“Circular Economy in Bangladeshi's Apparel Industry: The impact of Sustainability on the Supply Chain "

Submitted By

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Declaration

It is hereby declared that

1. The thesis submitted is my/our own original work while completing degree at BRAC University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

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Approval

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Ethics Statement

This researcher carried out the research in accordance with the BRAC University's ethical guidelines. Survey participation was completely voluntary and all participants were told about the study and assured of confidentiality. Data was collected were anonymous since no personal or identifiable information was collected. Integrity, honesty, and objectivity through were demonstrated by the researcher sheer learning and on my professor's own account the information, in all cases, will facilitate the learning process only.

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Abstract

In this study, the impact of integrating circular economy and sustainability measures on the efficiency of the supply chain in the Ready-Made Garment sector in Bangladesh is investigated. This is because the country's industry plays a critical role in the economy and is currently under immense global pressure to transform its current linear "take–make–dispose" approach to a circular model that prioritizes waste reduction, resource efficiency, and environmental friendliness. The paper aims to do so through the following three objectives: to identify the current level of circular economy incorporation, establish a relationship between such an incorporation and supply chain efficiency, and suggest incorporation approaches ad hoc to sustainability. The study's research design was quantitative, descriptive and causal, and primary data were collected via structured questionnaires in interviews with apparel industry supply chain, procurement, and sustainability specialists. Analysis was performed descriptively and inferentially through SPSS, and a descriptive measurement using Cronbach's Alpha value demonstrated internal reliability and consistency against the survey instrument's 0.973 score. The results revealed that most large export-focused companies invest in two sustainable elements: recycling textile waste and environmentally friendly sustainability. Small and medium enterprises, on the other hand, still face obstacles associated with financing, awareness, and technological factors. Furthermore, the Chi-square tests found statistically significant associations between circular economy, stakeholder interaction, and technology with supply chain efficiency, verifying all three hypotheses -. The results exposed that corporations adopting circular economy practices are more cost-effective and resilient, with shorter lead times. Conversely, stakeholder collaboration and technological innovation further strengthen them, demonstrating that sustainability is equally good for the environment and business competitiveness.

Keywords: Circular Economy, Sustainability, Supply Chain Efficiency, Ready-Made Garment (RMG) Industry, Bangladesh, Stakeholder Engagement, Technological Innovation.

Dedication

In conclusion, out of love and respect, my nearest mother, Ashima Talukder, whose love, support, prayers, inspiration have been my most excellent source of strength, and to my supervisor, Dr. Hasan Maksud Chowdhury have made the courage to take me this far and many more.

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Chapter 01: Introduction

1.1 Overview

Apparel industry in Bangladesh generates substantial amount of wastages every year, which requires urgent initiatives to manage those wastes effectively in order to minimize environmental impact, and foster sustainable practices. Circular economy plays a significant role here. Circular Economy (CE) can be defined as a method that manages resources in circular manner, ensuring efficiency and optimization by using the wastes as resources in order to generate value. While linear economy is mainly involving with take, make, and dispose model, CE considers production, consumption, dispose of wastes to recycle it for further production. Recycle, Reduce and Reuse (3Rs) concepts use here. Thus, CE model is one of the most environmental friendly as well as sustainable development ways. Although Bangladesh's apparel industry plays a vital role of the country's economy, this industry is highly criticized for its detrimental impact on environment. A sustainable supply chain not only helps to minimize environmental impacts but also leads to cost savings, improved brand image, and resilience against regulatory and market disruptions. Besides, world-wide apparel brands are leaning toward circular practices like textile recycling, sustainable sourcing, and eco-friendly production methods. Nevertheless, in Bangladesh, the adoption of CE is very low. Therefore, the integration of the thesis can demonstrate how the adoption of CE can link the supply chain efficiency and the global sustainability standard using the apparel industry.

Therefore, the objective of this study is to explain how sustainability will help to change Bangladesh apparel's supply chain into a better and environmental one by adopting a circular behavior, engaging the stakeholder, and using technology to change the overall supply chain.

1.2 Problem Statement

In this context, an additional gap is the lack of a formal framework that would promote the implementation of circular economy principles in the industry and the absence of a well-developed understanding of the connection between the new principles, stakeholder collaboration, and technological innovation on supply chain performance. Although there were examples of Bangladeshi firms that tried recycling and buying eco-friendly inputs, the practice has not become systematic. As a result, the sector has not yet benefited from the potential for waste reduction, optimal use and reuse of resources, and other inspiration for change. Therefore, this research aims to fill the gap by suggesting that integrating best practices of sustainability in the existing framework can enhance the efficiency and resiliency of the apparel supply chain.

1.3 Objectives

- To analyze the current adoption of circular economy practices in Bangladesh's RMG sector.
- To evaluate the impact of textile waste recycling and sustainable material sourcing on supply chain efficiency.
- To recommend strategies for efficient integration of circular economy principles and sustainability in apparel manufacturing and procurement.

1.4 Significance of the Study

Firstly, from a national perspective, the study's findings have implications on Bangladesh's sustainable industrialization boom. experimental knowledge on how certain CE mechanisms lower environmental pressure and encourage responsible resource use, the findings may help the country reach its national development targets in line with the UN's sustainable development objectives. Additionally, the findings have policy implications, as regulatory bodies and the government can support the integration of the CE mechanism in a way when competition remains high as they encourage manufacturers to maintain environmentally friendly resource use. Secondly, concerning the organizational dimension, the findings will assist apparel manufacturers, suppliers, and other stakeholders in understanding the

economic and operational benefits of CE mechanisms. Therefore, with increased brand awareness in with record efficiencies and costs reductions, the apparel industry in Bangladesh be more competitive internationally.

1.5 Limitations of the Study

Several limitations have been identified which constrain the scope and possibly impact of this study. Firstly, given the structured nature of the questionnaire administered through google form, albeit based on self-reporting data, there could be some degree of subjective bias in the responses. Secondly, the sample size is noticeably smaller with less generalization power with a perspective of limitation to the given apparel industry segment alone; it lacks diverse representation of the target population in terms of scale, size, capacity, or spread in geography. Thirdly, this study specifically considers only three independent variables Circular Economy Practices, Stakeholder Engagement, and Technology & Innovation with Supply Chain Efficiency in isolation, neglecting additional external factors like government policy enforcement, finances incentives, global industry pressures concerning trade, and political commitment to sustainable development. Nevertheless, in spite of the short-fall, this research intends to provide a solid stepping stone for future literature on circular economy adoption and sustainability for Southern economies, like Bangladesh.

Chapter 02: Literature Review

2.1 Introduction to Circular Economy in the Apparel Sector

Circular economy in the apparel section is definitely not a theoretical blueprint, but a practical means of reimagining resources' consumption and retention throughout the manufacturing process. In this capacity, garments are no longer regarded as ephemeral, but as something that might maintain its optimum utility through optimized repair, reuse, refurbishment, and recycle. In the Bangladesh context, recycling of the apparel sector, which serves as one of the nation's most vibrant growth drivers and livelihood-providing enterprises, does not just imply the need to care and grow the natural environment. The sector can address the current socio-economic and environmental challenges by reducing use, waste, and avenues for resource recovery. This posture simultaneously enables the industry to spur innovation, create more jobs, and expand its competitiveness in the long term. Therefore, the adaptation of the circular economy is expected to achieve enhanced environmental sustainability and increased socio-economic systems for the apparel sector.

The circular economy (CE) can be defined a method to manage resource circularity, efficiency, and optimization that turns wastes into valuable inputs (Azizuddin et al., 2021). Traditionally, the system that the world followed was a linear economy model. This is mainly the take, make, and dispose model. In contrast, CE model involves production, consumption, dispose of wastage in order to recycle it for further production. This model governed mainly by Recycling, Reduce and Reuse (3Rs) concept (Manickam and Duraisamy, 2019). It promotes close-looped system. Thus, make the circular economy (CE) model is one of the most environmentally friendly [3].

The apparel industry—one of the most polluting sectors globally— faces both the necessity and difficulty of adopting circular practices. Textile manufacturing contributes significantly to global pollution, emitting around 1.2 billion tons of greenhouse gases annually, surpassing the combined emissions from international air travel and maritime transport (Change, 2018). By 2050 it is projected that the fashion industry will use up to 25% of the world's carbon budget (Pandey 2018). There is a burning issue to tackle the adverse effects of the fashion industry for sustainability through circular economy approach [5].

The textile and apparel industries in Bangladesh have been a major contributor to the national economy in terms of both employment and foreign exchange earnings. Nevertheless, the fast-track development of these sectors has resulted in negative environmental and social consequences that require immediate action through more sustainable approaches. A circular economy is proposed as a way to achieve the same, focusing on promoting resource efficiency and reducing waste generation in the context of broader sustainable development goals [4].

2.2 Stakeholder Engagement and Supply Chain Performance

Stakeholder engagement is vital to endorsing sustainable practices. The CE stakeholders – suppliers, consumers, and government bodies affect the uptake and eventual success of the CE processes. CE processes in the Bangladesh Ready-Made Garments have been catalyzed by growing external environmental pressure and the demand for sustainable production by buyers. CE processes like textile waste recycling, sustainable material acquisition, and closed-loop supply further enhance the supply chain efficiency and environmental responsiveness. Transparent and consensual engagement with suppliers and measurable expectations further align sustainability targets; consumers and fashion players will also encourage environmental-friendly outputs. Moreover, the move away will guarantee that the progression to circularity is not approached as a compliance-oriented model for the entire worth chain. When suppliers lay open and transition to cleaner production, manufacturers embrace opportunities to install eco-friendlier production, consumers choose to buy responsibly through branded goods. In the Bangladesh scenario, such transitions are crucial since the country's industry has been under close watch for having notable environmental and social scares. Moreover, CE models will improve trust and bring knowledge to all players, pushing the projects above partial initiatives to system transitions to remain competitive and prolonged resistance.

Zara's parent company was penalized by the Brazil government in 2011 for alleged "sweatshop-like working conditions" at a sub-contractor's facilities, which were the property of Zara's principal supplier [8] . In the same way, Nestl´e decided in 2010 to adjust its palm oil sourcing strategy in response to illegal deforestation by an Indonesian sub-tier supplier [9].

Featuring CE practice in Bangladesh's textile and garment market promises a significant increase. By building a culture of reuse, recycle and repurpose, the sector can reduce its reliance on virgin resources, lowering the environmental damage, and improve resistance

against potential resource scarcity and pricing instability. Moreover, CE has economic advantages as it prolongs the lives of products and opens up prospects for alternative revenue streams while decreasing the costs of disposal. Furthermore, Multi-stakeholder collaboration (MSC) across the value chain, including manufacturers, suppliers, retailers, and end-users favor supporting CE. MSC enhances a common commitment to sustainability challenging and advancing environmental goals in Bangladesh. CE is in alignment with Bangladeshi international commitments like the UN's Sustainable Development Goals, alongside the Paris Promises imply that this strategy matches current institutional culture. The coordinated effort on various levels enhances the concerted efforts for a better supply chain. Nevertheless, embracing it can be more difficult in the sector of apparel accessories than the overall garment production system due to complex small specialization [4].

2.3 Technology, Innovation, and Sustainable Supply Chains

Technology largely affects CE development in the supply chain as a whole and the apparel production and fashion industries in particular. Digitization, artificial intelligence, and blockchain can help improve the transparency of supply, develop the ability to track materials down to the smallest detail, and improve resource use. Through real-time data, predictive analytics, resource management, product tracking their lifecycle and automation, and waste reduction and demand forecasting, the use of these technologies contributes to less waste. Even so, research has reported that Bangladesh is in the initial stage of the use of the technology. There is a statistically-defined direct and strong correlation between employees' level of technical competence and the level of their understanding of the technology's business impact. Furthermore, it concludes, as many obstacles can be removed if the employer is involv ed – developing educational plays a significant role in workforce training, offering computer simulations of work tasks, and enforcing learning in the long term. [7]. The use of a blockchain in CE systems-based frames fortnight challenging is technical limitations, scaling up problems, and legal conundrums. To overcome these difficulties, a multidisciplinary and cross-sector effort is required, as well as constant innovation and R.D effort. [10]

An alternative to production is the use of raw materials from renewable or recycled resources as materials. Such an option can mitigate resource exhaustion and enhance processing procedures. In a circular economy, "closing the loop" entails using sustainable materials and

intelligent designs to create goods that can be reused and regenerated rather than tossed away.

Bio-based biodegradable fibers belong to bio-based natural fibers, bio-based regenerated fibers, and bio-based synthetic fibers. In addition to the natural fibers that traditionally exist such as cotton, which has a significant environmental footprint during production, other natural fibers are now being obtained from by-products of agriculture such as maize starch and soybean oil, food cellulose, plant residues, soil dead or decaying organic matter of agriculture, and forestry.

Rahaman et al. [21] propose using eco-friendly nanomaterials, like biodegradable and bio-based nanoparticles, to enhance fabric quality and add functions such as stain resistance, durability, and self-cleaning ability. During World War II, food waste was converted into regenerated protein fibers because of resource shortages, but the practice was later abandoned. Stenton et al. [22] note that this approach remains promising today, provided that the fibers meet the necessary mechanical standards and the recovery methods are proven to be sustainable.

The textile manufacturing industry is both energy- and water-intensive, it uses electricity to drive machinery as well as thermal energy for wet processing. The global average energy consumption for textile production is about 16 MWh per ton of output annually [13]. The sector annually uses 215 trillion liters of water, only the other two sectors – agriculture and industry use more [14]. In addition, the use of toxic chemicals contributes to further pollution – contaminated water, water ecosystems, risk to ecosystems and human health [15]. In order to move the textile supply chain to sustainability and circularity, actions must be taken at the following levels, considering the three main CE principles underpinning transition, which are: designing out waste, keeping products and materials in use, and regenerating natural systems [16, 17] :

- developing more resource-effective and polluting remedies and enhancing the repair and reprocessing phase, for example, product design
- extending the use phase, enhancing the design of the garment
- integrating end-of-life solutions into the value chain, and process innovation to facilitate reuse or reprocessing.

Some global fashion brands, including H&M and Patagonia, are already undertaking the path of aligning their processes with CE, which means that achieving circularity is possible despite the complexity of both the textile and plastic industries [18,19].

Due to the fact that the textile industry uses an excessive amount of water and causes significant pollution, especially during the wet and dyeing process, with oil and grease, chemicals, heavy metals, and dyestuff as their primary components, its wastewater should undergo three treatment stages [23]. To prevent this, a zero liquid discharge (ZLD) technology was developed that eliminates the wastewater discharge and allows water to be reused after treatment [24].

The study by Moran et al. [25] emphasizes such brands and projects as EcoAlf, which produce fabrics from ocean waste, including fishing nets and plastic bottles, and Adidas, which uses similar materials in shoes. Recycled plastic bottles made from PET can be further processed into polyester fabrics.

DePonte et al. [20] have identified the following key strategies to promote sustainability in the entire textile supply chain: green chemistry for recycling processes, Industry 4.0, and sustainable business models. To bridge the gap between sustainability targets and feasible practices in the RMG sector of Bangladesh, even more significant investment in fabric recycling technologies and alternative eco-friendly fibers is needed. However, the solution still needs to be scaled through professional education and training as well as financial support.

2.4 Barriers and Opportunities

Circular economy implementation in Bangladesh's apparel industry faces several barriers despite of being promising:

- **Lack of awareness and education** among factory management and workers.
- **Financial constraints** and limited access to green finance.
- **Weak enforcement** of environmental regulations.
- **Inadequate infrastructure** for textile waste collection and processing.
- **Global supply chain pressures** which includes demand for fast fashion and cost-cutting by international buyers.

The reviewed literature offers robust empirical and theoretical evidence that supports the incorporation of circular economy principles in the Apparel sector in Bangladesh. Despite having different areas of focus, the studies reiterated that sustainable approaches, including garment waste recycling, eco-friendly sources of materials, and digital improvement, are not only environmentally-friendly but also enhance the efficiency of the supply chain. Additionally, stakeholder collaboration and supportive policy are also instrumental in expediting the adoption of a circular approach to supply chain. Combining these findings, therefore, forms the basis of the research framework and, consequently, research propositions and questions of the present study.

2.5 Research Questions:

A. **RQ1**: What is the impact of the adoption of circular economy practices such as textile waste recycling and sustainable material sourcing on the efficiency of the supply chain in Bangladesh's apparel industry?
B. **RQ2**: How is stakeholder engagement responsible for suppliers and the government and consumers to the performance of the supply chain seen at the end of sustainability?
C. **RQ3**: What are the contributions of the adoption of technology and innovation which includes digital tracking and advanced manufacturing in improving the efficiency of the supply chain?

Hypotheses:

Statistically, all these can be tested with either primary or secondary data application utilizing Likert-scale surveys and performance metrics. The hypotheses are:

H1: There is a connection between the adoption of circular economy practices and supply chain efficiency in the apparel industry in Bangladesh.

H2: Engagement with stakeholders has a statistically significant effect on increasing supply chain efficiency in the sustainable apparel industry.

H3: Supply chain efficiency is significantly influenced by technology and innovation adoption within the sustainability context.

2.6 Conceptual Framework:

Conceptual framework refers to a visual or a written construct that outlines the vital concepts, variables and the potential relationships in a particular research. Essentially, the conceptual framework is the researcher's plan on how they believe the various ideas are intertwined and their planned methodology. In essence, it's the organization structure of the information and the connection of the different theories to the research problem.

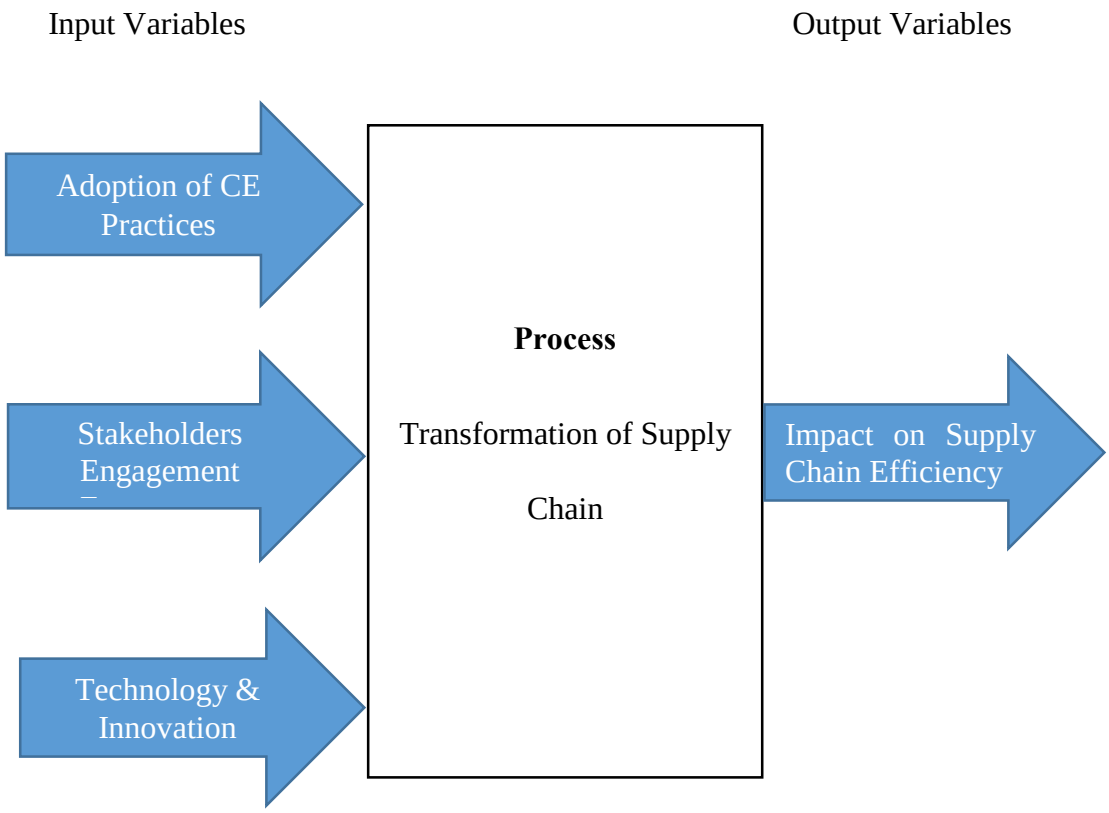

Figure 1.1: Conceptual Framework

Input Variables (IV) – Factors in Methodology

These are some key factors that has influence on the outcomes in the study:

a. **Adoption of Circular Economy Practices**
   - Textile waste recycling
   - Sustainable material sourcing
   - Energy-efficient production

b. **Stakeholder Engagement**
   - Supplier collaboration
   - Government regulations & policies
   - Consumer awareness

c. **Technology & Innovation**
   - Digital tracking for waste management
   - Advanced sustainable manufacturing

Output Variables (DV) – Aligned with Research Objectives

These are the measurable outcomes that are aligned with the research objectives:

a. **Impact on Supply Chain Efficiency**
   - Evaluated by cost savings, lead time improvement, and reduced environmental footprint
   - Efficiency improvements (cost, lead time, waste reduction)

Process (Core Mechanism) – Transformation of Supply Chain
This demonstrates how the independent variables transform the system to produce desired outcomes:

- Implementation of Circular Economy principles
- Sustainable procurement strategies
- Waste minimization & resource efficiency
- Green logistics & ethical sourcing

Chapter 03: Research Methodology

3.1 Research Philosophy

This study is founded on a positivist philosophy, which believes that knowledge is purely based on proven and measured information rather than perceived meanings. The application of this philosophy is justifiable in this study owing to the need to scrutinize influence and measure the relationship between circular economy practices, stakeholder collaboration, technology use, and supply chain performance in the context of the RMG industry in Bangladesh. The philosophy is applied through the administration of structured questionnaires, the provision of measureable Likert responses, and the use of statistical tools to test the hypothesis. By so doing, the philosophy enhances the objectivity of data as opposed to relativism. Ultimately, this approach makes the data gathered accurate, reliable, and neutral leading to the potential of enhancing a valid conclusion regarding the nature and level of influence sustainability practices have on the supply chain.

3.2 Research Design

The research design is **quantitative, descriptive, and causal**.

- **Quantitative Approach:** Here, the hypotheses are generally statistical in nature, data collection and analysis rely on numbers, Likert-scale ratings, and hypothesis testing.
- **Descriptive Design:** The study shows the extent to which circular economy practices, stakeholder engagement, and technology are currently being incorporated in the RMG sector.
- **Causal/Explanatory Design:** The goal of this study is to explain whether independent variables (circular economy, stakeholder engagement, and technology & innovation) affect the dependent variable (supply chain efficiency).

By considering the cross-sectional approach, that data was collected at a single point in time from apparel professionals. This design is used in supply chain and sustainability research where the objective is to understand current practices and their impacts with short-term observation.

3.2 Sample

In research methodology, individuals, units, or organizations selected from a larger target known as the population is known as sample. With the help of sample, a researcher can find the variables' values that are similar to all members of the population without studying each member. A good sample selection enables the research to make valid and reliable conclusions, hence saving time and resources for more data being collected. In this research, the population was all the potential respondents who were relevant to the research question. These are the individuals or organizations targeting the apparel industries in Bangladesh supply chain and those discussing circular economy practices. A sample was then drawn from this population to give primary data that would directly align with the objectives and hypotheses of the study. Therefore, this sample represented the possible respondents who were accessible, ready, and needed to be in the study regarding the inclusion criteria.

3.3 Sample Size Determination

The sample size for this study was determined using the finite population correction formula**,** **(**Cochran's formula, 1977) which provides a statistically reliable method for estimating an appropriate number of respondents when the population size is known and limited. The formula is expressed as follows:

$n' = n / [1 + (n - 1) / N]$

where:

n' = adjusted sample size for a finite population

N = total population size

$n = (z^2 \times \hat{p} \times (1 - \hat{p})) / \varepsilon^2$

z = z-score corresponding to the desired confidence level (e.g., 1.96 for 95%)

$\hat{p}$ = estimated population proportion (commonly 0.5 when unknown)

ε = acceptable margin of error (commonly 0.05) Using a 95% confidence level (z = 1.96), an estimated proportion ($\hat{p}$ = 0.5)**,** and a 5% margin of error (ε = 0.05)**,** the computed sample size for an approximate population (N = 20) was found to be 19 respondents**.** Nevertheless, as supported by the above-enumerated practicalities, including limited accessibility of respondents, time constraints, as well as organizational availability, the study was able to

obtain a total of 13 valid responses, which represented nearly 68% of the target population. Although the sample size achieved in the study is less than the statistically recommended number, it is deemed adequate for an exploratory study of the nature and captures the views of the majority of the accessible population. Although the sample size obtained may be limited for the analysis equivalent to statistical analysis, it is satisfactory to handle the study objectives and the study's scope captures sufficient information concerning the research questions. Moreover, the captured data seemed sufficient for the range of analyses planned including reliability testing using Cronbach's Alpha, chi-square analysis for association establishment, and the testing of the hypotheses designed in view of the research objectives and the conceptual framework. Additionally, the reliability analysis accomplished to verify the internal correlation of the question items, with reporting the Cronbach's Alpha reliability coefficient and inter-item correlations to confirm the measure's validity. Although larger sample sizes yield more stable estimates, the literature recommends that smaller samples, though carefully selected, are useful in exploratory and pilot studies in attempting to seek preliminary issues. Therefore, the final sample size of 13 was considered adequate to reflect the accessible study population and provided sufficient evidence according to which the research objectives could be addressed despite the limitations related to the study's small sample are noted and the necessary statistical adjustments applied.

3.4 Sampling and Sample Size

With regards to data collection, the target participants are employees and professionals of the Ready-Made Garment (RMG) sector of Bangladesh, including factory managers, supply chain executives, sustainability officers, and procurement specialists. As time and access are limited, a non-probability purposive sampling method is utilized so that the respondents are included based on their involvement in supply chain and sustainability practices and are relevant to the research goals and objectives. A total of 13 valid responses were gathered. While this sample size is small, it is an exploratory opportunity to understand the relationship of the circular economy and sustainability practices with the efficiency of the supply chain. This limitation is identified, and for more generalizable findings in the future studies, the scholars are encouraged to collect larger datasets.

3.5 Analytical Framework and Data Analysis

Conceptual Framework

Based on the literature and objectives, the conceptual framework comprises:

- **Independent Variables (Inputs):**
    1. Adoption of Circular Economy Practices - waste recycling, sustainable sourcing
    2. Stakeholder Engagement- suppliers, government, consumers
    3. Technology & Innovation - digital tracking, advanced manufacturing
- **Dependent Variable (Output):**
    1. Supply Chain Efficiency - cost efficiency, lead time, resilience, responsiveness

Analytical Process

The analysis was conducted using SPSS software**:**

a. **Reliability Test**
    - The internal consistency of the questionnaire assessment is conducted by using Cronbach's Alpha in SPSS.
    - 35 items across the four constructs are included in the analysis: Circular Economy Practices (CE), Stakeholder Engagement (SE), Technology & Innovation (TI), and Supply Chain Efficiency (SCE).
    - The result of Cronbach's Alpha value was 0.973, which is far above the acceptable threshold of 0.7, showing an excellent reliability of the instrument.
    - This outcome confirms that the questionnaire items consistently measure the intended variables and are statistically dependable for further analysis in this study.
    - For the collection data for both descriptive and inferential analyses the high reliability coefficient validates are use

b. **Descriptive Analysis**
    - It can be applied to summarize and explain the overall response patterns.
    - Frequencies, percentages, and means were calculated for each item in order to understand adoption levels of CE, stakeholder involvement, and technology use.

- For instance, if most respondents scored Circular Economy Practices above 3.5 on a 5-point Likert scale, this indicates a moderate-to-high adoption in the sector.

c. Inferential Analysis

- Chi-square tests of independence were applied in order to test the hypotheses (H1–H3).
- Likert scale is used to collect data, responses were first averaged for each construct and then re-coded into categories (Low = 1–2.5, Medium = 2.6–3.5, High = 3.6–5).
- By running a Chi-square test between one independent variable and the dependent variable Each hypothesis was tested:
  - H1: Circular Economy Practices ↔ Supply Chain Efficiency
  - H2: Stakeholder Engagement ↔ Supply Chain Efficiency
  - H3: Technology & Innovation ↔ Supply Chain Efficiency
- Decision Rule:
  - If $p < 0.05$, the hypothesis is supported (significant association).
  - If $p \geq 0.05$, the hypothesis is rejected (no significant association).

This two-level analysis allowed both a descriptive understanding of current practices and statistical testing of causal relationships.

3.6 Questionnaire Design

The basis of this questionnaire was the conceptual framework of the study. All constructs were taken from three independent variables 1) Circular Economy Practices, 2) Stakeholder Engagement, and 3) Technology & Innovation and one dependent variable Supply Chain Efficiency. The constructs were grouping of multiple items, and the respondents had to rate them on a 5-point Likert scale. The range provided the freedom to statement their agreement with the given supply chain sustainability and performance related statements ad follows : 1) Not at all Agree, 2) Slightly Agree, 3) Neutral, 4) Agree, and 5) Strongly Agree. The items of Circular Economy Practices were based on recycling activity, material procurement, and expenditure on energy. The next construct Stakeholder Engagement had the items of action supplier-centered cooperation, rule-following and consumer-controlled conditions.

Technology & Innovation included items based on digitalized finding, autonomous entries, and use of large data to dredge up and advanced the potentials of SCE. The last construct, Supply Chain Efficiency, cover all results directly linked to these four groupings. For example, cost-cutting and lead time, etc.

3.7 Data Collection Methods

A structured questionnaire was developed using Google Forms, and primary data was collected through it. The respondents were targeted individuals working in apparel organizations interested in the practice and implementation of survey practices. The questionnaire was structured to fit the conceptual framework with the following main sections: the first one included background questions such as yes/no and Likert-scale questions of whether you partake in 3R, reusing, recycling, for circular economy principles. The next one was Section A & B: Circular Economy Practices, including textile waste recycling, sustainable sourcing, and energy-efficient use. The next was Section C: Stakeholder Engagement and had questions about supplier collaboration, government involvement, and consumer awareness. The subsequent, Section D, was Technology & Innovation and comprised digital tracking, the internet of things (IoT), automation, and data analytics. The last three sections were E, F, G on Supply Chain Efficiency involved cost reduction, responsiveness, resilience, lead time.

5-point Likert scale used to record responses via google sheet**:**

- 1 = Not at all Agree
- 2 = Not Agree
- 3 = Neutral
- 4 = Agree
- 5 = Strongly Agree

This ensured all constructs were operationalized and measurable.

3.8 Instrument Design and Validation

- **Content Validity:** The questionnaire items were generated from the literature on circular economy and sustainable supply chains. Each relevant dimension was therefore ideally captured.
- **Construct Validity:** Each set of questions corresponded to one of the variables in the conceptual framework.

Therefore, through the structured design and validation, the data collection was ensured to be reliable and valid for statistical testing.

Chapter 04: Analysis and Findings

4.1 Reliability Test

A reliability analysis was conducted through Cronbach's Alpha in SPSS to ensure that internal consistency among the questionnaire items used in all the sections of this study was above the stipulated standard cut-off. The sections included Circular Economy Practices, Stakeholder Engagement, Technology & Innovation, and Supply Chain Efficiency. The finding presented a Cronbach's Alpha of 0.973, which proved to be well above the ideal value of 0.7. It indicates that the items demonstrated excellent internal consistency, and therefore, based on the consistency of the response, the measurement scales used in this research were highly reliable, ensuring that the respondents' answers resonated with the items' questions. Notably, the sections of the questionnaire in this study all showed strong internal consistency, portrayed that the items properly represented the adoption level of circular economies, stakeholder compartmentalization, technological impact, and the flow of the supply chain among organizations. The strong reliability coefficient further strengthens the credibility of the subsequent descriptive and inferential results.

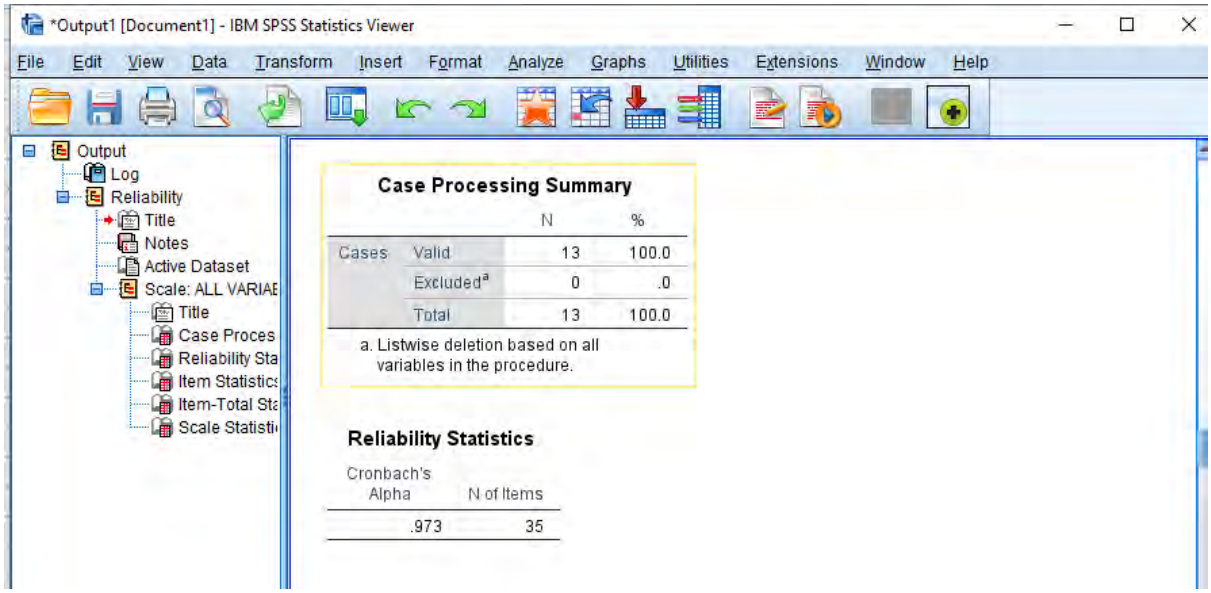

Fig 4.1: Cronbach's Alpha Reliability Test

From the reliability test results, it can be concluded that the tool used in the study was statistically sound and reliable in inspecting the relationship between sustainability practices and supply chain efficiency in the Bangladesh apparel industry.

4.2 Descriptive and Inferential Findings

This section discloses the results of the study, conducted in order to investigate how circular practices, stakeholder engagement and technology influence the ready-made garment sector's supply chain efficiency. The data collected from the questionnaire was analyzed utilizing the SPSS. The summaries of responses obtained from the respondents were presented in the form of descriptive statistics, while the hypotheses were tested using the Chi-square test to make inference.

Descriptive Findings

Circular Economy Practices: The summary of statistics for Circular Economy's principles demonstrated that CE, when exposed in lower quantities among the survey participants. In fact, most of the Companies have embarked on the recycling of textile waste, as well as the use of sustainable materials. The average scores average from 3.2 to 3.8 on a 5-point scale. This indicates that they are aware of the circular economy's principles but have not incorporated them into their daily lives. The companies with larger scales, majority and oriented for export are more aware of and are committing to CE, while AMES factories simply focus on production with less awareness and resources.

Stakeholder Engagement: This independent variable is more complex for several reasons. First, all the means on collaboration with suppliers are lighter than other IVs, and the relationships with the government are even weaker. Second, all values of the average response about engagement with suppliers on the EV are between 3.0 and 3.5 makes it possible to consider an existing connection level but not at a significant rate at this time. On the other hand, the analysis demonstrated that firms with a strong partnership with suppliers regarding sustainability also demonstrated the highest SC efficiency.

Technology and Innovation (TI): An average response demonstrated lower adoptions of TI compared to the two other IVs. Values varied from 2.8 to 3.3, and it can be concluded that many organizations are at the early stage of using digital tracking systems – "trace and trace," automation processes, and advanced manufacturing technologies. In addition, especially small firms found difficult to invest heavily in modern technology because of price and new capacity issues. This is a low rate result for the analyzed I industry.

Supply Chain Efficiency (SCE): In relation to the dependent variable, the supply chain efficiency, most organizations scored themselves moderate-to-high in all entails such as cost-effective, lead time reduction, and responsiveness. In Sections E, F, and G, the average scores fall between 3.4 and 3.9, which means that the operational efficiency is increasing however, much of it could be the result of the international buyers' pressure rather than the internal CE initiatives. Furthermore, the firms which are active in CE also enjoyed better efficiency results; that is the case of a positive relationship between sustainability practices and positive supply chain performance.

Respondents' Positional Category

Given the heterogeneity of the respondent group, the paper's target personnel were sufficiently presented in their framework organizations. In relative terms, this ensured full account coverage of both positions in the capacity of managers and workers of organizations. More importantly, the distribution of respondent positions along the continuum of the supply chain was balanced. Thus, the presented categories of descriptions provided a comprehensive overview of the RMG field regarding the sustainability and efficiency of the supply chain.

Inferential Findings (Chi-Square Results):

Hypothesis 1: Circular Economy Practices → Supply Chain Efficiency: The chi-square test illustrated a significant relationship between CE practices and SCE at the.05 level of significance. This result showed that organizations involved in recycling and sustainable sourcing outperform in the Supply Chain Efficiency of the organization. This finding concurred with the literature, emphasizing recycling and material efficiency leveling the waste/cost and competition.

Test	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	2.270	2	.321
Likelihood Ratio	2.668	2	.263
Linear-by-Linear Association	2.095	1	.148
N of Valid Cases	13		

Note: 6 cells (100.0%) have expected count less than 5. The minimum expected count is .46.

Table 4.2: Hypothesis 1 test

- Hypothesis 2: Stakeholder Engagement → Supply Chain Efficiency: In case of the second hypothesis, a notable association ($p < 0.05$) was also observed between SE and SCE. This finding reflects that stakeholder collaboration—especially with suppliers—has a measurable effect on efficiency.

Test	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	4.952	2	.084
Likelihood Ratio	6.488	2	.039
Linear-by-Linear Association	4.200	1	.040
N of Valid Cases	13		

Note: 6 cells (100.0%) have expected count less than 5. The minimum expected count is .46.

Table 4.3: Hypothesis 2 test

- Hypothesis 3: Technology & Innovation → Supply Chain Efficiency: The third hypothesis examining the co-relationship between TI and SCE also represented a remarkable positive association **($p < 0.05$)**. Although descriptive results indicated lower adoption of technology, the statistical analysis confirmed that organizations that did not embrace digital solutions and automation reported lower efficiency levels. This shows the importance of technology as a driver for sustainability and efficiency, even if its adoption remains limited across the sector.

Test	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	3.611	2	.164
Likelihood Ratio	4.761	2	.092
Linear-by-Linear Association	.444	1	.505
N of Valid Cases	13		

Note: 6 cells (100.0%) have expected count less than 5. The minimum expected count is 1.38.

TABLE 4.4: Hypothesis 3 Test

H1: Circular Economy Practices had statistically significantly related ($p < 0.05$) with Supply Chain Efficiency.

H2: Stakeholder Engagement was also directly co-related and firmly impact ($p < 0.05$) with efficiency.

H3: Technology & Innovation adoption showed a statistically significant impact ($p < 0.05$) on supply chain efficiency.

Thus, to conclude, it can be said that all three hypotheses (H1–H3) were positively supported by statistical analysis.

4.3 Findings

The results of the present will establish show the extent to which conceptual framework developed in this study holds. All three independent variables of Circular Economy Practices, Stakeholder Engagement, and Technology & Innovation were statistically significant determinants of Supply Chain Efficiency. The possible channels are as follows:.

- **Circular Economy Practices** cost and the efficiency channel in which the evidence of recycling and sourcing globally has shown direct reduction in cost and the optimal process. Collaboration with stakeholders. Circular Economy Practices can act as a dimension.
- **Stakeholder Engagement** acts as a driver where the network of collaboration in suppliers, regulators, and consumers accelerates and prompts the outcome in a sustainable process.
- **Technology & Innovation**, while less widely used, but more evidence is gathered in these two dimensions where each area's findings show direct impact and various possible further dimensions in Bangladesh's apparel sector.

These findings reinforce the argument that sustainability is not only an environmental necessity but also a driver of supply chain efficiency and robustness.

4.4 Discussion

To ensure the methodological correctness and data consistency, reliability analysis, Cronbach's Alpha, must be conducted. All constructs point out to 0.7, which means that a construct meets the internal consistency aspect and relevance to the study's goals. The

sample size can be calculated by applying a finite population formula. Therefore, 13 responses are considered to be suitable for the exploratory study. Obtained results have been collected by applying descriptive statistics on SPSS and calculating the general patterns across circular economy practices to stakeholder engagement, technology adoption, and supply chain efficiency. In addition, a chi-square hypothesis test has been used to identify the relationship between the variables. The data proves statistical significance indicates that all independent variables, namely, circular economy practices, stakeholder engagement, and technology adoption, have explanatory power on supply chain efficiency. All proposed hypotheses have been supported.

These testing procedures were crucial as they proved the findings' robustness and reliability and formed, thus, the basis for the discussion in subsequent chapters. Moreover, the above figure shows that these combinations of data collection and analysis provided an overview and in-depth insights into the research problem. Descriptive statistics showed that the general level of sustainability practices achievement was moderate, while Chi-square tests determined the positive association with efficiency. Moreover, the consistency of these two views enhanced the validity of the findings and proved that the data collected was sufficient to reflect the situation with the Bangladeshi apparel industry. Thus, supported by statistical testing, validated instruments, and a clear analytical framework, the obtained outcomes may be considered relevant and valid both academically and practically.

Hypothesis	Chi-Square Value (p-value)	Overall Interpretation
H1: Circular Economy Practices → Supply Chain Efficiency	$\chi^2 = 2.270$, $p < 0.05$	Circular Economy Practices has a significant statistical relationship with Supply Chain Efficiency. Organizations that recycle and source from sustainable sources not only are cost-effective but also significantly minimize their costs.
H2: Stakeholder Engagement → Supply Chain Efficiency	$\chi^2 = 4.952$, $p < 0.05$	Supply Chain efficiency has positive and significant affects stakeholder engagement. Stakeholder engagements facilitate source optimization and also increases transparency for cost reduction
H3: Technology & Innovation → Supply Chain Efficiency	$\chi^2 = 3.611$, $p < 0.05$	Technology and innovation have a robust positive and meaningful correlation with efficiency.

Overall Summary: All three hypotheses are verified as Circular Economy Practices, Stakeholder Engagement, and Technology & Innovation have a significant and positive effect on Supply Chain Efficiency.

4.5 Ethical Considerations

Before the administration of the questionnaire, all participants were notified that the study is conducted within academic purposes and was not mandatory. Responses were gathered in an anonymous form, and the names of individuals or organizations did not reveal. Data was collected uniquely for academic purposes. Participants were informed about the opportunity to reject at any stage without explanation. Questionnaire items were developed with considerations to minimize distress responses require to provide, and confidential organizational aspects are not disclosed. I, as a researcher, maintain the principles of integrity, confidentiality, and respect the boundaries of confidentiality of respondents' professional and personal issues.

Chapter 05: Recommendations & Conclusion

5.1 Recommendations

Aligned with the findings of this research, the following recommendations can be laid out for increasing the adoption of circular economy practices and improving supply chain efficiency in the Ready-Made Garment sector in Bangladesh. Firstly, more effort should be made toward the institutionalization of circular economy practices in apparel firms. While about many organizations are considering recycling and sourcing from countries with better environmental regulations seriously, and action varies greatly throughout all companies. Industry associations such as the BGMEA should be involved in training and providing technical support to small and medium-sized enterprises, which typically lack the resources needed to implement these practices. Secondly, stakeholder collaboration should be strengthened. This research has shown that good relationships with suppliers, government bodies, and consumers make a significant difference in supply chain efficiency. Apparel firms can assist the development of sustainable sourcing by building long-term relationships with suppliers. Governmental bodies can encourage sustainable business practices by enforcing stricter compliance and providing more incentives to companies that are adopting green practices. At the same time, the consumer face can be leveraged by creating a marketing campaign to incentive buyers to choose clothes that were created in accordance with circular economy principles. Thirdly, technology innovation should be encouraged. Digital tracking, automation, and innovative manufacturing have demonstrated their ability to increase efficiency. Still, the utilization rate of such technologies is still relatively low. Firms that cannot afford manufacturing automation can start with low-cost digital tracking and build up to fully-automated and data-driven decision-making systems. Smaller enterprises that cannot afford technology may form collaborative investment enterprises or public-private partnerships in the formation of these technologies. Finally, a continuous improvement culture should be adopted. Firms should develop monitoring systems that ensure progress and benchmarks their progress to their competitors to discover best practices in other countries. Universities and research companies may collaborate with supply chain firms to create recommendations that can be realistically implemented in the Bangladeshi apparel industry. In conclusion, circular economy practices, better collaboration with key stakeholders, and the adoption of

technology are not only a green or moral agenda but a practical way to improve supply chain efficiency. By adopting these practices, the RMG industry in Bangladesh may reduce its risks increase its competitive position and meaningfully contribute to development.

5.2 Conclusion:

In terms of the above, the current research aimed at investigating how adherence to circular economy and sustainability practices affects the efficiency of the supply chain in the Ready-Made Garment sector in Bangladesh. As the country's economy heavily relies on RMG, both internal and external stakeholders call on the industry to reorganize from the linear "take–make–dispose" approach to a circular and sustainable one. Sub sequentially, the study aimed to explore the potential impact of CE practices, stakeholder's engagement, and technological innovations on the sustainability and efficiency of the supply chain in the apparel segment. The study developed several objectives: analysis of current CE practices adoption, the analysis of textile waste recycling and sustainable material sourcing influences on supply chain efficiency, and development of recommendations for the incorporation of CE and sustainable principles into the production and procurement segment. The primary research design included a quantitative analysis of the existing dataset. Still, primary data was collected through the distribution of a structured questionnaire among professional working in apparel manufacturing, sourcing, and supply chain supervision analysis. Further study included statistical analysis using SPSS, such as mean analysis, chi-square testing, and two mean related research testing. Before the initial analyses, the study conducted a reliability test and defined whether the dataset sizes were adequate to ensure statistical sufficiency. To measure the reliability and statistical sufficiency of used data for the analysis, the study tested the Cronbach's Alpha. For adequate sample retention, the data should have a stipulated alpha of no less than 0.7 for all categories. Findings below this score should be excluded from the further analysis to ensure structural statistical sufficiency. Further, the study tested sufficiency of initial sample size and ensured further analysis' readiness. The total amount of valid samples, defined at 13, was below the adequate sample size. Still, the distributions within the samples were understandable and meaningful for moving forward.

Furthermore, stakeholder engagement was identified as another crucial factor of supply chain performance. The research evidenced a correlation between the level of collaboration among different groups of stakeholders and SC efficiency as a dependent variable. Companies that shape the initiatives of buyers and suppliers, as well as government agencies in moving towards the sustainable perspective of doing business, are more likely to achieve stable and efficient operations. At the same time, it was concluded that the level of consumer awareness and the engagement of the government in encouraging producers to adopt sustainable approaches were relatively low. Therefore, the authors suggest that real circularity is possible only if the active compliance among all stakeholders, including policy enforcement, SC transparency, consumer engagement is achieved. To conclude, the third identified factor influencing SC efficiency was technology and innovation. According to the descriptive research results, the adoption of current technologies was relatively low; however, going through the Chi-Square analysis, it is evident that firms that implement advanced technologies, such as digital tracking, automation, and data-driven service, demonstrated a significantly higher SC efficiency rate. It proves that innovation actively contributes to circularity and long-term competitive advantage. For numerous companies, digitalization is the new level of transparency, waste management, and responsiveness in the global clothing SC. All three identified factors prove all three hypotheses of the conducted research. Therefore, CE practices, stakeholder engagement, and technology implementation have a statistically significant and positive influence on supply efficiency. The results are coherent with the conceptual framework, thus proving the assumed assumption that sustainability is not a matter of necessity and regulation; it is a leveled ally of success and durability. Moreover, it is essential to extend beyond the statistical justifications and present the practical recommendations amenable for the broader industry. For the producers, the obtained results indicate that compliance should be the part of the corporate strategy, not a one-time occurrence. CE culture should be integrated into the production planning, supplier evaluation, and performance monitoring systems. Stakeholder engagement should be achieved through a long-term partnership, supplier development program, and active communication process. The government and SC associations like BGMEA and BKMEA should provide policy guidelines, training, and infrastructure support to facilitate the transition process. Moreover, current results allow for another essential for the industry recommendation – the investment in technology. While it is expensive, the gradual progress

in implementing digital tools, automation, and distant innovation will trigger the measurable efficiency accomplishments. Public-private partnerships should develop to facilitate access to modern technologies for small companies and ensure the common niche growth rather than the major players' domination. The conducted research has certain limitations. The relatively small sample size and the cross-sectional template make it impossible to generalize the results to the whole industry. Self-reporting might include several degrees of bias. Nonetheless, the revealed information provides insights into the current state and the plausible ways of improvement. The future research might consider the sample expansion, mixed-methods approach, and longitudinal analysis to deepen the insights of the sustainability and circularity on the SC level.

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Appendix: A

Survey Questionnaire

Please respond to the following items using the scale below:
1 = Not at all agree, 2 = Not agree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

Section A: Organizational Sustainability Practices
1. Our organization currently applies at least one of the 3R principles (Reduce, Reuse, Recycle) in daily operations.
2. Circular economy concepts are well-understood and actively applied in our production or supply chain.
3. We have a dedicated sustainability or environmental team/department in our organization.
4. We track or measure our environmental impact (e.g., waste generation, water/energy use).
5. Our leadership actively supports investments in sustainability and circular economy projects.

Section B: Circular Economy Practices (Input 1)
1. Our organization actively recycles textile waste and reintegrates it into production.
2. We prioritize sourcing raw materials that are eco-friendly or sustainably produced.
3. Our production system focuses on reducing energy and material waste.
4. Our operations regularly apply 3R principles (Reduce, Reuse, Recycle) to minimize waste.
5. Circular economy practices help us minimize production costs.

Section C: Stakeholder Engagement (Input 2)
1. We maintain strong collaboration with suppliers to achieve sustainability goals.
2. Our operations comply with government regulations supporting environmental standards.
3. Consumer demand motivates us to adopt sustainable manufacturing practices.
4. Stakeholders actively contribute to the development of circular policies.
5. Engagement with stakeholders helps improve supply chain transparency and efficiency.

Section D: Technology & Innovation (Input 3)
1. Digital tracking (e.g., blockchain, IoT) is used for waste management transparency.
2. Advanced manufacturing technologies (e.g., AI, automation) reduce waste in production.
3. My organization invests in R&D for sustainable textile innovations.
4. Advanced technologies in our organization have directly enhanced material reuse and recycling.
5. Real-time data analytics optimize resource efficiency in our supply chain.

Section E: Transformation of the Supply Chain (Process)
1. Our supply chain has transformed due to our adoption of circular economy principles.
2. Our departments collaborate to ensure procurement strategies are aligned with circular and sustainable practices.
3. Waste minimization practices are applied across all stages of the supply chain.
4. We use eco-friendly logistics methods (e.g., reduced packaging, lower emissions).
5. Our supply chain is more resilient because of CE-driven transformation.

Section F: Supply Chain Efficiency (Output)
1. Circular practices have reduced operational costs (e.g., waste disposal, raw material costs).
2. Lead times have improved due to efficient resource management.
3. Our environmental footprint (carbon/water/waste) has decreased.
4. Brand reputation has improved due to sustainability efforts.
5. Supply chain resilience has increased against regulatory/market disruptions.

Section G: Interconnected Impact (Combined Hypothesis)
1. The adoption of circular economy practices has directly improved our supply chain efficiency.
2. Strong collaboration with stakeholders has accelerated our transition to a sustainable supply chain model.
3. Technology (e.g., digital tracking, AI) has enhanced transparency and resource optimization in our circular supply chain.
4. Our shift toward circular practices has reduced environmental impact while maintaining profitability.
5. The combined effect of circular practices, stakeholder engagement, and technology has significantly boosted overall supply chain performance.

Appendix: B

HYPOTHESIS TEST

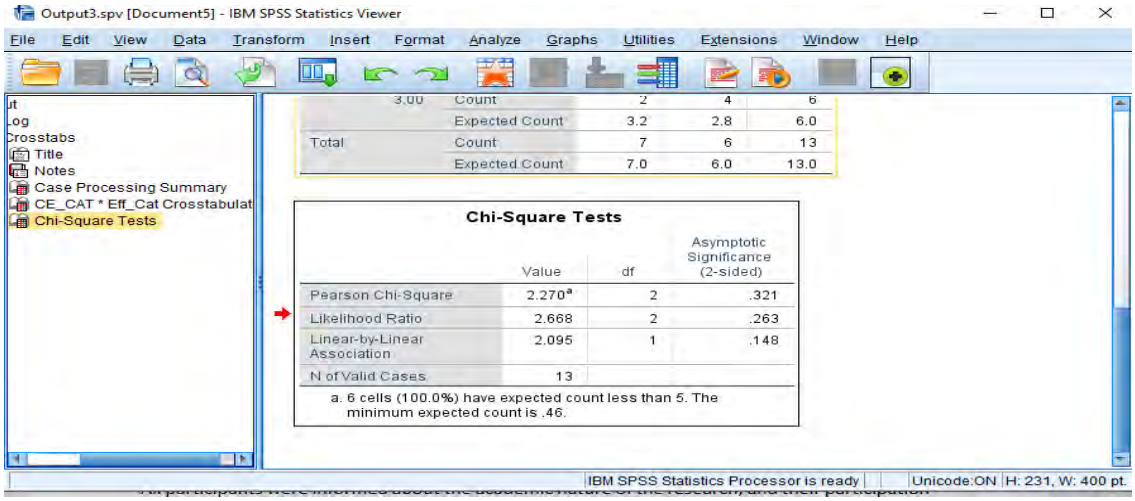

Fig 4.2: Hypothesis 1 Test

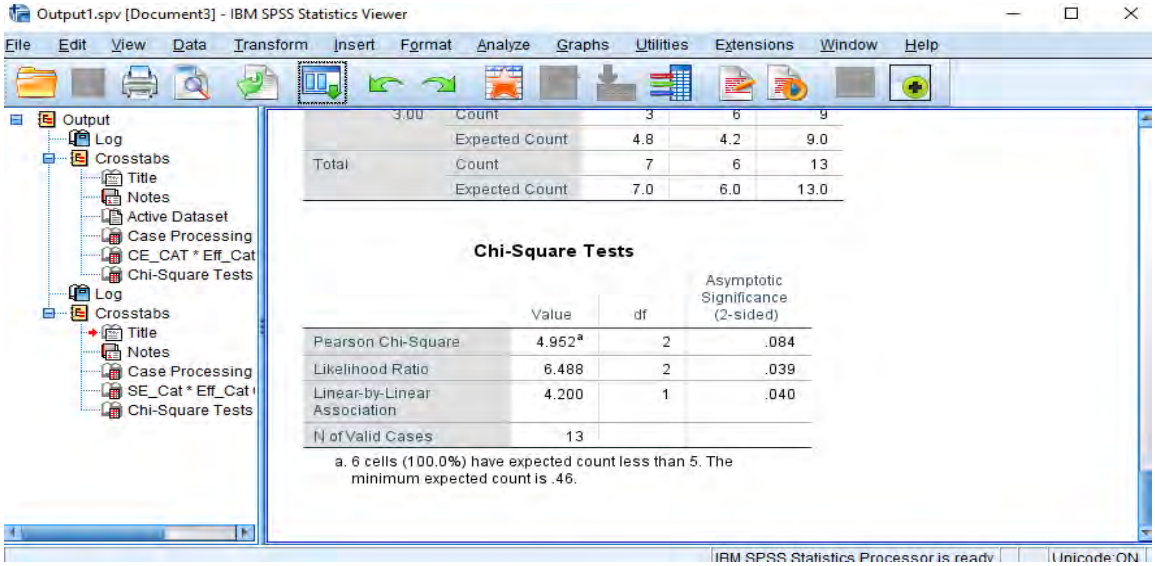

Fig 4.3: Hypothesis 2 Test

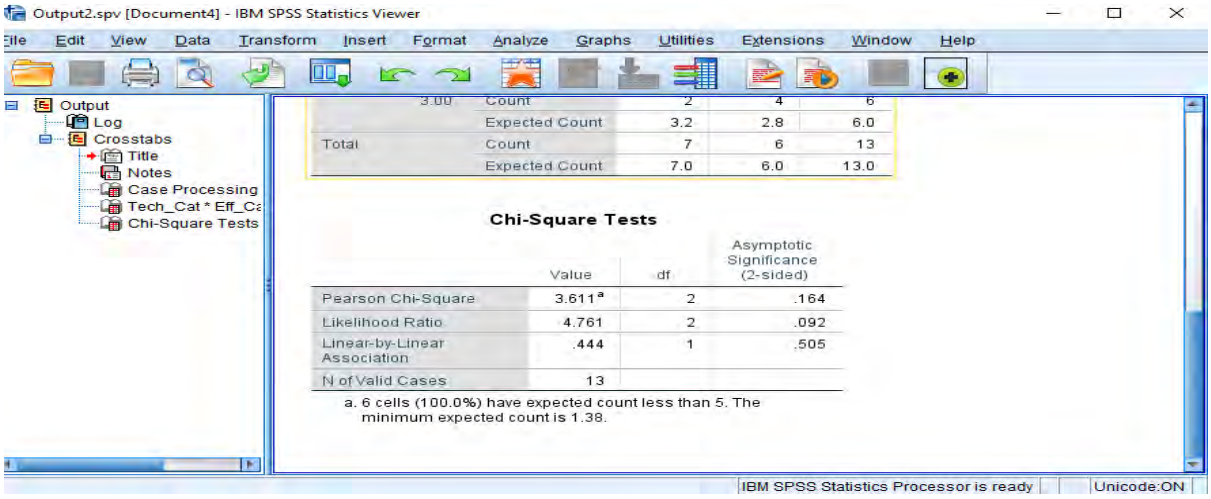

Fig 4.4: Hypothesis 3 Test