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OPERATIONAL EFFICIENCY, RESOURCE UTILIZATION, WASTE, AND ENVIRONMENTAL PERFORMANCE IN BANGLADESH APPAREL MANUFACTURING: A DATA-DRIVEN SUSTAINABILITY MODEL

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ABSTRACT

Bangladesh's apparel sector faces pressure to improve production efficiency while reducing resource consumption, textile waste, and environmental burdens. Yet prior research often embeds these issues within broad sustainability indices, obscuring the operational mechanisms connecting them. This study develops a quantitative sustainability decision model for Bangladesh apparel manufacturing using four tightly connected constructs. The main objective is to explain how operational efficiency may improve environmental performance through resource utilization and waste reduction. Three questions assess upstream relationships, downstream effects, and the mediating roles of resource utilization and waste reduction. Six hypotheses predict positive direct relationships across these paths and positive indirect effects through both proposed mediators. The Natural-Resource-Based View grounds the model because it explains how resource-related capabilities can generate measurable environmental outcomes. The factory-level scope excludes household behavior and macroeconomic indicators while focusing on qualified managers and technical professionals. The study adopts a post-positivist, deductive, explanatory, quantitative, and cross-sectional design for organization-level analysis. A primary survey of 350–450 respondents are proposed, supported by stratification across factory size and geographic concentration. Covariance-based structural equation modeling tests theory, while partial least squares structural equation modeling assesses predictive robustness. Artificial neural network analysis provides a secondary nonlinear predictive extension after structural relationships are established. External Bangladesh benchmarks report 88 percent lighting efficiency adoption, 72 percent efficient motors, and 51 percent waste segregation. However, no common respondent-level dataset currently measures all four constructs, so the six hypotheses remain unestimated. This evidence boundary prevents

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claims about original path coefficients, mediation sizes, predictive accuracy, or causal relationships. The study contributes a parsimonious theoretical mechanism and an auditable decision framework for managers, policymakers, and researchers. Future research should collect harmonized longitudinal firm-level data linked with objective plant metrics to strengthen causal testing and policy design.

1 INTRODUCTION

Within apparel manufacturing, the term operational efficiency denotes a factory's capacity to convert production time, along with labor, materials, capital, water, and energy, into output that can be sold, while holding avoidable loss to a minimum. Sustainability research attaches weight to this capacity because ordinary operating routines are where a substantial part of environmental performance is produced: production decisions are joined to environmental outcomes through energy use, cutting yield, chemical processing, water intensity, defects, rework, and waste disposal. What makes Bangladesh analytically important is the combination of an apparel industry that continues to anchor national export earnings with the infrastructure, resource, compliance, and waste pressures bearing on that industry. Annual textile and garment waste in the country has been placed at roughly 600,000 metric tons by UNIDO, even as the sector has operated as a major export engine. Environmental improvement can be achieved through operational interventions, as resource-efficiency and international financing programs of recent years demonstrate; end-of-pipe treatment is not the sole route (Asian Development Bank, 2025; International Finance Corporation, 2024; United Nations Industrial Development Organization, 2023).

That environmental and wider sustainability performance can be raised by green supply chain management, by circular-economy practices, and by organizational capabilities is well established; what varies across studies is the level at which the constructs are modeled. Stakeholder pressure and supply-chain practices receive emphasis in one group of studies, whereas other centers on green human resources, on circularity, on certification, or on aggregate sustainable performance. Evidence generated in Bangladesh is robust enough to establish that these relationships can be measured empirically. Habib et al. (2022), to take one example, drew on 403 garment-manufacturing firms to model 12 GSCM constructs and reported positive associations of GSCM with performance that is environmental, economic, and operational. A sample of 303 managers was analyzed with PLS-SEM by Islam et al. (2024) to examine how sustainable supply chain management and circular economy affect sustainable performance, while covariance-based SEM was applied to 450 employees in a separate textile-sector study published in 2024. Configurations that combine market pressure with organizational commitment, policy engagement, and financing capacity govern LEED adoption according to recent factory-level research, and no antecedent acting alone does so. One question is left open by this body of work: within a single decision model, by what route do operating efficiency and resource utilization become waste reduction and environmental performance every day?

The present study takes up that question by confining the analysis of sustainability to four constructs that interlock: operational efficiency, resource utilization, waste reduction, and environmental performance. Its scope is operational by design rather than macroeconomic. National environmental indicators, household textile behavior, and consumer sustainability attitudes fall outside it; apparel-manufacturing organizations, together with the managers and technical professionals positioned to judge production, resource, and waste practices, fall within it. Developing and empirically specifying a structural model constitutes the principal objective, a model in which operational efficiency functions as the upstream organizational capability, resource utilization and waste reduction as intermediate mechanisms, and environmental performance as the downstream outcome. Two sources inform this architecture: the Natural-Resource-Based View, and the efficiency literature, in which productivity and resource constraints count as economically substantive elements of firm-level performance (Hart, 1995; Syverson, 2011; Teece, 2019). Three quantitative questions organize the article: is operational efficiency associated with stronger resource utilization and waste reduction; are resource utilization and waste reduction associated with environmental performance; and is the link running from operational efficiency to environmental performance mediated by those two constructs? Six testable hypotheses follow from them. What the article expects to contribute is not one more general assertion that green practices count, but a mechanism model pinpointing which operational decisions enter the pathway toward sustainability, and where intervention might be aimed. Factory managers who design resource-productivity programs, policymakers who shape green industrial incentives, buyers who assess supplier capability, and researchers in search of a parsimonious model of manufacturing in emerging economies all have a stake in that contribution. Thereafter the article reviews the pertinent evidence, builds the conceptual and theoretical framework, states objectives and hypotheses, lays out the empirical design along with its limitations of data, benchmarks the verified Bangladesh evidence, and considers what the resulting decision architecture implies theoretically and practically.

2 LITERATURE REVIEW

2.1 Theoretical Framework

Among candidate theories, the Natural-Resource-Based View (NRBV) supplies the most coherent single foundation for the model advanced here, since it accounts for the transformation of environmental constraints into capability at the organizational level and into competitive advantage. Pollution prevention, product stewardship, and sustainable development were framed by Hart (1995) as capabilities of strategic relevance. Translated to an apparel factory, operational efficiency becomes the organizational ability to curtail process losses, hold throughput steady, and deploy inputs to better effect; resource utilization registers the intensity and efficiency with which water, energy, scarce materials, and production inputs are turned into output; waste reduction registers the capacity of the firm to prevent material losses, or else to reuse them, recover them, or otherwise keep them to a minimum; and environmental performance stands for what those operating capabilities produce environmentally. Sustainability gains should be most immediate, the theory holds, where environmental objectives are built into routine production instead of being handled as a separate compliance task. This reading is consistent with evidence that environmental outcomes and operational ones alike are affected by green supply chain practices (Green et al., 2012; Zhu & Sarkis, 2004).

A distinction drawn in the efficiency literature is likewise honored by the model: obtaining greater output from an unchanged input bundle is not the same as obtaining unchanged output from fewer resources or with fewer undesirable outputs. Differences in environmental outcomes that can be measured have been associated, in environmental-efficiency studies, with worker incentives, organizational practices, firm characteristics, and productivity (Hossain et al., 2026; Lazăr, 2016; Martin et al., 2012). A boundary condition applies, however, because nothing in NRBV entails that improvements in efficiency are invariably beneficial environmentally: total environmental load can climb with expanded production even where intensity declines. Environmental performance is accordingly modeled as a distinct downstream construct, on the understanding that it cannot be substituted for efficiency.

Table 1. Construct operationalization and proposed measurement architecture

Construct	Role	Operational definition	Indicative measurement items	Scale
Operational Efficiency	Exogenous	Ability to achieve planned output with controlled time, labor, material and process inputs.	OE1–OE4: schedule reliability; process productivity; defect/rework control; input-output efficiency.	7-point Likert
Resource Utilization	Mediator 1	Extent to which material, water, energy and production inputs are used efficiently and with limited avoidable loss.	RU1–RU4: material yield; energy efficiency; water efficiency; input monitoring.	7-point Likert

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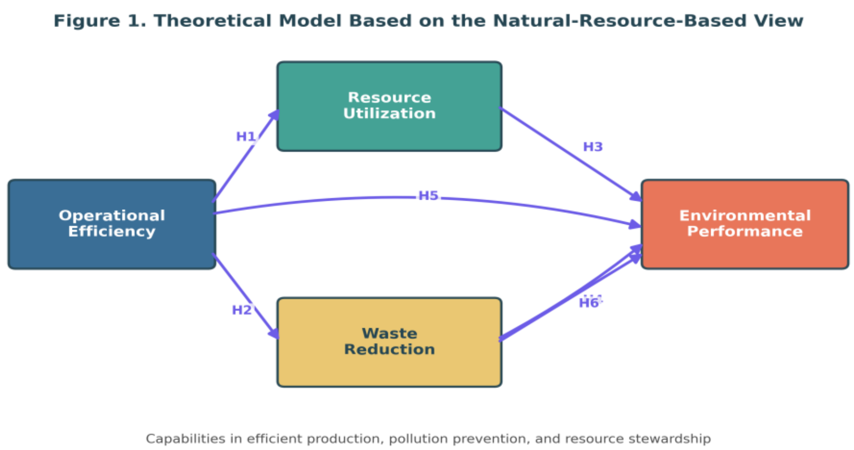
Waste Reduction	Mediator 2	Extent to which material waste and production residues are prevented, reused, recovered, recycled or minimized.	WR1–WR4: waste prevention; reuse; recovery/recycling; waste monitoring.	7-point Likert
Environmental Performance	Endogenous	Extent to which the factory reduces environmental burdens generated by production.	EP1–EP5: reduced emissions; lower resource intensity; improved effluent; reduced environmental incidents; compliance performance.	7-point Likert
Firm size / export orientation	Controls	Organizational scale and export exposure that may affect resource capability and environmental investment.	Employees; export share/category; factory type.	Mixed

Note. What the items represent are proposed measurement domains awaiting a validated questionnaire. No common respondent-level item set spanning all four constructs is available in the accessible secondary sources; the table consequently specifies a model and asserts nothing about prior statistical validation of these items in the present sample.

2.2 Conceptual Framework

Operational efficiency is positioned upstream in the conceptual framework, with resource utilization and waste reduction operating as parallel mechanisms. Both mediators are expected to exert positive direct effects on environmental performance. Excluded from the six-hypothesis baseline model is the direct path running from operational efficiency to environmental performance, since the object of the article is to establish whether sustainability gains travel through tangible production mechanisms. Such mediation logic follows from the NRBV premise that organizational routines lowering pollution and improving resource stewardship are what convert capabilities into environmental outcomes. Deliberately, then, the proposed model is narrower than a full GSCM framework, its purpose being to isolate one decision chain observable and actionable by those who manage factories.

Figure 1. Proposed structural model linking operational efficiency, resource utilization, waste reduction, and environmental performance



2.3 Operational Efficiency and Resource/Waste Outcomes

The upstream operating pathway is the subject of RQ1. Technology, management, input allocation, and organizational practices, not scale by itself, have long been shown by productivity research to account for performance differences among firms (Jain et al., 2011; Syverson, 2011). Efficiency acquires environmental consequence in manufacturing when the source of higher productivity is shorter idle time, reduced material loss, tighter input control, and fewer defects instead of expanded throughput alone. A structural model was used by Green et al. (2012) to demonstrate an association between green supply chain practices and performance, and the frontier of attainable performance can be shifted by organizational practices, as Martin et al. (2012) and cognate environmental-efficiency work indicate. Context is supplied by Bangladesh evidence: environmental efficiency was positively related to labor and capital productivity in the 2026 apparel study of 2,172 firms drawn from the Manufacturing Industry Survey, though certain organizational characteristics exerted heterogeneous effects. What remains unresolved in the literature is whether a single apparel-sector model should represent operational efficiency as a predictor, broadly, of resource utilization and waste reduction alike. Two hypotheses insufficiently isolated in earlier Bangladesh studies follow from this gap: H1, operational efficiency has a positive association with resource utilization; and H2, operational efficiency has a positive association with waste reduction. Separating efficient use of inputs from the prevention of waste across two paths avoids treating the constructs as identical.

2.4 Resource Utilization, Waste Reduction, and Environmental Performance

Turning operating practices into environmental performance is the concern of RQ2. Cooperation, ecological purchasing, internal environmental management, and allied practices are generally predicted by the literature on green supply chains to yield positive environmental effects (Habib et al., 2022; Zhu & Sarkis, 2004). That logic is extended in circular-economy research, where the emphasis falls on reuse, recovery, recycling, and diminished reliance on virgin inputs. Sustainable supply chain management and circular-economy practices have been linked, among green garment firms in Bangladesh, to sustainable performance, and recent LEED evidence records the presence, at differing levels across surveyed factories, of efficient sewing motors, energy-efficient lighting, effluent-treatment infrastructure, solar energy, water recycling, and waste segregation. Mechanisms that managers are able to influence directly are nevertheless obscured where the empirical literature folds waste management and resource efficiency into broader indices of sustainability. From this gap follow H3, resource utilization has a positive association with environmental performance, and H4, waste reduction has a positive association with environmental performance. Directionality is deliberate in both cases, since each mechanism amounts to a reduction in resource intensity or in undesirable outputs of the kind NRBV counts as an environmental capability. On total as against intensity-based environmental effects the model stays cautious: improved utilization is expected to strengthen performance, conditional as that is on the output context, and not to shrink the absolute environmental footprint automatically.

2.5 Integrated Mediation Pathways

Whether operational efficiency reaches environmental performance by way of the two intermediate mechanisms is what RQ3 asks. Theoretically, mediation matters because misleading conclusions can follow from a direct efficiency-to-environment link when resource and waste routines are what generate the environmental effect. Greater productivity need not make a factory greener if the added output brings more emissions or waste; where efficiency gains arrive together with improved material yield, waste prevention, and a reduced intensity of energy or water use, the environmental consequences should be clearer. That organizational capabilities work by way of management systems and intermediate routines finds support in the wider sustainability literature (Hart, 1995; Teece, 2019), and mediation evidence in adjacent Bangladesh settings, among them sustainability management accounting as well as employee or environmental performance, points the same way. What is unresolved, then, is not the general relevance of green practices but whether the particular route from operational efficiency to environmental performance in apparel manufacturing is explained by resource utilization and waste reduction. Hence H5, resource utilization mediates the relationship between operational efficiency and environmental performance, and H6, waste reduction mediates the relationship between operational efficiency and

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environmental performance. The six hypotheses, taken as a set, cross-reference RQ1 through RQ3 and yield a model capable of distinguishing operating capability, taken directly, from the mechanisms out of which sustainability outcomes arise.

2.6 Problem Statement

Three connected problems emerge from the evidence base. The first is that green and operational practices have been shown by Bangladesh apparel research to be associated with outcomes that are environmental or sustainable, yet efficiency, waste, and resource use are frequently handled there as elements within broader indices. The second is that water, energy, finance, waste, market pressure, and certification are increasingly identified as relevant factors in factory-level sustainability studies, none of which offers a shared mechanism model built around production efficiency. The third is the fragmentation of open Bangladesh datasets across constructs as well as levels of analysis. Missing, as a result, is an empirically testable and mechanism-oriented model that connects operational efficiency to environmental performance through resource utilization and waste reduction while holding construct boundaries clear. This article responds by specifying a model of that kind and by setting out precisely which real-world evidence already exists and which respondent-level evidence definitive estimation still requires.

3 OBJECTIVE OF THE STUDY

Development and empirical specification of a Natural-Resource-Based sustainability decision model, one that ties operational efficiency to resource utilization, waste reduction, and environmental performance within Bangladesh apparel manufacturing, has been the main objective pursued in this study.

3.1 Specific Research Questions

RQ1. To what extent has operational efficiency been associated with resource utilization and waste reduction in Bangladesh apparel manufacturing?

RQ2. To what extent have resource utilization and waste reduction been associated with environmental performance in Bangladesh apparel manufacturing?

RQ3. To what extent have resource utilization and waste reduction mediated the relationship between operational efficiency and environmental performance?

3.2 Hypotheses Development

H1: Operational efficiency has a positive relationship with resource utilization.

Firms that keep defects, cycle time, downtime, input allocation, and rework under control should, by this reasoning, draw more useful output out of an unchanged resource base. Both the capability logic of the NRBV and the productivity literature underwrite the prediction (Hart, 1995; Syverson, 2011).

H2: Operational efficiency has a positive relationship with waste reduction.

Process stability supplies the anticipated mechanism: avoidable material losses and reprocessing should fall as defects decline, planning improves, and production inputs come under closer control. Waste prevention is kept separate from resource utilization in this hypothesis, since efficiency can improve at a firm without every waste stream contracting.

H3: Resource utilization has a positive relationship with environmental performance.

Where factories consume less material, energy, or water for each unit of output and track those inputs systematically, the expectation is that resource productivity will lower how environmentally intensive production is. An empirical and theoretical basis for the direction of this link comes from environmental-efficiency studies (Kuosmanen & Johnson, 2010; Lazăr & Istrate, 2018).

H4: Waste reduction has a positive relationship with environmental performance.

Undesirable outputs fall as waste is prevented, reused, recovered, and recycled, so environmental performance should improve. Circular-economy reasoning and evidence from GSCM studies in the garment sector both support the prediction (Jia et al., 2020; Habib et al., 2022).

H5: Resource utilization mediates the relationship between operational efficiency and environmental performance.

How an operating capability turns into an environmental outcome is what the mediation hypothesis specifies: production resources are used better as efficiency rises, and environmental performance responds to that improved utilization. A mechanism, rather than a correlation alone, is therefore what the hypothesis puts to the test.

H6: Waste reduction mediates the relationship between operational efficiency and environmental performance.

A parallel mechanism is proposed here, one in which avoidable waste falls under operating discipline and environmental performance improves as undesirable outputs decline. Which of resource productivity and waste prevention carries the greater share of the efficiency-to-environment pathway will become apparent when H5 and H6 are tested jointly.

4 METHODOLOGY

4.1 Research Design

An explanatory design that is post-positivist, deductive, quantitative, and cross-sectional is proposed. Analysis proceeds at the level of the apparel-manufacturing organization, for which a technical professional or manager whose knowledge of environmental, waste, resource, and production practices is first-hand serves as respondent. Because latent constructs and mediation hypotheses make up the model, covariance-based structural equation modeling (CB-SEM) is the primary method for theory testing. Two considerations make the design cross-sectional: the comparable evidence identified to date is survey-based, and the immediate aim is to test indirect pathways and associations, not to assert longitudinal causality.

4.2 Population, Sampling Technique, and Sample Size

Apparel-manufacturing factories in Bangladesh, whether domestic or export-oriented, together constitute the target population. Respondents qualify if they hold organizational experience for a year or more along with direct responsibility for decisions in operations, production, quality, industrial engineering, compliance, sustainability, or supply chain. Stratification is the preferable approach, with geographic concentration and factory size defining the strata, since scale and operating models may differentiate resource and environmental capabilities. Rather than a rule-of-thumb respondent count, a power analysis conducted a priori on the six-path structural model should fix the minimum sample for the final primary survey. Subject to what that analysis returns and to the sampling frame available, 350–450 completed organizational responses is a defensible target, a figure in keeping with the scale of earlier Bangladesh studies drawing on 303 managers, 403 garment firms, and 450 textile employees.

4.3 Instrumentation and Questionnaire Design

Four construct sections plus controls should make up the questionnaire. A seven-point agreement scale and multiple reflective indicators should serve every latent variable. Validated domains covering green supply chain, efficiency, waste management, and environmental performance should supply the items, which should then be checked against Bangladesh apparel terminology. Completion time, comprehension, face validity, and item redundancy should be evaluated in a pretest with 30–50 respondents drawn from the target population, and items whose conceptual fit proves weak should be revised ahead of the main survey. Since no single validated item battery spanning all four proposed constructs is available in the accessible secondary datasets, the operationalization set out in Table 1 amounts to a measurement-development specification and not a completed reliability result.

4.4 Three Quantitative Methodologies

Method 1—Covariance-Based Structural Equation Modeling (AMOS). Whether the theoretical model is consistent with the hypothesized structural and measurement relationships is tested through CB-SEM, the backbone of the analysis. Its workflow runs as follows: confirm the factor structure; evaluate reliability, standardized loadings, discriminant validity, and convergent validity; estimate the structural paths; test H1–H6 using bootstrapped indirect effects; and finally report indices of model fit. Descriptive diagnostics and data screening are handled in SPSS, while theory-based SEM and confirmatory factor analysis are handled in AMOS.

Method 2—Partial Least Squares Structural Equation Modeling with SmartPLS. An extension and robustness analysis oriented toward prediction is what PLS-SEM contributes. The workflow proceeds thus: evaluate indicator reliability, Cronbach's alpha, rho_A, composite reliability, AVE, HTMT, and VIF; use bootstrapping to estimate the path model; report beta, t, p, confidence intervals, R^2, f^2, and Q^2predict; and run PLSpredict and IPMA wherever the data support them. Export orientation or factory size may additionally be examined through multi-group analysis, but only once measurement invariance has been established.

Method 3—Artificial Neural Network (ANN) predictive extension. Once the structural model has been estimated, ANN analysis is proposed as a way of capturing predictive patterns of a nonlinear kind that

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SEM may leave unrepresented. Environmental performance would be the dependent target, with operational efficiency, resource utilization, and waste reduction acting as predictors. Overfitting should be guarded against through validation, model training, repeated cross-validation, and importance assessment based on permutation or sensitivity. Hypothesis testing is extended rather than replaced by this third method, which is appropriate only where the size of the final respondent dataset suffices to sustain training and validation splits that remain stable.

4.5 Data Sources, Collection, and Evidence Boundary

A genuine respondent-level dataset is required by the study protocol, which likewise prohibits synthetic observations. An openly licensed 364-case Bangladesh dataset whose respondents are supply chain professionals based in Dhaka and Chittagong is identified in a 2026 Mendeley Data record, which also provides a downloadable SAV file. Supply chain integration, green supply chain management, sustainability management accounting, blockchain adoption, and sustainable organizational performance are the constructs it concerns. A textile-industry dataset that three five-point Likert dimensions summarize, namely regulatory effectiveness, online platform utilization, and waste fabric management, is reported in a separate 2025 Mendeley Data record. Useful as both records are as evidence resources, jointly they still do not constitute a single respondent-level dataset valid for precisely the four-construct model proposed here. They are therefore left unmerged. Neither original respondent-level coefficient estimates, nor invented survey responses appear anywhere in the manuscript. Collecting one coherent dataset, or else supplying a raw file in which operational-efficiency, resource-utilization, waste-reduction, and environmental-performance indicators are measured on the same respondents, is the appropriate next empirical step.

4.6 Data Screening and Preliminary Analysis

Screening of the final primary dataset should precede SEM estimation. Incomplete responses, coding errors, duplicate records, outliers, straight-lining, improbable completion times, missing-value patterns, inconsistent eligibility responses, and reverse-coded items where applicable should all be identified in the audit. Inspection should cover kurtosis, skewness, ranges, frequency distributions, and descriptive statistics. Tolerance and VIF should be used to assess multicollinearity, while common-method bias should be handled through clear instructions, anonymous administration, predictor and outcome sections kept apart, and a statistical diagnostic, full-collinearity VIF or a factor-based test among them. Only after those checks have been carried out in practice should the final manuscript report the number of excluded cases and the final usable sample.

4.7 Validity, Reliability, and Ethics

Expert review should establish content validity, with CFA or PLS measurement-model assessment to follow. Approximately 0.70 or higher is the conventional internal-consistency benchmark for composite reliability and Cronbach's alpha, while AVE serves convergent validity and HTMT discriminant validity. Institutional ethical approval should be obtained where required for the final study, informed consent used, voluntary withdrawal permitted, unnecessary identifiers left uncollected, and data stored securely. Unless the underlying documentation exists, no response rate, ethics approval number, pilot reliability coefficient, or final sample size should appear in the article.

5 RESULTS

The unestimated structural model and the verified empirical benchmarks are deliberately kept apart in this section. Traceability of every empirical value to a real source, as the study protocol requires, is preserved by that separation. Sustainability research of a quantitative kind is demonstrably feasible at substantial scale in Bangladesh on the available evidence, yet no shared respondent-level dataset holding every proposed construct is exposed by the sources located during preparation of this manuscript. Real external evidence is therefore what Table 2 and Figures 2–4 summarize; they are not offered as results produced by the present model.

Table 2. Verified Bangladesh quantitative evidence relevant to the proposed sustainability decision model

Source	**Context / sample**	**Method**	**Relevant empirical contribution**	**Use in present article**
Habib et al. (2022)	403 garment-manufacturing firms	CFA + SEM	GSCM linked to environmental, economic and operational performance; higher-order GSCM structure supported.	Supports green practice → performance logic.
Islam et al. (2024)	303 managers, green garment firms	PLS-SEM	Sustainable supply chain management and circular economy modeled as antecedents of sustainable performance.	Supports circularity and supply-chain pathways.
Islam et al. (2024)	450 textile employees	AMOS SEM	GHRM/GSCM examined environmental and employee performance mechanisms.	Supports mediator-based sustainability modeling.
Ali et al. (2026)	423 personnel across 21 RMG factories	Mixed-method factory study	LEED adoption shaped by buyer pressure, management commitment, finance and technical capacity; practice adoption varied across factories.	Benchmarks concrete resource/waste practices.
Hossain et al. (2026)	2,172 apparel-producing firms	Two-stage DEA + second-stage models	Labor and capital productivity were positively related to environmental efficiency; effects varied by organizational conditions.	Directly motivates operational-efficiency pathway.
Siddiqi et al. (2026)	364 supply-chain professionals	SEM; SAV file listed	GSCM and supply-chain integration are linked to sustainable organizational	Confirms availability of an open Bangladesh SEM dataset, but constructs differ

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			performance, with sustainability management accounting as a mediator.	from present model.

Figure 2. Sample sizes reported in verified Bangladesh apparel/textile quantitative studies relevant to the model.

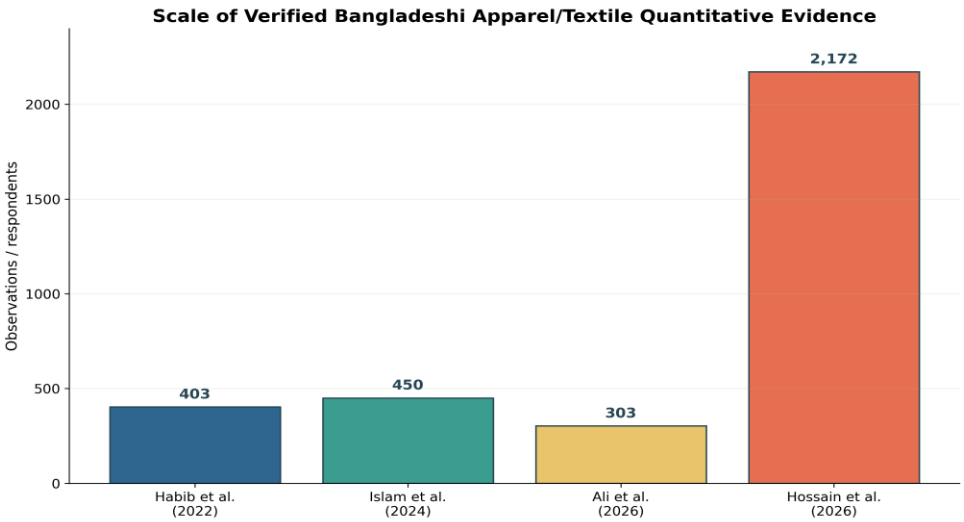
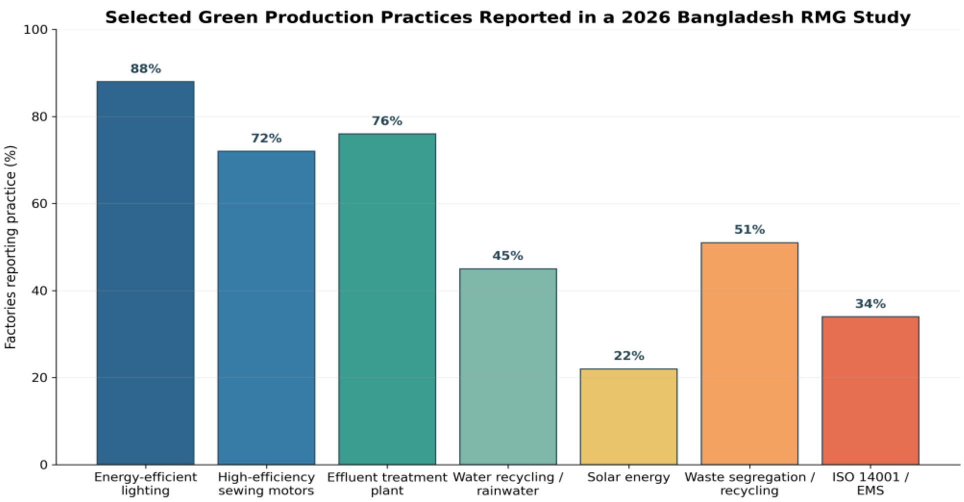


Figure 3. Selected green production practices reported in a 2026 Bangladesh ready-made-garment factory study



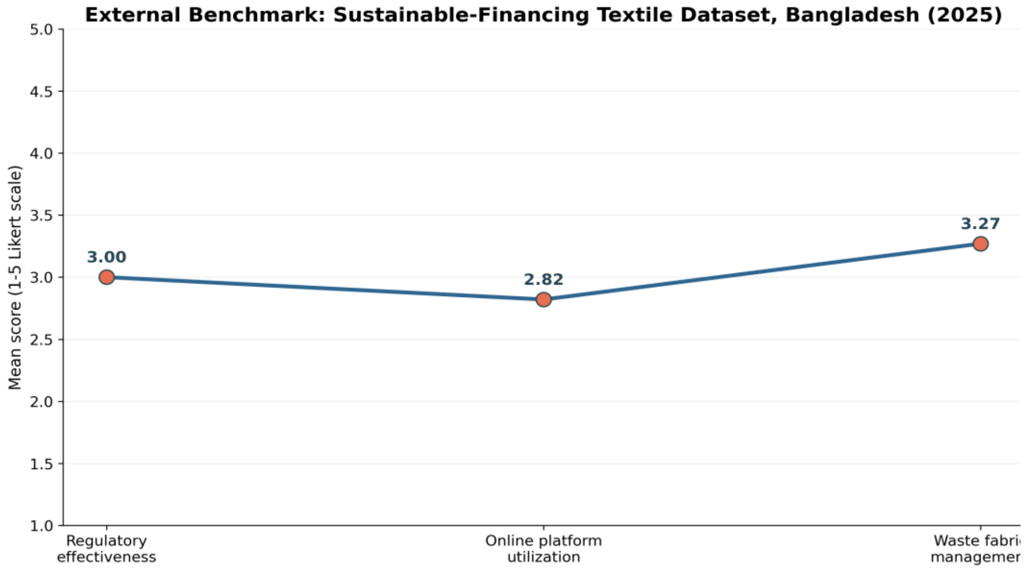
5.1 External Benchmarking of Resource and Waste Practices

Adoption of production practices bearing directly on the proposed constructs was measured and reported by Ali et al. (2026). The reported figures were 88% of factories for energy-efficient lighting, 72% for high-efficiency sewing motors, 76% for effluent-treatment plants, 45% for water recycling or rainwater harvesting, 22% for solar energy, 51% for waste segregation or recycling, and 34% for ISO 14001 or environmental-management systems. Waste and resource mechanisms can thus be given operational form in factory terms instead of by way of an abstract index of sustainability. Management commitment and buyer requirements were further reported by that study as important enabling conditions, whereas finance and technical capacity acted as constraints on smaller and non-export-oriented factories. Since those observations originate in an external study having its own design at factory level, they serve here as benchmarks and not as re-estimated model inputs.

5.2 External Benchmark: Textile Sustainability-Financing Indicators

Mean scores of approximately 3.00 for regulatory effectiveness, 2.82 for online platform utilization, and 3.27 for waste fabric management, all on a five-point Likert scale, are reported in a separate Mendeley Data record published in 2025. Moderate implementation conditions are indicated by these values, which position waste fabric management ahead of the other two dimensions reported in that dataset. Because its construct architecture differs, no merger of the dataset with the proposed model is undertaken. It appears solely as an external benchmark, transparently offered, for the logic of measurement surrounding enabling conditions and waste management.

Figure 4. Mean scores reported in the 2025 Bangladesh textile sustainable-financing dataset (five-point Likert



5.3 Hypothesis Testing Boundary

Absent a coherent respondent-level dataset in which the proposed item measures appear, no original beta coefficients, standard errors, p-values, confidence intervals, R^2 values, or indirect effects can be assigned to H1–H6 out of the evidence assembled here. The hypothesized pathways are supported by prior empirical literature; however, coefficients from separate studies cannot be transferred to the proposed model. Accordingly, no original SmartPLS or AMOS estimates are reported without a common respondent-level dataset, and external benchmark values are interpreted only as contextual evidence rather than as estimates of the proposed structural model.

Table 3. External benchmark values used without pooling or re-estimation

Benchmark	Observed value	Unit / scale	Source	Interpretive role
Energy-efficient lighting adoption	88	% of surveyed factories	Ali et al. (2026)	Resource-efficiency practice benchmark
High-efficiency sewing motor adoption	72	% of surveyed factories	Ali et al. (2026)	Operational energy-efficiency benchmark

Waste segregation / recycling	51	% of surveyed factories	Ali et al. (2026)	Waste-reduction benchmark
Water recycling / rainwater	45	% of surveyed factories	Ali et al. (2026)	Water-utilization benchmark
Waste fabric management mean	3.27	5-point Likert	Mohiuddin et al. (2025)	External measurement benchmark
Online platform utilization mean	2.82	5-point Likert	Mohiuddin et al. (2025)	External digital-enabling benchmark

5.4 Evidence-to-Hypothesis Alignment

Table 4. Mapping of hypotheses to verified evidence and required original estimation

Hypothesis	**Empirical support already documented**	**What remains to be estimated**	**Status**
H1	Productivity and environmental-efficiency evidence link operating productivity with environmental outcomes.	Operational efficiency → resource utilization path using common respondent measures.	Not estimated
H2	Green production and factory evidence link process practices with waste-related improvements.	Operational efficiency → waste reduction path.	Not estimated
H3	GSCM and resource-efficiency literature links resource practices with environmental performance.	Resource utilization → environmental performance path.	Not estimated
H4	GSCM, circular-economy and waste-management evidence supports environmental benefits of waste prevention/recovery.	Waste reduction → environmental performance path.	Not estimated
H5	Mediation has been reported in adjacent Bangladesh sustainability models.	Indirect effect through resource utilization within the present model.	Not estimated
H6	Mediation logic is consistent with the NRBV and adjacent sustainability studies.	Indirect effect through waste reduction within the present model.	Not estimated

6 DISCUSSION

A narrower reading of decision-making about sustainability in apparel manufacturing is what the assembled evidence supports: measurable production mechanisms should be what connects operational capability to environmental outcomes. Associations between sustainability outcomes and green supply chain management, circular economy, certification, environmental capability, and organizational practices are already demonstrated in the Bangladesh literature. Less settled is the causal architecture as it stands at the operating level. Instead of embedding resource utilization and waste reduction inside a broad sustainability score, the proposed model makes them explicit. That distinction carries weight because energy use, material yield, defect rates, water use, rework, recovery, waste segregation, and disposal are the subject of daily factory decisions, and operational indicators can track them.

Theory is the concern of the first contribution. Precision accrues to the Natural-Resource-Based View once the abstract logic of capability it carries is rendered as a measurable operating sequence: organizational capacity is created by efficiency, intermediate routines are represented by resource utilization and waste reduction, and the downstream environmental consequence is captured by environmental performance. Broad environmental strategy is what Hart's (1995) framework is commonly invoked to explain; a mechanism testable inside a production context is what the present model specifies. Productivity is also not equated with environmental improvement in the model, a caution consistent with environmental-efficiency research, in which input productivity, efficiency scores, scale effects, and undesirable outputs are held apart. Managers, by implication, should not read environmental progress of conventional productivity metrics or output growth alone.

Empirical and contextual matters occupy the second contribution. Advanced quantitative methods and large samples are shown by the verified Bangladesh studies to be feasible already within textile and apparel research: SEM was applied to 403 garment firms, PLS-SEM to 303 managers, AMOS-based SEM to 450 textile employees, and a two-stage environmental-efficiency design to 2,172 apparel firms. Considerable variation in measurable factory practices is demonstrated by the latest LEED evidence, while heterogeneous relationships linking organizational practices to environmental efficiency are reported in the 2026 firm-level efficiency study. Value could accordingly be added by one multi-construct respondent dataset held in common, bringing operational efficiency together with waste, resource use, and environmental performance onto a single measurement scale.

Method is the substance of the third contribution. Pairing CB-SEM with PLS-SEM is defensible given that the questions are theory-testing and prediction-oriented at once. ANN has value as a secondary predictive extension and nothing more. Sequencing the methods this way forestalls a familiar problem within applied studies of sustainability, namely the use of a prediction method of great flexibility as a substitute for theoretical explanation. Measurement quality and directional relationships should be established first by the primary model, and only afterwards should nonlinear or predictive extensions be interpreted. Bootstrapping stability, alternative structural specifications, PLSpredict, and group comparisons should likewise be reported in the final study only where measurement invariance and the data warrant it.

A straightforward decision order is implied by the model in practice. Production-efficiency indicators that expose avoidable losses directly should be put in place first by factory managers, then tied to energy, material, and water-use metrics, and those resource metrics in turn linked to environmental outcomes and waste streams. Treating equipment upgrades, recycling, or certification as stand-alone sustainability projects is not the intention. Every intervention should instead be judged by the effect it has on the operating mechanism, that is, whether resource intensity falls, material yield rises, defects and rework decline, or waste is prevented. Green-finance criteria and supplier assessments can be designed on the same logic by buyers and policymakers, since operational capabilities can be observed and acted on more readily than broad claims about sustainability.

6.1 Implications of the Study

Three practical implications follow from the study. The first is that operational-efficiency indicators belong alongside resource and waste indicators on apparel-factory sustainability dashboards, rather than environmental performance being reported on its own. The second is that projects yielding changes traceable in waste generation or resource intensity deserve priority in incentive programs, whereby environmental benefits become auditable at process level. The third is that a

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shared respondent-level battery of measures covering operational efficiency, resource utilization, waste reduction, and environmental performance should be developed by researchers and industry associations, so that SEM comparisons across factories become possible.

6.2 Acknowledgment of Limitations

At the center of the limitations is the evidence boundary. One openly licensed SAV file and large Bangladesh datasets are identified in verified public records, yet any single respondent-level dataset holding precisely the four latent constructs proposed here goes unexposed by the available sources. No honest claim regarding predictive accuracy, model fitness, mediation size, hypothesis significance, or original SEM coefficients can therefore be made in the article. Being cross-sectional, moreover, the conceptual model could not establish causality in time even once primary data had been collected. Common-method and social-desirability bias may enter through self-report measurement, while generalization may be constrained by buyer requirements, factory heterogeneity, technology differences, and product mix.

6.3 Suggestions for Future Research

One Bangladesh apparel dataset, longitudinal or repeated cross-sectional, should be collected in future research, carrying firm-level identifiers together with harmonized measures of the four constructs, namely operational efficiency, resource utilization, waste reduction, and environmental performance, alongside technology adoption, export orientation, and firm size. Invariance of measurement across factories that are small, medium, and large should then be tested as a second step, before structural paths are compared. Linking responses from the survey to objective plant metrics, among them water per kilogram of fabric, energy per garment, defect rates, cutting utilization, waste per unit of output, and recycled-material share, constitutes a third step. Perception-based sustainability assessment would give way, through such linkage, to operating performance that can be measured, and the mediation hypotheses could be examined with stronger causal credibility.

7 CONCLUSION

The textile manufacturing sector in Bangladesh cannot dissociate environmental advancements from the production decisions that dictate the flow of materials, energy, water, labour, and waste within industrial processes. This research aimed to develop a sustainability decision model that can be experimentally validated, elucidating environmental performance via the interrelated functions of operational efficiency, resource use, and waste minimisation. The initial study inquiry investigated if enhanced operational efficiency correlates with better resource utilisation and diminished waste. The compiled evidence from Bangladesh corroborates the suggested trajectory of both relationships, suggesting that disciplined production methods, enhancements in productivity, input regulation, and minimised process losses offer a plausible foundation for Hypotheses 1 and 2; nonetheless, their effect sizes and statistical significance are yet to be established within the proposed framework. The second study inquiry examined the correlation between resource utilisation and waste minimisation with environmental performance. Current factory-level and sustainability data consistently corroborate the rationale for Hypotheses 3 and 4, whereas recorded disparities in energy efficiency, water management, recycling, and waste practices indicate that these mechanisms can be monitored and regulated at the production level. These associations, however, continue to be hypotheses necessitating evaluation from a singular matched dataset instead of validated outcomes produced by this research. The third research inquiry examined if the use of resources and minimisation of waste conveys the impact of operational efficiency on environmental performance. Theoretical rationale and previous mediation findings offer a robust foundation for the two indirect routes indicated by Hypotheses 5 and 6; however, the current evidence fails to determine the extent, importance, or comparative strength of either mediating process. Consequently, the primary outcome is not the statistical validation of six structural connections; rather, it is the formulation of a coherent and verifiable mechanism that specifies precisely what needs to be assessed to ascertain if operational efficiency yields environmental benefits via enhanced resource productivity and reduced waste. This mechanism is the primary theoretical contribution of the study by converting the Natural-Resource-Based View from a general capabilities' perspective into a factory-level series of specific, quantifiable operational elements. Its methodological contribution is rooted in establishing a systematic analytical sequence where the evaluation of measurement quality and theory validation occur prior to assessing predictive robustness and nonlinear forecasting, so ensuring that predictive methods do not replace structural elucidation. Its contextual significance lies in the amalgamation of operational efficiency, resource allocation, waste minimisation, and environmental performance within a singular framework of Bangladesh's garment industry, where prior evidence is fragmented across several constructs, samples, and analytical tiers. Factory managers must incorporate indicators of production efficiency, material yield, energy consumption, water usage, defects, rework, and waste into a unified sustainability performance framework and assess expenditures based on quantifiable alterations in these operational results. Policymakers and purchasers ought to focus green incentives, funding standards, and supplier evaluations on initiatives that exhibit verifiable decreases in resource consumption or waste, rather than solely depending on general sustainability labels or certification credentials. Scholars and industry organisations ought to create a unified measurement tool encompassing all four dimensions to enable consistent comparisons of factories using standardised definitions and metrics. These suggestions should be constrained by the study's restrictions. No existing respondent-level dataset encompasses all four constructs for identical organisations, thus the suggested structural relationships remain unquantified; a cross-sectional design fails to determine temporal causality; self-reported metrics may introduce common-method and social-desirability biases; and factory heterogeneity may limit generalisability. Subsequent investigations ought to tackle these limitations by acquiring longitudinal or repeatedly cross-sectional data on the Bangladeshi apparel sector with standardised metrics, assessing measurement invariance across varying factory sizes, and correlating survey feedback with objective plant metrics such as energy consumption per garment, water usage intensity, defect rates, cutting efficiency, waste per output unit, and proportion of recycled materials. Such evidence would enable thorough examinations of the six hypotheses, facilitate comparisons between the two mediation routes, and enhance the assessment of whether operational enhancements result in environmental benefits. The primary revelation of this research is that efficiency by itself cannot be indicative of sustainability; it is essential to exhibit environmental value through the resource and waste processes that underpin efficiency. Creating and evaluating the operational framework provides a robust basis for more reliable research, more factory oversight, and more focused sustainability initiatives in Bangladesh's garment industry.

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