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# Textile-apparel manufacturing and material waste management in the circular economy: A conceptual model to achieve sustainable development goal (SDG) 12 for Bangladesh

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A R T I C L E I N F O

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A B S T R A C T

The textiles and apparel manufacturing industry in the upstream fashion supply chain generates substantial materials waste that requires urgent efforts to manage effectively, reduce environmental impact, and foster sustainable practices. A huge research scope lies in materials waste management of upstream textiles and apparel manufacturing within the scopes of circular economy to achieve Sustainable Development Goal (SDG) 12 for Bangladesh. This research identifies and categorises the materials waste generated in various production stages, determines the economic loss, and traces the informal trading of waste materials. Following an exploratory multiple-case approach, this research collects data from 17 textiles and apparel factories through semi-structured questionnaires, followed by materials stream mapping and observations. The study estimates a loss of approximately 0.70 USD for every piece of apparel export. To trace the destination of waste, it has been found that approximately 15 tons of informal trading of wastes took place in a single underground market. Overall, it leads to a significant loss of value addition that could have been added through a circular economy. Finally, to help achieve SDG 12, this study develops a conceptual waste management model in upstream textiles and apparel manufacturing with potential application opportunities within the circular economy.

## 1. Introduction

The fashion and textiles industry is widely criticised for a detrimental environmental impact (e.g. waste generation, resources consumption, carbon footprint) throughout its supply chain operations (Niinimamp et al., 2020). Textiles and apparel manufacturing consumes substantial energy, water, and other natural resources and contributes to the fast generation of a large volume of waste (Gupta et al., 2020; Islam, 2021). Recently, responses to the textile and apparel business challenge focused mostly on sustainable practices to address the climate crisis and environmental burden (Shamsuzzaman et al., 2021). Increasing demand from fashion consumers and the trend of fast fashion have radically increased the production and consumption of apparel (Sobuj et al., 2021), which generates a substantial amount of waste in every stage of manufacturing, including spinning, knitting/weaving, dyeing, apparel making, and finishing (Koszewska, 2019). Various studies have estimated that the global textiles industry generated approximately 92 million tons of waste in 2014, of which a minimal amount is reused or recycled, and a significant amount ends up in landfills or incinerated (Pensupa et al., 2017; Niinimamp et al., 2020). Approximately 577,000 tons of waste is reported to be generated from the apparel industry and fabric mills of Bangladesh, of which 250,000 tons, almost half of the total, is 100% recyclable cotton waste valued at approximately 100 million USD (Pavarini, 2021). Besides, global textiles waste is estimated to increase 60% each year between 2015 and 2030, generating an additional 57 million tons of waste every year, and reaching a total of 148 million tons annually (Niinimamp et al., 2020; Shirvanimoghaddam et al., 2020).

With the unprecedented attention given to sustainability initiatives in water and energy, the lesser focus given to material waste in the supply chain makes it an impending problem for the textiles and apparel

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industry (Islam 2021). The material waste generated from the apparel industry in Bangladesh is locally known as '*jhut*' (Patnaik and Tshifularo, 2021). Management of material waste is becoming a major concern due to its direct environmental impacts (Sarkar et al., 2020; Uddin et al., 2021). At present, there is a vast knowledge gap concerning the amount of waste generated from the textiles and apparel manufacturing industry, and it is essential to fill that gap if waste is to be utilised sustainably within the scope of the circular economy (Shirvanimoghaddam et al., 2020). Alongside its adverse effects on the surrounding environment, material waste results in potentially a massive loss in value and business opportunity in the textile-apparel production chain.

Bangladesh is a key manufacturing hub for global apparel and textiles products, and the industry plays a significant role in the country's socio-economic development (Habib et al., 2021). As a result, any sustainability goals related to Bangladesh's SDG commitment should be linked with the achievement of the textiles and apparel industry. Since its independence in 1971, Bangladesh has committed to join and ratify international legislation related to social, economic and environmental growth, notably the UN-led 17 sustainable development goals (SDG). Under this SDG umbrella, a 10-year Framework Programme (10YFP) on Sustainable Consumption and Pattern (SCP) was adopted, known as SDG 12, to accelerate practices of SCP and resource efficiency initiatives (UNDESA, 2014). The framework targets environmental sustainability to minimise resource consumption, waste generation, and pollution levels throughout the supply chain, from manufacturing to post-end use. As one of the nations most affected by climate change and with the potential for creating many climate refugees, SCP could be one of the most effective approaches for producing a circular economy in Bangladesh, and could mitigate climate change by producing a low-carbon economy. The Government of Bangladesh has pledged to achieve the sustainable management and efficient use of natural resources, and to substantially reduce waste generation through prevention, reduction, recycling and reuse by 2030 (SDG Cell, 2018). This study is aligned with the key strategic document issued by the Government of Bangladesh, 'Monitoring and Evaluation Framework for SDGs: Bangladesh Perspective', published in 2018, which shows 'metadata yet to be finalised,' and indicates a significant gap in data availability (GED, 2018).

The circular economy is considered a crucial knowledge domain in the sustainable development ethos, and several gaps are reported in academic research regarding the UN policy agenda alignments (Belmonte-Ureña et al., 2021). Hence, an attempt is made to address this challenge through a conceptual model on the circular economy and SCP targeting material waste in the textile industry. We attempt an exploratory case study investigation on materials waste generated in different production stages of the textiles and apparel industry, and reveal potential applications and opportunities within the scope of the circular economy in line with SDG 12 for Bangladesh.

The remainder of this paper is organised as follows. We first discuss the key literature and theoretical background to textiles-apparel industries and the value stream mapping (VSM) approach. The methodology section presents an exploratory multiple-case study approach, followed by a discussion of the findings, the research implications, conclusions, and limitations.

### 1.1. Research objectives

The specific objectives of this research are:

1. Identify and analyse materials waste in the textiles and apparel industry and the monetary value lost in the process with a value stream mapping approach.
2. Trace post-production wastage and determine the scope for re-utilising within the circular economy.
3. Show how SDG-12 can be achieved with a circular economy-led conceptual model for Bangladesh.

## 2. Review of literature

### 2.1. Material waste in textile-apparel supply chains

In 2015, the textile and apparel industry was valued at USD 1.3 trillion. It consumed approximately 53 million tons of textile fibre, of which 73% was landfilled or incinerated. Less than 1% of material is recycled for new clothing, representing a loss of more than USD 100 billion worth of materials each year (MacArthur Foundation, 2017). The major fibres that were used to manufacture apparel in 2018 were mostly synthetic fibres (~62.2%), followed by cotton (~24.4%) and others such as rayon and wool (~14%). The textile-apparel manufacturing chain involves the following operations (Kabir et al., 2019; Khan and Islam, 2015; Nayak et al., 2019):

- Production of fibres - both natural (cotton, wool, silk, flax, hemp, etc.) and synthetic fibres (polyester, nylon, acrylic, polypropylene, etc.). Other manufactured fibres are produced from natural resources like viscose, modal, lyocell, etc. The textile and apparel industry of Bangladesh is predominantly cotton-based.
- Production of yarns - cotton is processed into yarns through a ring/rotor spinning mechanism. Synthetic fibres are also processed into synthetic yarns through a melt/dry/wet spinning mechanism.
- Production of fabrics –knitted and woven fabrics are mainly used for apparel production. The knitting and weaving industries process the two types of fabrics, knitted and woven, respectively.
- Wet processing - this includes dyeing, printing, washing and finishing in any form – fibre, yarn, fabric and garment
- Apparel manufacturing-assembling finished fabrics into apparel through apparel manufacturing units, consisting of cutting, pattern making, sewing, and finishing.

The production waste, produced during textiles and apparel manufacturing, includes fibre, yarn, fabric, and apparel, as shown in Table 1. The amount of waste can range from ~12% to 15%, or as high as 25–30% (Runnel et al., 2017). In the yarn manufacturing stage, during the processing of yarn from cotton in the subsequent spinning operation, the accumulation of short fibres takes place around the machines and on the floor, and is known as 'cotton lint' (Meloy, 1918). Additionally, damaged or quality failed leftover yarns after production are regarded as waste from the spinning industry. The knitting and weaving industry produces knitted and woven fabrics, for which cotton yarn is used as the primary raw material in Bangladesh. Material waste from these stages consists of fly fibres and greige or unfinished fabrics (Guha and Sadi, 2016). The wet processing industry represents the dyeing, finishing, printing, and washing stages, where the greige fabric is coloured and treated with the required chemicals for the desired quality of finished fabric (Khan et al., 2020; Uddin et al., 2015). Dyed and finished excess fabrics or fabrics rejected due to quality issues become material waste from the wet processing stage (Pensupa et al., 2017). The apparel manufacturing stage produces fabric cut pieces and leftover fabrics from the cutting section, and excess apparel evolves due to excess production of development samples and final products (Kavitha et al., 2014).

**Table 1**
Material waste from textile-apparel production chain.

| Industry | Raw Materials | Material Waste |
|---|---|---|
| Spinning | Cotton and other natural fibres, synthetic fibres | Cotton lint, damaged yarn, unfinished cones |
| Knitting/ weaving | Natural and synthetic yarn | Fly fibre, scrap yarn, greige/unfinished fabric |
| Wet processing | Greige/unfinished fabric | Rejected coloured fabric, excess finished fabric |
| Apparel | Finished fabric | Fabric cut pieces (cutting waste), excess development samples, excess apparel |

Production wastes generated from the various textiles and apparel manufacturing stages are listed in Table 2.

The solid form of textile waste contains biodegradable substances such as fibre, yarn and fabric scraps (Islam, 2021). These substances can be recycled into new raw materials (Yalcin-enis et al., 2019), and they can decompose in nature since they are organic matter. The waste from the apparel industry is a mixture of natural fibres, synthetic fibres, and other substances, such as metallic zippers, acrylic buttons, wood buttons, shell buttons, and metallic snap fasteners used in the apparel, which makes it hard to degrade (Haule et al., 2016; Muthu, 2015). Most of the literature on the material waste domain in textiles and apparel are research outcomes on ways to recover, reuse and recycle waste materials efficiently and cost-effectively (Guha and Sadi, 2016; Nikolakopoulos, 2018; Yalcin-enis et al., 2019). Researchers suggest using eco-friendly raw materials and dyeing and finishing processes (e.g. reduced water dyeing and waterless dyeing) to reduce materials waste in fabric processing (Baydar et al., 2015; Islam and Khan, 2014). Some studies also concentrated on production wastes from apparel industries, and the unsold, unused, and rejected apparel wastes from developed countries (Gardetti and Muthu, 2015; Niinimäki, 2013).

Thus, the literature indicates that apparel solid waste is a matter of great concern, especially in developed countries, where initiatives should be taken for recycling, reusing and sustainable waste management. But the studies on waste generation and management in the upstream textiles and apparel production chain are limited, especially in developing countries. Therefore, in this research, an attempt has been made to address this research gap taking the Bangladesh textiles-apparel industry as an ideal case scenario.

### *2.2. Bangladesh textile-apparel industry and waste generation scenario*

After China, Bangladesh is the second-largest exporter of readymade apparel globally (Habib et al., 2021; Hamja et al., 2019a), with a strong production capacity, quality and growth (Maalouf et al., 2021). The apparel industry consists of more than 83% of Bangladesh's total exports, worth over 33 billion USD in 2019, and holds a 6% market share of global apparel exports (BKMEA, 2019). The apparel sector employs around 4.2 million people (BKMEA, 2019) and the textile sector, which is the backward linkage industry of the apparel sector, employs approximately 5 million people (BTMA, 2019). In 2019, 4621 export-oriented apparel factories were reported, and a total of 1487 textile companies with 432 spinning units, 809 weaving units, and 246 dyeing/printing/finishing units (BTMA, 2019). The annual capacity of the different industries is reported in Table 3.

In the last decades, emphasis has shifted towards sustainable production issues, particularly for water and energy (Islam et al., 2020). Various initiatives in this regard are taken by the donor organisations (GIZ, 2019), development partners (IFC, 2020), the government of Bangladesh (SREDA, 2015) and the private sector itself. As of 2020, six out of the world's top ten green factories are located in Bangladesh, housing 125 LEED-certified factories, along with another 500 units in the process of obtaining certification from the US Green Buildings Council (USGBC) (BGMEA, 2021).

The sector depends on the import of raw materials, particularly cotton fibre. In 2019–20 fiscal year up to November 2019, the import of raw cotton was 1785 million kg, while polyester staple fibre and viscose staple fibre were 96,077 tons and 53,289 tons respectively (BTMA, 2019). 100% of raw fibres, 65% of woven fabrics, and 10% of knitted fabrics are imported to meet the demand of the apparel industry (BKMEA, 2019). As the most significant chunk of the cost associated with apparel production comes from the material price, profitability heavily depends on the quantity of material wasted in the process. However, the knowledge of materials wastes generated from the textiles and apparel manufacturing production chain in Bangladesh is still limited.

**Table 2**
Production waste in Textile-apparel manufacturing.

| Wastes from Textile Industry | Wastes from Apparel Industry |
|---|---|
| **Cotton lint, damaged yarn, fly fibre, greige fabrics, rejected fabrics, finished fabrics, cutting wastes** | Excess production, defective apparel, rejected apparel, cancelled shipment products |

**Table 3**
Approximate manufacturing capacity in the Bangladesh textile industry.

| Industry Type | Number of units | Annual Capacity | Reference |
|---|---|---|---|
| Spinning | 432 | 2964 million kg | BTMA (2019) |
| Weaving | 809 | 3761 million meters | BTMA (2019) |
| Knitting | 950 | 4500 million meters | BKMEA (2019) |
| Fabric Processing (dyeing/printing/finishing) | 246 | Woven: 2503 million metersKnitted:585 million kg | BTMA (2019) |

Different research papers indicate different amounts of materials wastes being generated from the textiles and apparel industry. Rahman et. al. (2016) reported 26.5% fabric wastage in their investigation of a knit T-shirt factory. According to their study, 13.57% of this waste is unavoidable cutting section waste, whereas the rest can be optimised. Another report says that 550 tons of apparel waste (*jhut*) is exported from Chittagong port every day (Textile Textile Today, 2017). A comprehensive study by Reverse Resource reports from their analysis of 4 manufacturers: *the total volume of leftovers in different forms (yarns, cutting scraps, cut pieces, roll ends, overproduction, rejected pieces and garments, etc.) can sometimes be as much as 47% of the total raw material input. Even with the best optimisation methods, we have found the volume can not be lower than 20%* (Runnel, 2019). The report also estimates that at least 500,000 tons of leftovers are generated from the apparel industry per year, and more leftovers and wastes are generated from the textiles and apparel production operations. It was also suggested that waste materials have a substantial economic scope if handled appropriately. However, the precise quantity and ratio of materials generated as wastes or leftovers from the subsequent textile-apparel processes, and their economic value, are still unknown.

### *2.3. The value stream mapping (VSM) approach*

The value stream mapping (VSM) technique is used to construct a map to conveniently identify and represent waste sources (Khalid et al., 2014). VSM is a widely used tool for lean implementation in different manufacturing organisations (Jeyaraj et al., 2013; Kurdve et al., 2015). It is primarily used to identify value-adding activities, wasteful materials, and the flow of information and people (Julia et al., 2014). Application of VSM tools for identifying non-value-added processes in the apparel manufacturing industry can be found in Sri Lanka (Yildiz and Güner, 2013), India (Marudhamuthu et al., 2011) and Bangladesh (Hamja et al., 2019a; 2019b). The rationale behind using the VSM approach in identifying materials waste can be explained from the work of Hines and Rich (1997), where seven waste types were listed, identified by Ohno (1988), which can be visualised with VSM: 1) overproduction, 2) waiting, 3) transport, 4) inappropriate processing, 5) unnecessary inventory, 6) unnecessary motion, and 7) defects. In this research, overproduction, inappropriate processing, unnecessary inventory, and defects are the problems of visualising material waste. Along with quantifying average material consumption, average material waste, and excess inventory, this study also interprets the information in economic terms to visualise and quantify value lost in the complete textiles-apparel production chain.

## 3. Material and methods

### 3.1. Method and sampling

An exploratory multiple-case approach was followed to investigate this study (Yin, 2014; Saunders et al., 2016). Purposive sampling followed by snowball techniques was undertaken to select the case company and the participants who would answer the research questions (Yin, 2014). They were selected according to topic relevance, experiences and knowledgeability, (Patton, 2015). An initial list of case companies was drawn up from the textiles and apparel industry directory and trade bodies membership lists. Case companies were approached through email or directly via phone. Selection criteria were: (i) the company should be based in Bangladesh, (ii) involved in the textiles and apparel export-oriented manufacturing business, and (iii) willing to share information for research purposes. Although we approached 50 companies comprising different manufacturing factories in the textiles-apparel production chain, only 17 companies, after repeated persuasion, including spinning, fabric manufacturing, dyeing/washing/finishing (wet processing) and apparel manufacturing, agreed to participate. These companies represent a variety of sizes and product categories. Table 4 shows the case company and respondent profile in brief. The case companies are mostly located around Dhaka, the largest textile industries cluster of the country (Fig. 1).

**Table 4**
Case factories and participant profiles.

| Case factory and type | Production capacity (kg)/ yearly | End-product Category | Respondent Position |
|---|---|---|---|
| F1: Spinning | 6,372,000 | Finished yarn: Cotton, wool, viscose, polyester | Manager, Spinning |
| F2: Spinning | 4,248,000 | Finished yarn: Carded and combed yarn | Assistant General Manager, Production |
| F3:Spinning | 3,186,000 | Finished yarn: Ring and open-end | Manager, Quality Assurance |
| F4: Spinning | 20,590,000 | Finished yarn: Ring, open-end, carded and combed | Deputy Manager, Production |
| F5: Spinning | 10,200,000 | Finished yarn: Ring and open-end | Manager, Production |
| F6: Fabric manufacturing (Knitting) | 5,382,559 | Knit fabric: Single jersey, rib, interlock, fleece etc. | Manager, Fabric Planning |
| F7: Fabric manufacturing (Knitting) | 6,328,460 | Knit fabric: Single jersey, rib, interlock, fleece etc. | Manager, Knitting |
| F8:Fabric Manufacturing (Denim) | 5,374,877 | Denim fabric: Twill denim, cotton and polyester denim | Head of Weaving |
| F9: Fabric Manufacturing (Weaving) | 5,374,877 | Woven fabric: Yarns, Woven and denim fabrics, jeans | Manager, Weaving |
| F10: Wet Processing | 6,600,000 | Finished fabric | Manager, Dyeing and Finishing |
| F11: Wet Processing | 2,590,000 | Finished fabric | Manager, Dyehouse |
| F12: Apparel Manufacturing (Knit) | 1,236,012 | Apparel: T-shirts, polo-shirts, tank tops | Production Manager, Sewing |
| F13: Apparel Manufacturing (Knit) | 3,200,000 | Apparel: T-shirts, polo-shirts, tank tops etc. | Production Manager, Sewing |
| F14: Apparel Manufacturing (Knit) | 8,400,000 | Apparel: T-shirts, polo-shirts, sweat shirts, etc. | Manager, Production |
| F15: Apparel Manufacturing (Knit) | 4,930,914 | Apparel: T-shirts, polo shirts, baby wears, sweatshirts, | Production Assitant General Manager |
| F16:Apparel Manufacturing (Woven) | 4,412,932 | Apparel: Denim Pants, Jeans | Manager, Production |
| F17: Apparel Manufacturing (woven) | 2,800,000 | Apparel: Shirts, shorts, pants | Manager, Production |

### 3.2. Data collection and analysis

A semi-structured questionnaire (Appendix 1, 2, 3, and 4) was developed in line with the research theme to get in-depth insights into waste generation in Bangladesh's textiles and apparel industry as the ideal case scenario. According to the research protocol, the questionnaire was sent to respondents from different operation stages (e.g., spinning, knitting, dyeing, apparel production) and positions (e.g. directors, general managers, managers, executives, production officers) (Easterby--Smith et al., 2018). To collect the raw data for calculation (Table 6), the questionnaire was sent to the company contact person through email, followed by follow-up communication with the industries over telephone and email. The number of sample companies increased gradually using the snowball technique to cover the textiles-apparel production chain (spinning, knitting, dyeing/finishing, apparel) and product category (knitted, woven, denim), where the participating company and researcher's collaborative network helped find the others. However, due to data secrecy, particularly on waste materials, the case company information remains confidential. Information from the case company website, archival records, documents, relevant industry sources and follow-up communications were employed to ensure the greater reliability and validity of the collected data (Houghton et al., 2013). A generalisation cannot be made, as is typical for quantitative research, yet, the study contributes significantly to the practical and theoretical contexts of Bangladesh textiles-apparel industries.

With the primary target of finding out the lost economic value of the waste data, a formula has been developed to calculate the average amount of materials consumed, wasted and over-produced (excess inventory) in the process of a particular style of apparel order. Identifying an exact style of apparel order in different factories is practically impossible. To simplify this problem, the end product is represented as materials measured by weight (kg). Calculations have been carried out to quantify the amount of material consumed in subsequent processes (in yarn manufacturing, fabric manufacturing, wet processing and apparel manufacturing) for every 100 kg of end product. A similar cycle of calculations has been carried out to quantify average material waste and excess inventory in each of the production processes of the textiles-apparel production chain. Table 5 shows the types of raw material and end-product in the respective textiles-apparel production processes.

Collected raw data from the 17 factories was analysed using the appropriate calculation method. Variables calculated were: average material consumption, average material wasted, and average excess inventory material (Table 6). For a particular amount of export, a percentage of extra production occurs. However, this percentage always varies, depending on the style and quantity, material types, factory types and overall waste percentage maintained by the factories. Thus this excess inventory refers to those quality products produced '*in excess*' to export the actual order quantity. Again, any apparel factory runs according to the export orders from buyers/brands. Thus any production and subsequent sourcing of materials and accessories, relies on those order quantities, and at least theoretically, should source and produce only what it can export. Thus, producing excess to the order quantity is an indication that the excess quantity is to be informally traded in the waste market or local underground market. The material conversion rate and value addition rate in subsequent processes were determined in percentage, where the 100 kg end product was considered the 'standard'. The Material Conversion rate is the amount of raw material required to produce 100 kg of end product in percentage. The VSM tool was used to represent the data in a material stream map (MSM) for a close visualisation.

This study traces the transformation route whereby production

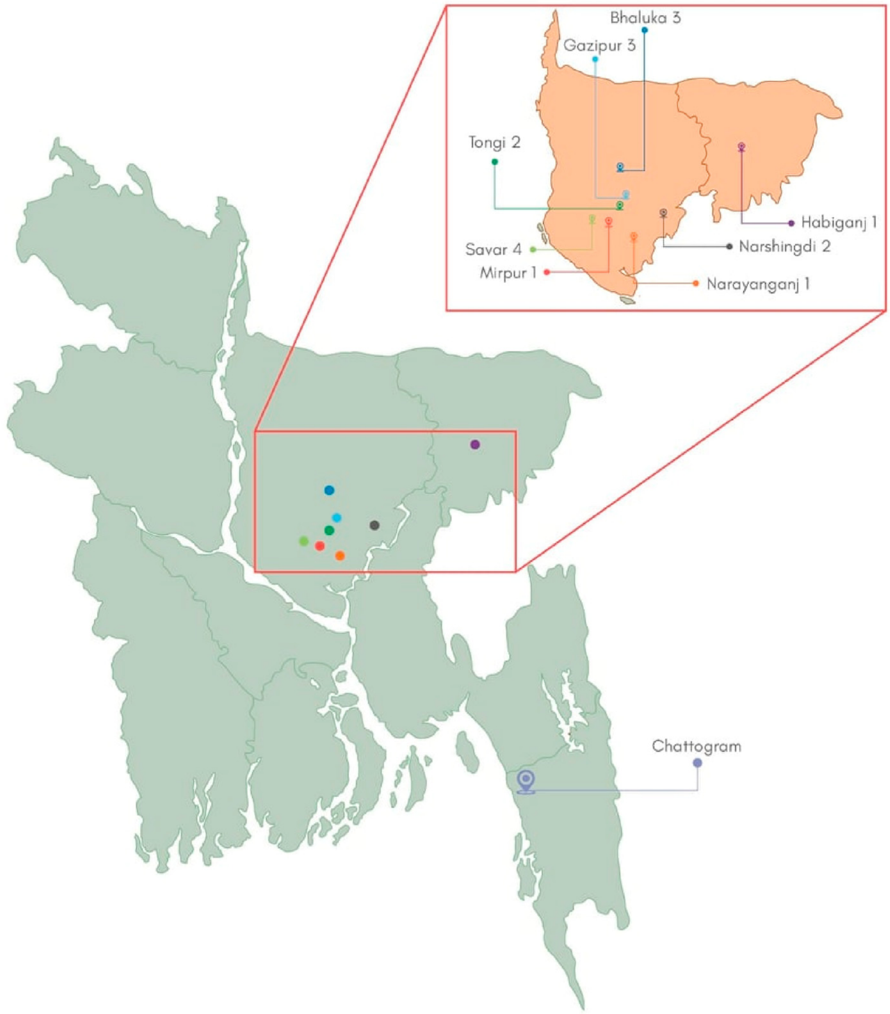


**Fig. 1.** The sample textiles and apparel industries clusters in Bangladesh.

**Table 5**
Input and output in Textile-Apparel manufacturing chain.

| Process | Raw Material (Input) | End Product (Output) |
|---|---|---|
| **Yarn manufacturing/Spinning** | Fibre (cotton) | Yarn |
| **Fabric manufacturing/Knitting and weaving** | Yarn | Greige fabric |
| **Wet processing/Dyeing, finishing, printing** | Greige fabric | Finished fabric |
| **Apparel manufacturing** | Finished fabric | Apparel |

wastes turn into value-added products. The case study findings reveal some remarkable underground business facts about textiles and apparel production waste. The researchers collected data for this explorative case study using semi-structured interviews with five factory personnel and field observations. Three of the interviewees are associated with the waste management policies of the corresponding factories. The remaining two are involved in the local trade of apparel production waste. However, respondent information remains confidential due to data secrecy, particularly regarding waste materials and the underground *jhut* business. Researchers followed local markets known for textile waste trading, identified where the materials finally ended up, and explored how those wastes are altered into value-added products. In filling the knowledge gap, this study develops the following research boundaries and scope (Fig. 2).

**Table 6**
Calculation Methods for different Processes in the textiles-apparel production chain.

| Item | Equations |
|---|---|
| Average Material Consumption | $\frac{\text{Total consumption of raw materials}}{\text{Total end product delivered (exported)}}$ |
| Average Material Wasted | $\frac{\text{Total wastage of raw materials}}{\text{Total end product delivered (exported)}}$ |
| Average Material Excess Inventory | Total actual end-product production – total end product delivered (exported) |
| Material Conversion Rate (%) | $\frac{\text{100 kg end product delivered (exported)}}{\text{Total raw materials consumption to produce 100 kg end product}} \text{ x } 100$ |
| Value Addition (%) | $\left(\frac{\text{Averge price of 100 kg end product}}{\text{Average raw material price to produce 100 kg end product}} - 1\right)\text{x}100$ |

## 4. Results and discussion

### 4.1. Material and value lost

The research outcome visualises the material stream mapping (MSM) of the textile and apparel production of the factories under investigation (Fig. 3), providing quantitative insights on consumption and wastage of materials throughout the different production stages.

In the MSM, the respective boxes represent different types of factory in the textiles-apparel production chain. The factory type, the end product, the average actual consumption of raw material, and the average actual material wastage are represented in the boxes. The triangles below every box represent the average amount of excess inventory in the respective processes. The arrows at the top and the bottom represent the material conversion rate and value addition percentage respectively. The conversion rate shows the amount of material required to produce 100 kg of output from all respective industries in the production chain. In our calculation, a total of 519 kg of materials (e.g. fibres) were consumed in producing 400 kg (100 kg of yarn, 100 kg of greige fabric, 100 kg of finished fabric, and 100 kg of apparel) of end products; 77% when converted to a percentage. The value addition percentage is based on the selling price of each product category to the next stage of the production chain, which means from fibre to yarn, yarn to greige fabric, greige fabric to finished fabric, and finished fabric to apparel. The overall value addition (e.g. 126%) is calculated based on the selling price (freight on board, FOB) of 100 kg apparel divided by the purchasing price of the total amount of required fibre to produce those quantities of apparel, expressed as a percentage.

The findings, as reflected in the above MSM, regarding the material flow between each of the industries involved in the textiles-apparel production chain, are as follows:

**Spinning:** According to the findings, for every 100 kg of yarn produced, on average, 124.1 kg of cotton fibre is consumed, 37.3 kg of fibre is wasted, and the excess inventory is 26 kg. We found a huge gap between the actual yarn production quantity and the quantity of yarn delivered to the next subsequent industry. The material consumption here depends on the quality of fibre and the production efficiency. In contrast, wastage is an accumulated amount of process loss (which is unavoidable in most cases) and rejections due to quality issues. The material conversion rate of 89% means only 89 kg of yarn is produced from processing 100 kg cotton.

**Fabric manufacturing:** This industry consists of the knitting and weaving processes. Actual data shows that, for every 100 kg of knit/woven greige fabric, 110.4 kg of yarn is consumed on average. The amount of wastage here is 2.5 kg, and the excess inventory is recorded as 7.5 kg. The types of waste here are yarn leftovers and faulty fabrics.

**Wet Processing (Dyeing/finishing/washing):** Here, the greige fabric is treated with required chemicals, auxiliaries and dyes to impart the desired colour and properties. The study's actual data shows that, for every 100 kg of finished fabric, 124.4 kg of greige fabric is consumed. The amount of excess inventory is 14.8 kg for every 100 kg. Actual data also shows that on average, 18.8 kg material is wasted for every 100 kg of fabric dyeing. The potential reasons behind this considerable wastage are primarily concerned with uneven dyeing due to fabric faults and GSM issues. For every 100 kg of fabric processing, the wet processing industries use around 63% of excess materials.

**Apparel Manufacturing:** According to our collected data, for 100 kg of final products, 161.3 kg of finished fabric was cut in the cutting section on average. Again, 7.7 kg of final apparel is separated as excess inventory, and 11.8 kg of materials are being wasted in the process. This 11.8 kg of materials is composed of the fabric cut wastes during cutting, and the residues collected during the apparel sewing operation.

From the above MSM analysis, a question arises about the amount of value lost in the process and where the excess inventory ends. From Fig. 4, it can be visualised that the total amounts of material lost (total of excess inventory and wastes on average) in the process are approximately 63.3% in spinning, 10% in fabric manufacturing, 33.6% in wet processing, and 19.5% in the apparel industry. This translates to a considerable value loss in textiles-apparel production. An attempt was made to visualise the monetary loss in the process (Table 7). The average unit of material cost (Fig. 5) is calculated according to the current market price collected from the respective personnel from the factories.

**Spinning**-with an average price of yarn of 2.8 USD/kg for every 100 kg of yarn manufactured, the amount of wastage generated was equivalent to 177.24 USD, with 72.8 USD worth of yarn stocked as excess inventory. The vast difference between actual production and the actual delivered quantity of yarn creates a big question. The amount of process wastage in the spinning process is also the highest compared to the other processes. Only a tiny amount of this wastage is recycled and reused in the production process, and the rest is sold to the local market. According to our study, the value addition in the spinning industry stands at 21% on average. However, value addition can be increased by optimising the 63.3% of wastage and over-processing.

**Fabric manufacturing** - the value lost during fabric manufacturing was 30 USD, the least among all the processes. 22.5 USD out of this 30 USD is excess inventory, which perhaps is sold in the local market. Among the waste, the more significant portion is from leftover yarns, and the rest are fabrics rejected due to their inferior quality. The leftover yarn wastes are also sold as *jhut,* and the rejected fabrics are sold in the local market at low prices. Additional information from knitting factory F6 (Table 4), which has more than 5000 tons of production capacity per year, shows that 65 tons of waste yarn and 25 tons of leftover fabrics are

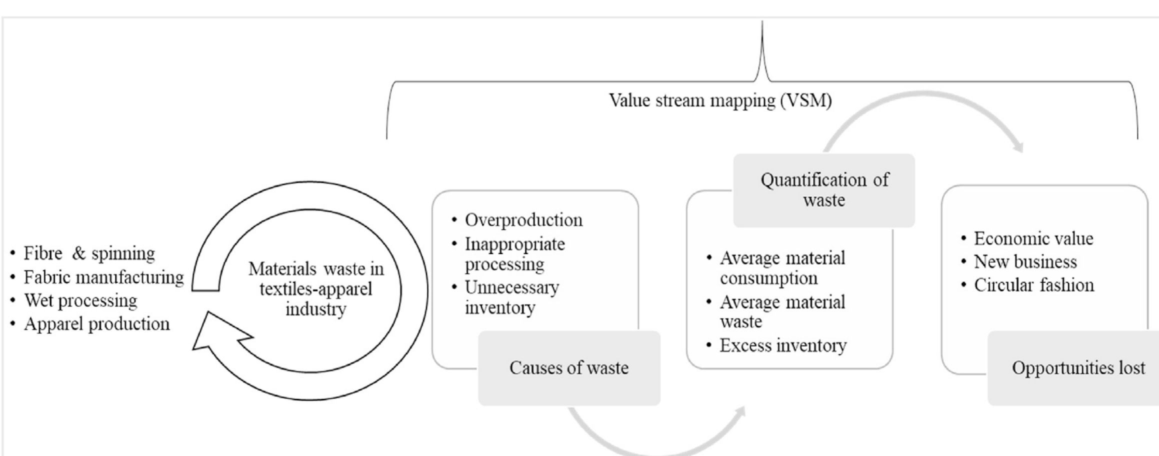


**Fig. 2.** Scope and boundaries for the research.

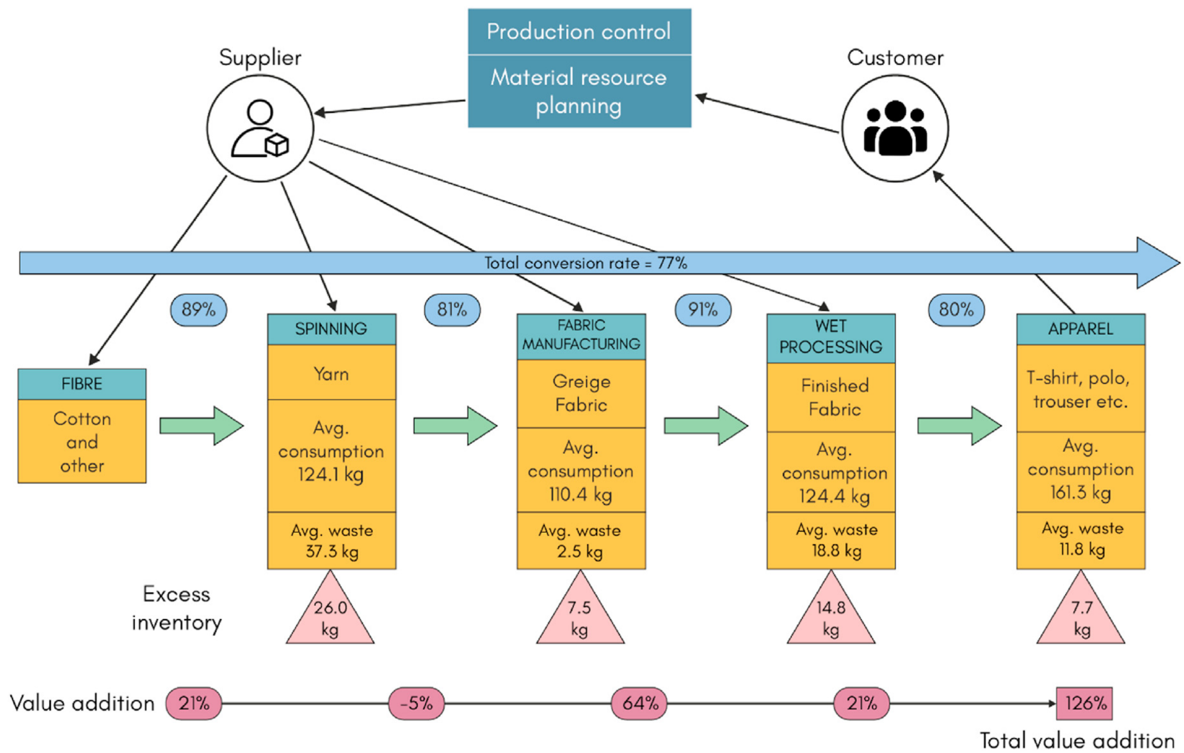


**Fig. 3.** Material stream map (MSM) of textile-apparel production chain.

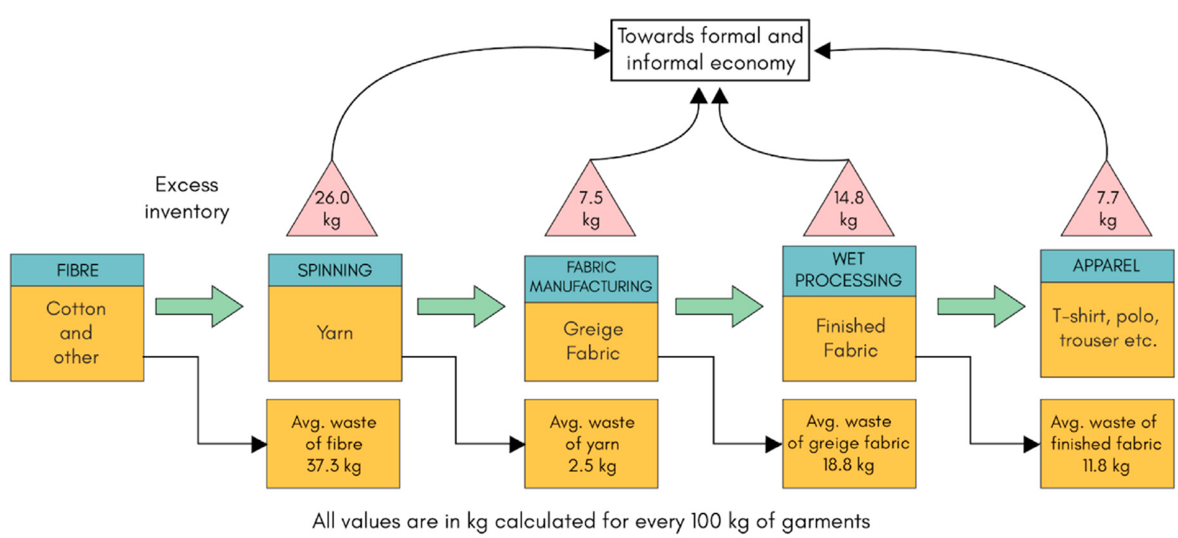


**Fig. 4.** Amount of material lost in the textile-apparel production chain.

sold in the local market as *jhut*, valued at 96,000 USD and 45,000 USD respectively. This resembles the amount of cash flow in the textile material waste market. Our industry expert finding reveals that the knitting industry's value addition is comparatively lower, typically around 8–10%, which means the amount of waste generated offsets the value addition towards a negative 5%.

**Wet Processing (Dyeing/finishing/washing)** - the possibility of value addition is higher in wet processing facilities, particularly where the finished fabric will be used to produce basic apparel, such as t-shirts, five-pocket jeans, etc. We have found the value addition to be as high as 64%, indicating that composite textile units, consisting of the apparel, dyeing/finishing and knitting/weaving processes, gain more price advantages during negotiation. As the value addition is high, the amount lost during the processing is also high. In the wet processing industry, 159.6 USD is lost during the processing of 100 kg of fabrics. 69.85 USD worth of over-processed fabric (excess inventory), and 89.74 USD worth of finished fabric waste is sold in the local market at a cheaper rate, or reused for smaller apparel orders where possible.

**Apparel manufacturing –** The cost of materials significantly impacts the overall cost structure of the apparel industry. The industry practice is to produce 5–15% excess to cover any shortfall, typically for quality issues in any particular order for export. In addition, the amount of cut-fabric waste is also significant. In our study, the total value lost for every 100 kg of apparel in the factories was calculated to be approximately ~68 USD, of which losses due to excess inventory were ~27 USD, and for cut-fabric waste and rejected apparel were ~41 USD.

**Table 7**
Material and value loss in textile-apparel production chain (per 100 kg of end product).

| Process | Material | Average Material Loss (kg) | Average Value Loss ($) |
|---|---|---|---|
| Spinning | Fibre, Yarn | 63.3 | 177.24 |
| Fabric Manufacturing (Weaving/knitting) | Yarn, Greige fabric | 10 | 30 |
| Wet Processing (Dyeing, printing, finishing) | Greige Fabric, Finished fabric | 33.6 | 159.6 |
| Apparel Production | Finished Fabric, Apparel | 19.5 | 68.25 |

Note: Value is calculated according to the current market prices collected from textile-apparel factories during the research period.

The approximate value lost for every piece of apparel was calculated at approximately 0.70 USD. In other words, due to material wastage in the textiles and apparel production chain, 70 cents is lost for every piece of apparel exported. Although it is an approximate valuation based on primary data from this research and analysis, it contributes to the quantitative aspects of textiles and apparel production waste, a knowledge gap identified in the literature. Along with this quantification, the sources of waste and the respective amounts in both weight and monetary terms represented by the MSM figures, are also shown to supplement this knowledge.

### 4.2. Traceability of apparel production waste

Traceability increasingly becomes a critical strategic component for sustainability and the circular economy, helping to trace products, components, and materials, and to assess the social and environmental conditions of production facilities in the supply chain and after use (Ellen Macarthur Foundation, 2018). Once the amount of waste generated in the production chain was calculated, an attempt was made to trace the fate of these wastes.

The exploration reveals a vast underground market dealing with *jhut* and excess inventory apparel, known as 'stock lot'. This market sells stock lot apparel as it is received or after a bit of refurbishing, and also newly sewn apparel from excess fabric or cut-fabric wastes. The local regulations prohibit dealings of excess inventory apparel or fabric illegally to protect the domestic market, which states that no materials should be sold in the local market since those are produced and imported under a duty-free bonded-warehouse license (NBR, 2021).

The dealers purchase the cutting waste or stock lot from the apparel manufacturers in a hidden manner (i.e., adopting informal practices) rather than through regular business practices, usually twice in a calendar year - between January/February and October/November. As with the fashion trend and market demand, the types of waste vary seasonally and according to the product category of the local business. The stock lot is traded in kg, and the price also varies depending on the product category and season. For example, 1 kg of Taffeta cut fabric could cost ~0.60 USD in peak seasons and ~0.45 USD in off-peak seasons. The ways that cutting waste and rejected apparel in the apparel industry are collected is shown in Fig. 6.

**Cut-fabric waste:** Cut fabric of ~ 2–125 mm is considered 'small', and good quality small fabric is recycled to produce 'garment fibre' through appropriate manual sorting and by a waste opener machine. The recycled yarn is created from this garment fibre to produce apparel with 100% or mixed recycled content. Inferior quality cut-fabric is also shredded to fibres but used in cushion fillings, mattresses, quilt fillings, carpets, toy stuffing, upholstering, etc. Because of these end-use variations, the cost of cut-fabric waste also has a significant difference – ~0.34 USD to ~0.14 USD per kg. The market price of recycled cotton fibre is ~0.40 USD per kg, approximately 5–6 times lower than the regular price of cotton fibre.

**Cut-fabric panel:** The faulty cut panels are produced during pattern cutting and subsequent sewing operations in apparel manufacturing. Some of these are 'Medium' or 'Large' in size. Cut panels of medium sizes are reused to make smaller-sized apparel. For example, faulty cut panels of large or extra-large sized T-shirts are used to make small-sized T-shirts. Thus, cutting faults are removed and reused to make new products. The large panels are used in boutique shops, bag making, cushion covers, quilt covers, and local apparel. Fig. 7 illustrates the cycle of how *jhut* waste turns into value-added products.

**Operation of Jhut Businesses** – Investigation in a local underground market found that around 15 tons of *jhut* fibre is handled every month by the upholsterers. About five to seven members are required to operate a *jhut* business with a monthly salary of 60–80 USD. Shops remain open from 8.00 a.m. to 10.00 p.m. The collected unsorted *jhuts* are sorted manually in chaotic and unhygienic conditions.

Although the business is informal, this market is an appropriate example of circularity. The generated 'Waste' is used as 'Resource' – the primary raw materials for the domestic textile and apparel market. Additionally, the underground marketing of the *jhut* contributes to reducing the apparent environmental effect of the waste textiles. However, the size of this underground market needs attention as it provides scope for bad practices in local manufacturers, and leads to a significant opportunity loss of value addition that could be added to the country's economy. Moreover, the working conditions and the occupational health and safety of the workers is completely overlooked in the underground markets, which is against the SDG 12 norms.

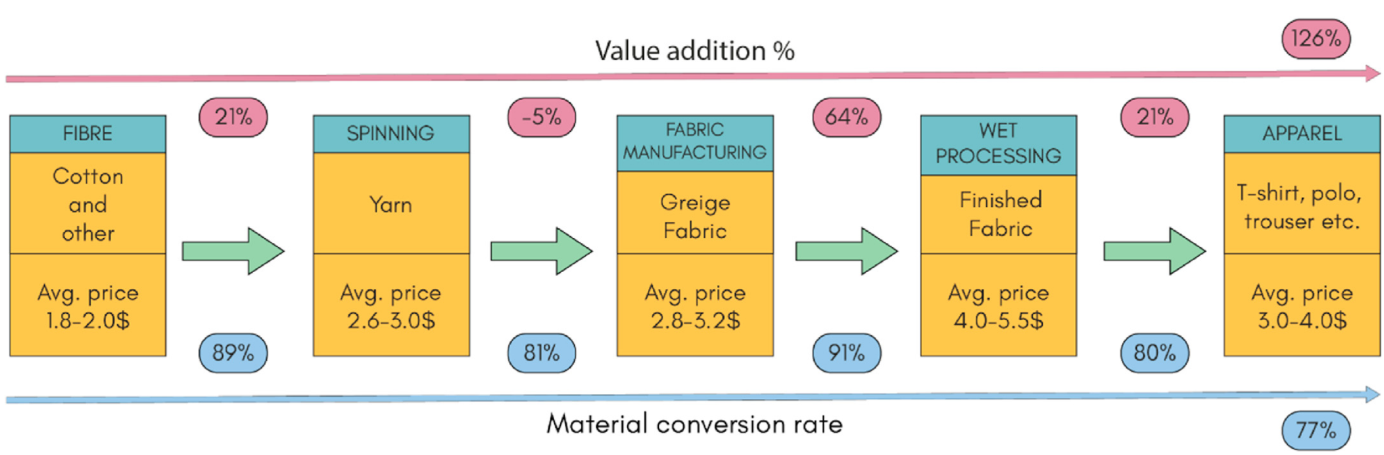


**Fig. 5.** Material price, value addition (%) and material conversion rate (%).

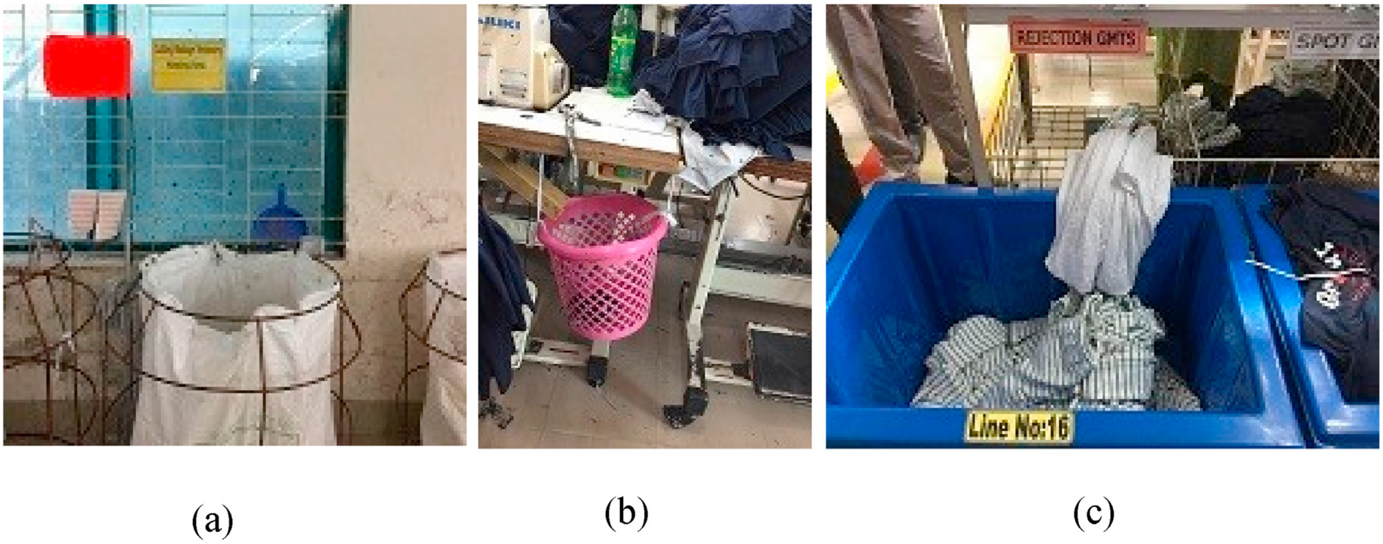


**Fig. 6.** (a) Temporary storing area of cutting waste, (b) Waste collection in the sewing section, (c) Rejected apparel in the sewing section.


**Fig. 7.** Traceability of post-industrial textiles and apparel waste.

### *4.3. A conceptual model of waste management in the circular economy for achieving SDG 12*

Due to the high volume of materials waste generated in the different manufacturing stages of the textiles and apparel industry, a practical waste management strategy within the scope of the circular economy can be an effective solution to support SDG 12. This would prevent increased landfill waste, promote natural resource efficiency, reduce energy consumption and environmental footprints, and also open new business opportunities. The circular economy model is widely recognised by industry and academia and is gaining more attention from fashion and textiles stakeholders, from both theoretical and practical perspectives (Ellen Macarthur Foundation, 2018; Shirvanimoghaddam et al., 2020; Islam, 2021).

Waste management strategy should include reducing inventories, beginning with the informed selection of the amount of raw material. This can be achieved by using systematic monitoring of the market and demand, and using methods based on data processing that will result in forecasting models for demand (based on artificial intelligence or traditional data processing methods). In addition, to reduce leftovers advanced optimisation techniques (combinatorial optimisation) may be used for minimisation of trim loss, implemented through automated cutting machines supported by CAD programs.

Environmentally harmful raw materials should not be used in product design for bulk production; instead, eco-friendly materials should be used for the product, which would foster recyclability, reusability, and extended life cycles. The processing of raw material in the different textiles and apparel manufacturing stages (e.g., spinning, knitting, weaving, dyeing, and apparel) should follow effective waste management and a culture governed by a legislative framework. In addition, the traceability of the production waste is essential, and can be achieved through collaborations among manufacturers, buyers, government, consumers and practitioners to ensure optimum utilisation for achieving sustainability through a circular economy. Incentives for data sharing can be provided through legislation, emphasising also that the outcome will be for the economic benefit of the private companies in the textile business. Simultaneously, it requires effective waste stewardship of different materials and products to reduce the environmental impacts at different stages of production, use and disposal through wider applications. The respective industries should take a shared responsibility to ensure that the materials waste in the textiles and apparel production chain are managed in line with circular economy principles that would mitigate their negative impacts. The potential applications for the generated waste undoubtedly provides scope for new business opportunities, products, services, and for creating new employment, which is vital for Bangladesh's socio-economic interests. Accelerating these requires collaborations and strategic approaches from stakeholders through effective policymaking, governance, and implementation.

However, any policymaking and implementation requires high-quality data and information from the industry and experts. One of the most challenging parts of this study is access to the industry and data availability, particularly in the context of material use. Quantification of primary raw materials and their economic value would help in the understanding of the value added to the products, and how they are reused, recycled, or enter the local economy for further use. Data collection over time would aid the understanding of changes in sustainable production patterns, which would further help policymaking at each stage of textiles production. This would also provide a mechanism to track energy and carbon emission in the textiles industry – as reuse and recycling in the current informal economy will also be included in sustainable reporting as required by SDG 12. Determining the economic value lost and identifying new business opportunities within the scope of the circular economy can be the core driving factor for practitioners and related stakeholders. However, we have realised through our study that methods of sustainable management and efficient use of waste resources, such as reuse, recycling, reducing, upcycling, recovering, and repairing, are not clearly defined sectors, particularly for upstream textile waste, which makes it difficult to identify and implement them within the scope of the circular economy to achieve SDG 12. Thus, the availability of waste data could help tremendously towards obtaining resource efficiency benefits, and provide an excellent opportunity for transitioning towards circularity.

To address this challenge and limitation, we develop and propose a circular economy-led conceptual model for waste management in the textiles and apparel industry to achieve SDG 12 (Fig. 8). SDG 12 demands responsible consumption and production patterns. The conceptual model complements SDG 12 with fundamental strategic approaches for waste management, performance indicators and potential implications. Notably, the study identifies the sources of waste in the textiles and apparel production chain and visualises them quantitatively to facilitate explicit actions to ensure a responsible production pattern. The material stream map reveals which factory in the production chain is responsible

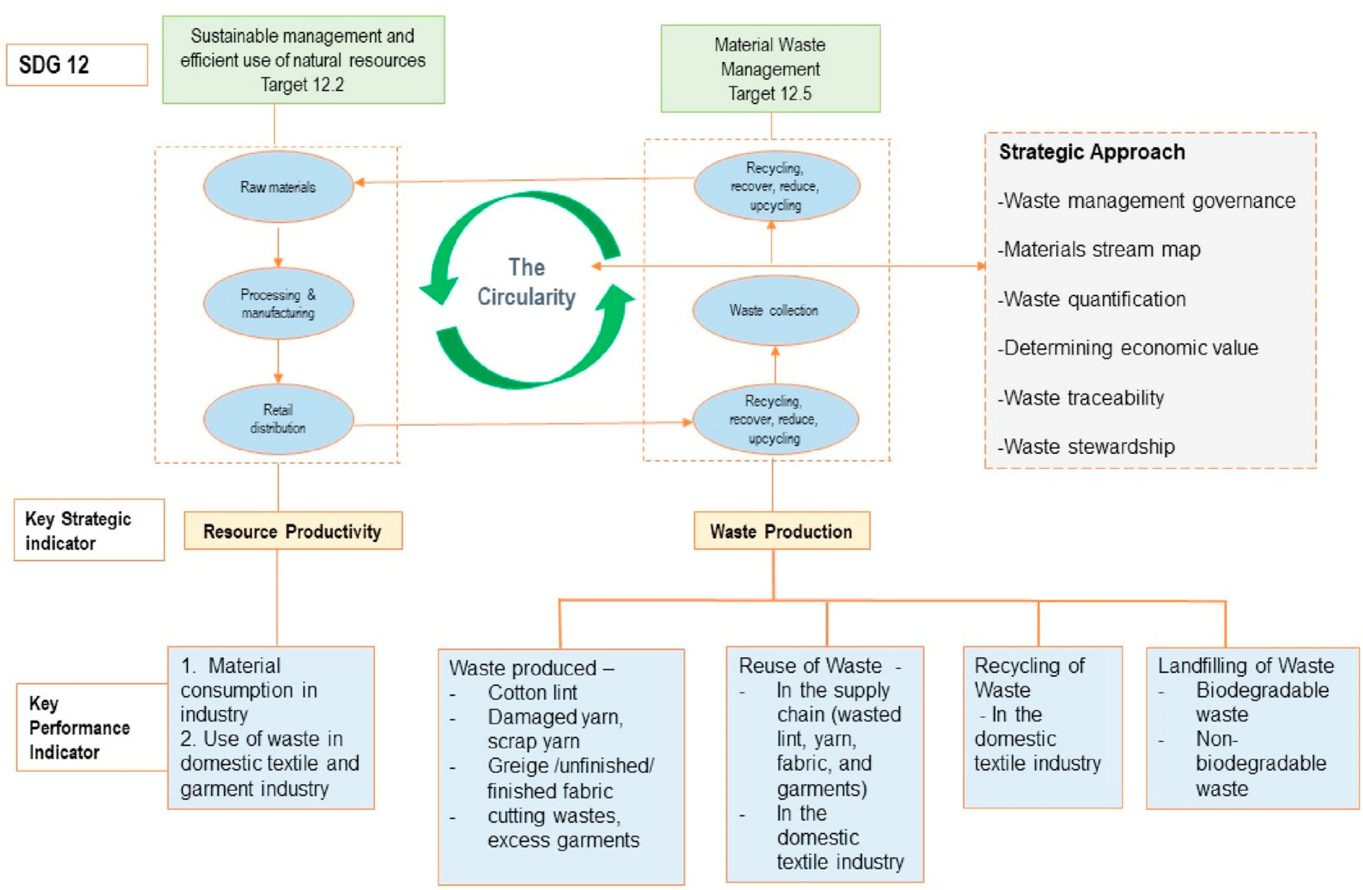


**Fig. 8.** Circular economy-led conceptual model for waste management in the textiles and apparel industry to achieve SDG 12.

for waste generation. Also, the same circular economy-led conceptual model can be extended to the efficiency parameters of other resources, such as water, energy, chemicals, and waste water for the textile industry.

### 4.4. Theoretical and industrial implications

This research has some important theoretical and practical implications. The key novelty of this research is that it is one of the pioneer studies of its kind from the Bangladesh textiles and apparel industry that identifies, categorises, maps the value stream of materials, and determines the economic value of materials waste. In addition, the traceability determination and development of a circular economyled conceptual model will help academics, researchers, and relevant stakeholders to explore, understand and address the multiple barriers and challenges of managing materials waste throughout the upstream fashion and textiles supply chain. The study also reveals viable solutions, potential applications, and new business opportunities, especially to help Bangladesh achieve SDG 12.

Firstly, drawing upon the categorisation and quantification of generated waste in different manufacturing stages enables industry practitioners to be more aware and take strategic steps to reduce waste generation and its negative environmental impact. Industry stakeholders in the respective production stages of spinning, fabric manufacturing, wet processing and apparel manufacturing may design responsible production patterns to enable the achievement of the SDG 12 goal. Secondly, manufacturing practitioners can use the visualisation techniques of waste through materials value stream mapping to engage with the other fields (e.g. chemicals, water) within the textiles and apparel industry. This could also be extended to other manufacturing units (e.g., printing, packaging, washing, embroidery). Thirdly, determining the economic value loss and return of waste materials could be a key driver for manufacturers to take care and focus more on sustainable waste management, given the high importance of economic sustainability in business.

Fourthly, part of this study has focused on the post-production waste scenario in Bangladesh's textiles and apparel industry. We have captured traceability in a way that reveals interesting and valuable insights for relevant stakeholders, indicating how apparel waste can turn into value-added products, opening a new business door and associated opportunities. Our traceability investigation reveals the limitations of *jhut* business in Bangladesh, including a lack of skilled labour, modern machines, technology and infrastructure, supportive policy, legislation, and recognition. Finally, the circular economy-led conceptual model will provide the factory management and relevant stakeholders with more comprehensive information to identify key strategies for managing materials waste and natural resources, and to find scope for potential applications in different sectors, including agriculture, automobile, buildings, and incinerations, and to gain strategic advantages. In summary, all the above-mentioned theoretical and practical implications can help to foster circularity practices in the textiles and apparel industry and help achieve SDG 12 in Bangladesh.

## 5. Conclusion, limitations, and future research directions

As the apparel industry produces more than 83% of Bangladesh's total exports, value retention in the production process can heavily contribute to the government's SCP move in line with SDG 12. A 0.70 USD value is lost from the textile-apparel production chain against every piece of apparel exported, which can be retained with circular approaches. This research reveals exciting and valuable insights by identifying, categorising, stream mapping and determining the value addition of materials waste alongside new business opportunities in the upstream manufacturing contexts. The research comprehensively portrays the scenario and potentials for empirical research extensions and materials waste management interventions. The textiles and apparel industry needs financial and technical support from the key stakeholders, i.e. brands, government, trade organisations and others, to establish a materials waste baseline throughout the supply chain to effectively manage them in the circular economy model and achieve SDG 12. Support is also needed to establish an informal economy and recycle/reuse business on a legitimate basis. At this moment, there is lots of secrecy surrounding this, and it requires transparent and viable solutions to make such a vast amount of materials waste into opportunities and to foster sustainability.

However, this research has a few limitations. Firstly, due to minimal data regarding waste generation, we had to conclude this study with limited information within the study boundary. The inclusion of more factories might reveal more interesting insights. Secondly, exploring how the materials waste varies across the different production units and contextual issues of a specific industry (e.g., size, product category, value chain roles, geography, and others) would reveal a more comprehensive scenario.

Finally, future research may adopt quantitative and mixed-method approaches to investigate materials waste scenarios by considering the full life cycle stages of fashion products, i.e. design to disposal. This would produce more generalised results and a more comprehensive understanding of materials in the global fashion business, in order to achieve SDG goals more objectively and broadly.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cesys.2022.100070.

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