72%
Recent CAGR	2020–2025	USD 27.5 billion	USD 38.82 billion	7.14%
Post-peak CAGR	2022–2025	USD 45.7 billion	USD 38.82 billion	–5.29%

This table shows that Bangladesh’s RMG sector achieved strong long-term growth, with exports expanding at an annualized rate of 8.72% between 2000 and 2025. However, the negative post-2022 CAGR indicates that recent export performance has not fully recovered from the 2023 correction. This supports the paper’s argument that growth remains strong but increasingly volatile.

Year-on-year growth, 2020–2025

Year-on-year export growth was calculated using:

$$YoY\text{Growth} = \frac{X_t - X_{t-1}}{X_{t-1}} \times 100$$

Table 5 Year-on-year growth, 2020–2025

Year	RMG Exports, USD Billion	YoY Growth
2020	27.50	—
2021	35.80	30.18%
2022	45.70	27.65%
2023	35.90	–21.44%
2024	38.48	7.19%
2025	38.82	0.88%

The year-on-year results show rapid rebound growth in 2021 and 2022, followed by a sharp decline in 2023 and modest recovery in 2024–2025. This confirms that Bangladesh’s RMG export model remains resilient, but also sensitive to global demand cycles, buyer sourcing decisions, and external shocks.

5.5.2. Forecasting model

A simple linear time-trend model was applied to estimate future RMG export values:

$$Export_t = \alpha + \beta t + \epsilon_t$$

where t represents the number of years after 2000.

The estimated model is:

The model has an estimated R^2 of 0.914, suggesting that the long-term time trend explains a substantial share of variation in export earnings. However, because recent years show volatility, the forecast should be interpreted cautiously.

Table 6 Baseline forecast of Bangladesh RMG exports, 2026–2030

Year	Baseline forecast, USD billion
2026	42.37
2027	43.93
2028	45.49
2029	47.05
2030	48.61

The baseline forecast suggests that Bangladesh's RMG exports may reach approximately USD 48.61 billion by 2030 if the long-term historical trend continues. However, the forecast remains below more ambitious industry targets, indicating that simple continuation of past growth may be insufficient for major competitiveness gains without structural upgrading.

Scenario-based forecast

To account for uncertainty, three scenarios were developed. The baseline scenario uses the linear trend forecast. The optimistic scenario assumes stronger performance through logistics improvement, product diversification, sustainability compliance, and functional upgrading. The pessimistic scenario assumes weaker global demand, slower upgrading, and pressure from LDC graduation.

Table 7 Scenario-based forecast of Bangladesh RMG exports, 2026–2030

Year	Pessimistic scenario	Baseline scenario	Optimistic scenario
2026	38.13	42.37	46.61
2027	39.54	43.93	48.32
2028	40.94	45.49	50.04
2029	42.35	47.05	51.76
2030	43.75	48.61	53.47

Forecasts are based on selected calendar-year observations rather than a complete annual time series; therefore, values should be interpreted as indicative projections.

The scenario results show that Bangladesh's future export performance depends heavily on the quality of industrial upgrading. Under the baseline trend, exports may approach USD 48.61 billion by 2030. Under an optimistic upgrading pathway, exports could exceed USD 53 billion, while weak upgrading and external shocks may keep exports near USD 44 billion.

5.5.3. Interpretation linking forecast with GVC upgrading

The forecasting results reinforce the paper's central argument that future competitiveness cannot depend solely on low-cost, high-volume production. Although the long-term trend remains positive, recent volatility after the 2022 peak shows the vulnerability of Bangladesh's current export model. Achieving the optimistic scenario would require functional upgrading from CMT/OEM toward design, branding, technical textiles, faster logistics, stronger compliance, and higher value-added production. Without such upgrading, Bangladesh may remain locked into buyer-driven, low-margin segments of the global apparel value chain.

6. Discussion

6.1. Structural Contradictions and Policy Implications

The findings reveal structural contradictions in Bangladesh's RMG industry development. While the sector has generated significant economic growth and employment, this success has been achieved through unsustainable practices that undermine long-term viability. The industry's competitive advantage rests on exceptionally low wages, inadequate labor rights, and environmental degradation [7]. This model faces growing challenges from global scrutiny, intensifying competition, and declining preference margins.

The contradictions are particularly evident in the relationship between women's employment and empowerment. While the industry has provided millions of women with economic independence, it has simultaneously reproduced gender inequalities through occupational segregation, wage discrimination, and exclusion from decision-making [11]. Automation now threatens to reverse previous gains, with women being displaced from the sector. This pattern reflects the structural logic of global capital, which exploits gender inequalities while generating limited transformative potential [28].

The sustainability paradox similarly illustrates structural contradictions. Bangladesh leads globally in LEED-certified green factories [23], but environmental compliance is concentrated among large exporters serving international brands. SMEs, which constitute a significant portion of the sector, lack adequate environmental management systems [26]. Regulatory enforcement remains weak, and the absence of comprehensive chemical management guidelines poses ongoing risks. This dualism—global leadership coexisting with widespread non-compliance—reflects the uneven impact of buyer-driven GVC governance.

6.2. Global Value Chain Governance and Upgrading Constraints

The buyer-driven nature of apparel GVCs fundamentally constrains upgrading opportunities. Lead firms' control over design, branding, and marketing limits suppliers' ability to capture higher value [9]. The relational governance structures identified by Gereffi et al. [9] are largely absent in Bangladesh, where power asymmetries and price pressures remain pronounced. This captive position reflects both supply-side constraints—limited design capabilities, inadequate skills, and weak research and development—and demand-side dynamics—buyers' preference to retain control over high-value activities [19].

The implications of this captive position are significant. Without functional upgrading, Bangladesh's RMG industry will remain in low-value segments, vulnerable to competition from even lower-cost producers. However, functional upgrading faces formidable obstacles, including weak institutional ecosystems, limited skills, and buyer resistance. Policy must address these constraints through investments in human capital, research and development, and infrastructure modernization [19].

6.3. Pathways for Sustainable Transformation

Addressing structural contradictions requires a coordinated strategy encompassing multiple dimensions. Infrastructure modernization is essential for reducing costs and improving competitiveness [21]. Sustainability integration must extend beyond safety compliance to encompass comprehensive environmental and social standards, with strengthened regulatory enforcement and expanded inspection coverage [23]. Industrial upgrading requires investments in human capital, technology, and research and development, with women supported to move into higher-skilled roles [8].

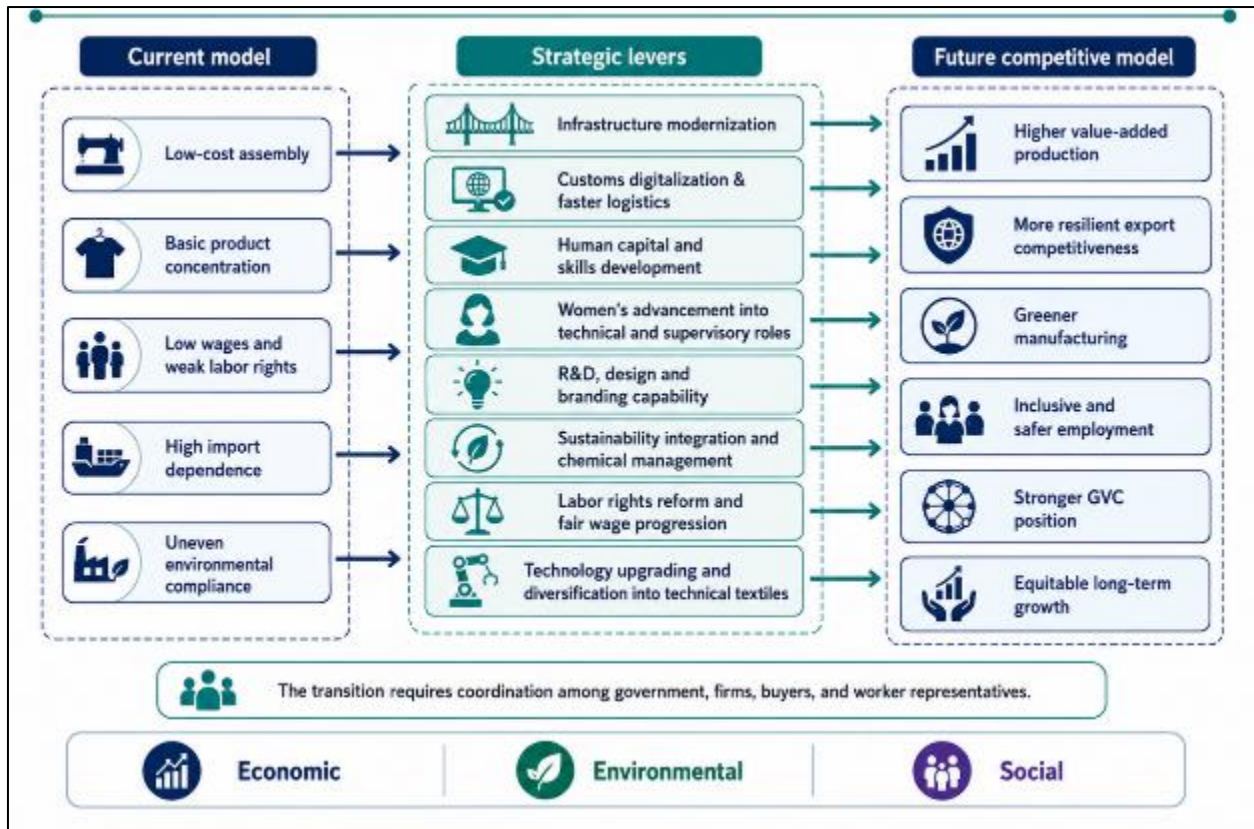


Figure 10 Strategic roadmap for transforming Bangladesh's textile and RMG industry from low-cost assembly toward sustainable, inclusive, and higher-value competitiveness.

This figure translates the discussion into a strategic pathway. It shows how Bangladesh can move from low-cost assembly, weak labor rights, and uneven compliance toward higher-value production, greener manufacturing, inclusive employment, and stronger GVC positioning through coordinated policy, industrial upgrading, and sustainability reforms.

Labor rights reform is particularly urgent. Genuine sustainability requires respect for workers' rights to collective bargaining, fair wages, and safe working conditions [6]. Strengthening institutional mechanisms for labor governance, social dialogue, and transparent enforcement can help address persistent gaps in compliance and worker protection. A renewed social contract based on workers' dignity, participation, and shared responsibility is essential for the industry's long-term legitimacy and stability.

The post-MFA era and the impending LDC graduation underscore the urgency of transformation. Bangladesh must move beyond low-cost assembly toward higher-value activities, genuine sustainability, and inclusive and equitable development [8]. The foundation exists—in the skills and dedication of workers, the dynamism of entrepreneurs, and the collective ambition of the nation. The challenge is to build on this foundation to create an industry that delivers not only exports and growth but also dignity, equality, and sustainability for all.

7. Conclusion

7.1. Summary of Findings

Bangladesh's textile and RMG industry represents one of the most remarkable success stories in global industrial development, transforming a war-torn, impoverished nation into the world's second-largest apparel exporter. The sector's achievements—in export growth, employment generation, and women's labor force participation—are genuinely impressive and have contributed substantially to poverty reduction and economic development.

However, this success has been built on foundations that are increasingly unsustainable. The industry's competitive advantage has rested on exceptionally low wages, inadequate labor rights, and environmental degradation—a model

that cannot endure in an era of global scrutiny, intensifying competition, and declining preference margins. The Rana Plaza disaster exposed the human costs of this model, while automation and technological change now threaten women's employment gains.

Structural contradictions shape the industry's development trajectory. Environmental and social sustainability improvements are uneven, concentrated among large exporters serving international brands. Women's employment has brought empowerment but also exploitation, and automation threatens to reverse previous gains. GVC governance limits upgrading opportunities, constraining the sector's ability to capture higher value.

7.2. Contributions

This paper contributes to the literature in three ways. First, it synthesizes fragmented research across disciplines into an integrated analytical framework, revealing the interconnections between economic, environmental, social, and GVC dimensions. Second, it identifies structural contradictions that shape the sector's development, providing a more nuanced understanding of challenges and opportunities. Third, it proposes concrete policy pathways for sustainable transformation, grounded in the analysis of these contradictions.

7.3. Limitations and Future Research

This study has limitations. The thematic analysis approach relies on secondary data and cannot capture the complexity of individual experiences or firms. Future research should incorporate primary data collection, including surveys, interviews, and case studies, to deepen understanding of sustainability practices and workers' experiences. Research on the impacts of automation on women's employment, the effectiveness of post-Rana Plaza reforms, and the potential for functional upgrading would be particularly valuable.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflicts of interest.

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Author Contributions

- **Delwar Hossain:** conceptualization, methodology, software, formal analysis, writing—original draft preparation, project administration.
- **Md. Mamunur Rashid:** investigation, resources, data curation, visualization, writing—review and editing.

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