Uncovering the circular economy potential of industrial waste in Sri Lanka (case study from textile industrial- fabric waste)

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Abstract. A comprehensive survey was undertaken to examine the production of fabric waste in the apparel manufacturing sector of Sri Lanka. The primary objective was to assess the composition, quantities, and potential economic value of the fabric waste generated within this sector. This investigation involved 120 carefully selected industries, and data collection was facilitated through a structured questionnaire. Additionally, on-site visits were conducted at random to verify the provided data. The total amount of fabric waste generated by these industries in 2022 was determined to be 28,745.3 tons, with the overall production reaching 288,456.6 tons. This waste predominantly consisted of fabric leftovers, accounting for approximately 88.3% of the total, while the remaining portion comprised yarn leftovers. The fabric leftovers were further categorized based on their material composition, with polyester accounting for 24.5%, nylon 25%, cotton 20%, and mixed material 30.5%. The prevalent methods employed for managing fabric waste were recycling (35.5%), reuse (5%), co-processing (35%), incineration (10.5%), open dumping (12%), and other methods (2%). The findings of this study reveal that around 60% of the fabric waste could be incorporated back into the material cycle with an estimated economic value of approximately USD 12.74 at present.

1 Introduction

The textile industry continues to hold a prominent position among global industries in terms of its market size, employment opportunities, and product value [1]. With an impressive annual value of $3 trillion, the global textile sector stands as a vibrant and dominant industry, contributing significantly to the global economy, representing around 2% of the global gross domestic product (GDP) [2]. However, despite its economic significance, the textile industry has garnered attention as one of the most environmentally polluting sectors worldwide, as noted by various scholars over the course of several decades [3, 4,5].

The textiles sector, spanning the entire life cycle from raw material extraction to disposal, exerts a profound environmental impact. Each year, the textile industry contributes to a staggering amount of CO_2 emissions, surpassing 1.2 billion tonnes, thereby accounting for approximately 8% of the global total emissions [6]. Notably, this industry stands as the second-largest consumer of water, responsible for 20% of industrial water pollution resulting from fabric treatment and dyeing processes [7]. Moreover, it plays a significant role in oceanic primary microplastic pollution, contributing to 35% of such pollution [8].

The textile production process, characterized by intensive resource utilization, fuel consumption, and chemical application, involves various stages like spinning, bleaching, and dyeing, consequently leading to substantial pollutant discharge [9].

Over the past two decades, there has been a substantial surge in global textile consumption, escalating from 5.9 kg to 13 kg per individual [10]. Presently, the worldwide consumption of textile products stands at approximately 62 million tonnes per annum, with projections indicating a rise to 102 million tonnes by 2030 [5]. Consequently, the textile industry, driven by its expanding production volume, has witnessed a commensurate increase in waste generation.

Textile waste is classified into three distinct categories: production waste, pre-consumer waste, and post-consumer waste [7, 11]. Production waste arises during the apparel manufacturing process and constitutes approximately 20% of global production waste in the textile and clothing industries [4].

Despite the inherent recyclability of textile materials, with studies indicating a 100% recyclability rate [12], the actual textile recycling rates remain disappointingly low, even in affluent countries such as the United States [13]. Surprisingly, in 2015, a mere 15% of post-consumer textile waste was collected separately for recycling, signifying that less than 1% of all textiles worldwide are currently being transformed into new textiles through recycling processes [14].

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This issue is not exclusive to any particular region, as across Europe, a mere 10% of clothing waste is recycled, while 8% is reused, leaving the majority to be either landfilled (approximately 57%) or incinerated (approximately 25%) [15]. In the United States, the reported textile recovery rate stands at around 15-16% [16]. Astonishingly, a significant portion of textile waste, roughly 80%, ultimately finds its way into landfills, with synthetic fibres accounting for the majority and natural fibres comprising the remaining portion [14]. This situation is further compounded by the proliferation of synthetic materials incorporating various fibre combinations, rendering recycling efforts increasingly complex [17].

Consequently, the widespread adoption of garment recycling emerges as a crucial solution in order to establish a closed-loop system for textile waste and promote an efficient recycling infrastructure. Furthermore, to accomplish this objective, it becomes imperative to address the issues of excessive manufacturing and consumption rates prevalent in the textile industry. Embracing the concept of a circular economy presents a compelling alternative to the conventional linear economy model that follows a pattern of production, utilization, and disposal.

Within the circular economy framework, the emphasis is placed on maximizing the lifespan of resources by continuously circulating them within the system, preserving their value throughout their entire life cycle, and eventually repurposing them to generate new products once their initial purpose is fulfilled. This shift towards a circular approach not only helps in minimizing waste but also contributes to the promotion of sustainability and the efficient utilization of our valuable resources. By adopting such practices, the textile industry can reduce its environmental footprint, optimize resource allocation, and promote a more sustainable and resourceful utilization of materials, thereby moving towards a more environmentally conscious and economically viable future.

The textile and apparel sector in Sri Lanka holds significant importance as a crucial export industry, contributing approximately 10% to the country's national GDP and providing direct employment opportunities to a workforce of 350,000 individuals. While the sector primarily caters to the export market in the European Union, there exists a notable focus on sustainability; however, the generation and management of waste within the industry remain inadequately addressed.

Nevertheless, the sector faces mounting pressure to adopt sustainable practices due to the European Commission's recent publication of a new action plan on Circular Economy, aimed at fostering a cleaner and more competitive Europe. This action plan presents a forward-looking roadmap that envisions a cleaner and more competitive Europe, emphasizing the importance of collaborative efforts among economic actors, consumers, citizens, and civil society organizations [18]. Consequently, the textile and apparel sector in Sri Lanka is compelled to align itself with the principles outlined in the Circular Economy action plan to meet the evolving expectations and demands of the European market.

The recently published action plan on Circular Economy puts forth a roadmap that places significant emphasis on practicing circularity within industries, aiming to achieve material savings across value chains and unlock economic opportunities [18]. Within this plan, the textile sector has been identified as a priority sector, signalling the increasing importance of sustainability within the industry.

As these new action plans are implemented, the product supply chain, particularly in the textile sector, will increasingly prioritize sustainability. This shift towards sustainability poses challenges for developing nations that provide textile products to the European market. It becomes crucial for these nations to identify and capitalize on opportunities related to waste management to maintain a strong and competitive business presence within the European market.

However, the textile sector in Sri Lanka faces obstacles due to inadequate infrastructure and insufficient waste treatment facilities. As a result, the sector is compelled to allocate additional financial resources towards waste treatment to comply with customer regulations. In this research paper, our objective is to assess the value addition of fabric waste generated during the production process from a circularity perspective. By evaluating the potential circularity value of fabric waste, we aim to provide insights and recommendations for improving waste management practices within the textile sector and enhancing its overall sustainability performance.

2 Methodology

2.1 Selection of Industries

This descriptive survey was conducted over a duration of twelve months, specifically from January 2022 to December 2022. The selection of industries for the survey was preceded by an initial data collection process, where information was gathered from the Board of Investments (BOI) in Sri Lanka. The BOI provided a comprehensive list of registered textile and apparel industries in the country, which served as the basis for selecting the industries to be included in the survey.

2.2 Data collection procedure

Data collection through questionnaire is an appropriate method to determine the opinion of stakeholders [19,20,21]. Several studies conducted in different fields have proven the effectiveness of the data collection through questionnaires [22,23,24]. Therefore, to collect the necessary data, a structured questionnaire was employed in this study. Prior to its administration, the management of the selected industries was contacted via telephone. During these conversations, the objectives of the survey were explained, and the management was encouraged to share their organization's perspectives on fabric waste generation, as well as their waste treatment and management facilities, including methods for fabric waste collection and treatment. To ensure a

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comprehensive understanding of the questionnaire, a covering letter was included. This letter, issued by the Lanka Responsible Care Council, accompanied the questionnaire and was addressed to the same individual who had been interviewed over the phone. The covering letter served to provide additional information and instructions regarding the questionnaire. The questionnaire consisted of three primary sections. The initial segment aimed to gather general information about the company. The subsequent part focused on acquiring data regarding the generation and types of fabric waste produced. The final section of the questionnaire was designed to elicit insights into the methods and approaches employed for fabric waste management and disposal.

To enhance participation and data quality, an awareness session was conducted for the industry representatives. This session aimed to educate them on how to effectively complete the questionnaire, ensuring accurate and reliable responses. In addition to the questionnaire-based data collection, a validation process was implemented through random site visits to the selected industries. A 10% sample of the population was chosen for these visits, following the approval of the respective industry representatives. The purpose of these site visits was to verify the accuracy and reliability of the data provided by the industries. During the site visits, a quick walk-through audit was conducted, allowing for a visual inspection of the facilities and waste management practices. Furthermore, a sample material balance, utilizing an input-output analysis approach, was performed to validate the collected data. This analysis helped ensure that the reported data aligned with the actual material flows within the industries. By employing both the structured questionnaire and the validation through site visits, this study was able to achieve a comprehensive and reliable collection of data on fabric waste generation and management practices in the selected industries. The insights gained from this study will contribute to evidence-based policy decisions and support the promotion of sustainable industrial development.

3 Results and discussion

3.1 Composition of fabric waste

The present study aimed to analyze the fabric waste generated by surveyed industries in the year 2022, with a specific focus on estimating the total waste produced and its proportion relative to the overall production. The findings indicate that out of a total production of 288,456.6 tons, the fabric waste amounted to approximately 28,745.3 tons. This data is visually represented in Fig. 2, providing a clear illustration of the waste generation within the surveyed industries during the specified time frame. This waste predominantly comprised fabric leftovers, accounting for 88.3 % of the total, while the remaining portion consisted of yarn leftovers. The composition of fabric waste was further examined, indicating percentages of polyester (24.5 %), nylon (25 %), cotton (20 %), and mixed material (30.5 %). It is important to note that these figures are specific to the year 2022 and may vary annually based on factors such as customer demand and order patterns.

Regarding waste treatment methods, the study identified the most commonly practiced approaches, including recycling (35.5 %), co-processing (35 %), incineration (10.5 %), open dumping (12%), reuse (5%), and other methods (2 %). Notably, the findings highlight that approximately 60% of fabric waste still presents an opportunity for integration into the material cycle. However, the study suggests that the existence of this barrier may be attributed to the prevalence of textile products made from mixed materials, for which recycling technologies are not yet commercially viable.

Moreover, the study conducted an assessment of the prevailing economic value of fabric waste based on selected circularity pathways. This evaluation contributes to the understanding of the potential economic benefits associated with effective management and utilization of fabric waste in line with circular economy principles.

3.2 Material recovery routes

Cotton, as the second most consumed fibre globally following polyester, holds a significant share in the overall fibre consumption. According to a report by [25], cotton accounted for approximately 24.1 % of the total fibre consumption by 2017. While cotton offers advantages as a natural fibre, its production is associated with notable environmental impacts, including high water consumption, land utilization, emissions, and pesticide usage. Fletcher (2014) estimated that approximately 11 % of global pesticide usage is attributed to cotton cultivation [26].

Cotton cultivation requires a substantial amount of water, ranging from 7 to 29 tonnes per kilogram, as reported by Clay (2009) [27], and Grose (2009) [28]. Additionally, the production of 1 kilogram of cotton fabric consumes approximately 140.1 MJ of energy and emits around 5.3 kilograms of CO2, as highlighted by Burçin Ütebay et al. (2019) [29]. Given these environmental concerns, the recycling of cotton fibres becomes imperative.

The efficiency of fibre recovery from cotton fabric waste can vary depending on the specific processes and technologies employed. Mechanical recycling, chemical recycling, and energy recovery are among the methods utilized for recycling and recovering cotton fibres from fabric waste. These approaches contribute to the circularity of cotton and enable the reuse of its fibres, thereby addressing environmental concerns and promoting sustainable practices within the textile industry

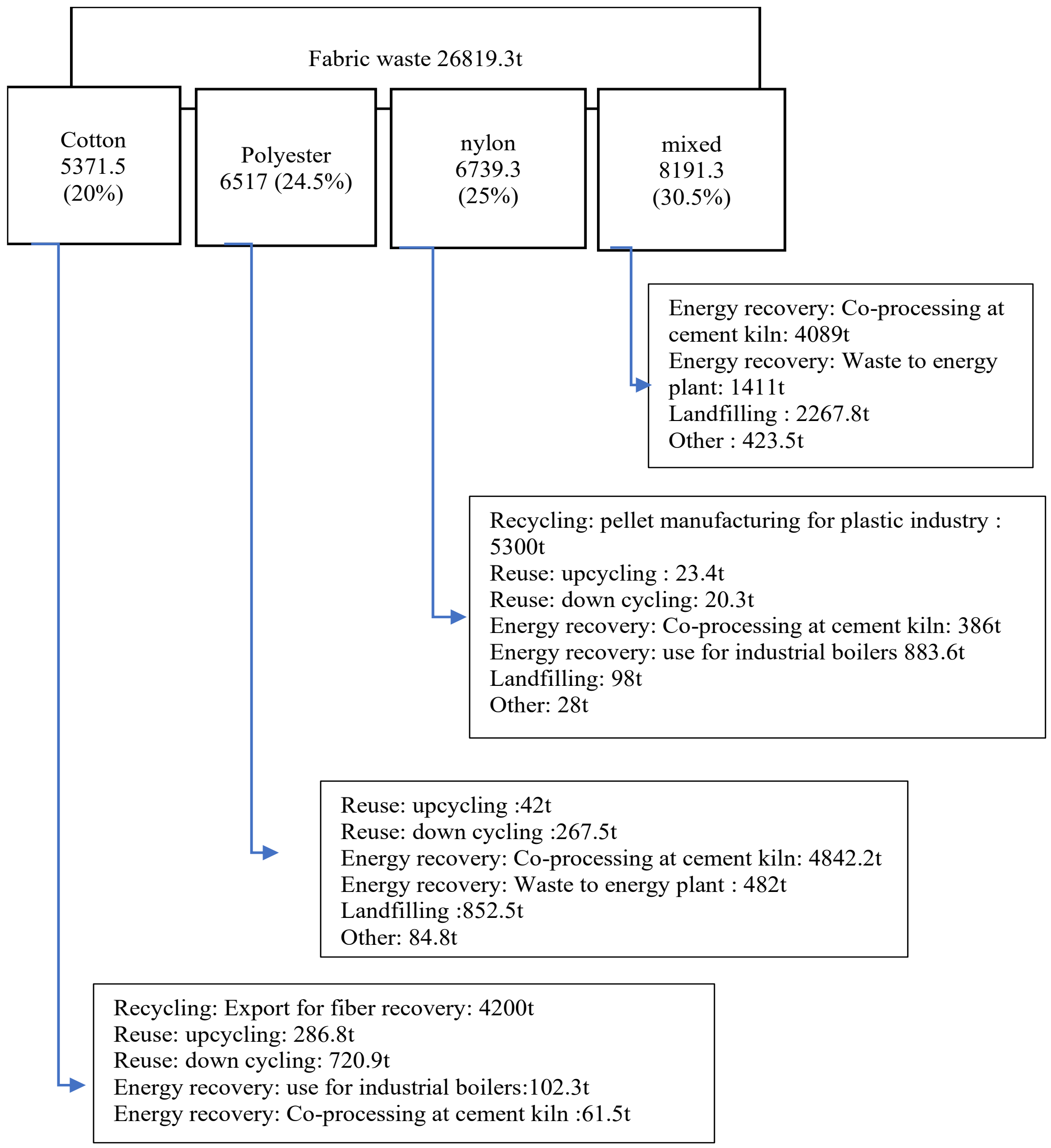

Fig. 2. Waste flow of fabric waste.

Mechanical recycling is commonly employed for the recovery of cotton fibres from fabric waste, and its efficiency can range but is generally reported to be around 80%. This process involves mechanical processes such as shredding, tearing, and carding to separate and extract the cotton fibres from the fabric waste.Chemical recycling methods offer an alternative approach, utilizing chemical solvents or treatments to dissolve or break down the fabric waste and enable the recovery of cotton fibres. The efficiency of chemical recycling can vary depending on the specific processes and chemicals used. Some studies have reported recovery efficiencies of up to 90% or even higher, indicating a promising potential for the effective recovery of cotton fibres. It is important to acknowledge that the efficiency of fibre recovery from fabric waste can be influenced by various factors. These factors include the quality and composition of the fabric waste, the presence of contaminants, and the technology and expertise available for processing. Different recycling facilities may possess varying capabilities and efficiencies in recovering cotton fibres, depending on their specific methodologies and equipment.Further research and advancements in recycling technologies are needed to improve the efficiency and effectiveness of cotton fibre recovery from fabric waste. This will contribute to the sustainable management of cotton resources and reduce the environmental impacts associated with cotton production and disposal.In cases where direct recovery of cotton fibres from fabric waste is not practical or efficient, alternative methods such as incineration or pyrolysis can be employed to harness the energy potential of the waste. While these processes do not facilitate fibre recovery, they offer value by converting the fabric waste into usable energy.

Energy recovery from fabric waste can be achieved through incineration or pyrolysis. Incineration involves the controlled burning of fabric waste, generating heat that can be utilized for various purposes, including steam production and electricity generation. The efficiency of energy recovery through incineration typically falls around 90 %, indicating a significant conversion of the fabric waste's energy content into usable heat or electricity. The energy content of fabric waste varies depending on factors such as fabric type, composition, and moisture content. Different fabrics possess distinct chemical compositions and moisture levels, resulting in variations in their energy content. As a general approximation, textile materials exhibit energy contents ranging from 16 to 25 MJ/kg.It is important to consider the specific fabric characteristics and energy conversion technologies employed to determine the precise amount of energy produced from 1 kg of fabric waste. These factors influence the efficiency and effectiveness of energy recovery processes and contribute to the overall sustainability and resource utilization of the textile industry.

The reduction of textile waste in landfills can be significantly achieved through the implementation of product redesign, manufacturing process optimization, and supply chain reconfiguration, with a focus on upcycling strategies to create high-value products from textile waste at the end of their life cycle. The efficiency of upcycling fabric waste can vary depending on the specific upcycling process employed and the desired outcome, which involves transforming fabric waste into new products of increased value or improved quality. Similarly, downcycling processes can also be utilized to manage fabric waste, although the resulting materials are typically of lower value or refinement compared to their original form. The efficiency of downcycling fabric waste depends on the specific downcycling process employed and the intended use of the resulting materials. For instance, the recycling of nylon fabric waste into pellets for the plastic industry presents an alternative source of raw material for plastic manufacturing processes. By transforming fabric waste into pellets, it becomes feasible to utilize the recycled material as a feedstock in various plastic-related applications. According to technical data sheets from recycling plant suppliers, the efficiency of this recycling process has been estimated to be approximately 90 %.

Implementing efficient upcycling and downcycling strategies for fabric waste contributes to waste reduction, resource conservation, and the development of sustainable practices within the textile industry.

Table 1. Current treatment and disposal methods of fabric waste.

Current treatment/ disposal method	**Amount (t per year)**	**Estimated efficiency factor of treatment options /recovery technology**	**Recovered material or energy**
Cotton fabric waste			
Recycling: Export for fibre recovery	4200	0.90	3780t
Reuse: upcycling	286.8	0.75	215.1t
Reuse: down cycling	720.9	0.53	382t
Energy recovery: use for industrial boilers	102.3	0.90	1841GJ
Energy recovery: Co-processing at cement kiln	61.5	0.90	1107GJ
Polyester fabric waste			
Reuse: upcycling	42	0.83	34.86t
Reuse: down cycling	267.5	0.50	133.75t
Energy recovery: Co-processing at cement kiln	4842.2	0.90	87,159.6GJ
Energy recovery: Waste to energy plant	482	0.90	8,676GJ
Landfilling	852.5	-	-
Other	84.8	-	-
Nylon fabric waste			
Recycling: pellet manufacturing for plastic industry	5300	0.90	4470t
Reuse: upcycling	23.4	0.63	14.7t
Reuse: down cycling	20.3	0.54	10.9t
Energy recovery: Co-processing at cement kiln	386	0.90	6,948 GJ
Energy recovery: use for industrial boilers	883.6	0.90	15,904.8GJ
Landfilling	98	-	-
Other	28	-	-
Mixed fabric waste			
Energy recovery: Co-processing at cement kiln	4089	0.90	73,602GJ
Energy recovery: Waste to energy plant	1411	0.90	25,398GJ
Landfilling	2267.8	-	-
Other	423.5	-	-

Table 1, presented above, provides an overview of the different recovery pathways employed for fabric waste, along with the corresponding materials that have been successfully recovered. The table also includes the efficiency of each technology utilized in the recovery process, which was considered in the subsequent calculations.

The results presented in Fig. 3 provide insights into the economic value of fabric waste, while Table 2 presents the specific details regarding the recovered materials and energy from the waste, along with their corresponding economic value.

Fig. 3 highlights the economic potential inherent in fabric waste management, showcasing the value that can be derived from effective recovery and utilization of these resources. Table 2 further complements this by providing a comprehensive breakdown of the recovered materials and energy, quantifying their economic significance within the context of waste management practices.

In 2022, a total of 9,041.31 tons of materials were recovered through various material recovery routes, and a significant amount of energy, amounting to 220,636.4 GJ, was recovered from different energy recovery routes. These recovery figures were obtained from the total fabric waste generated, which amounted to 26,819.3 tons.

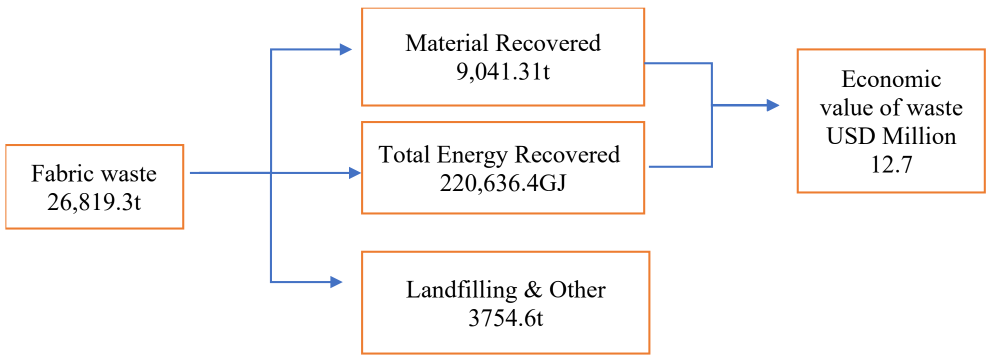

Fig. 3. Economic value of fabric waste

It is worth noting that the actual material recovery rate for fabric waste in 2022 was calculated to be 33%. This indicates the proportion of fabric waste that was successfully recovered and diverted from landfill or other disposal methods. The achieved recovery rate signifies the effectiveness of the implemented recovery strategies and highlights the potential for further improvement in the management of fabric waste within the industry.

Table 2. Material and energy recovered from waste & Economic value of the waste

Current treatment/ disposal method	**Recovered material (t)**	**Recovered energy (GJ)**	**Economic value of the material through saving of original material production (USD)***
Cotton fabric waste			
Recycling: Export for fibre recovery	3780		5,670,000
Reuse: upcycling	215.1		322,650
Reuse: down cycling	382		573,000
Energy recovery: use for industrial boilers		1841	46,540.8
Energy recovery: Co-processing at cement kiln		1107	6150
Polyester fabric waste			
Reuse: upcycling	34.86		69,720
Reuse: down cycling	133.75		267,500
Energy recovery: Co-processing at cement kiln		87,159.6	484,220
Energy recovery: Waste to energy plant		8,676	48,200
Landfilling			-
Other			-
Nylon fabric waste			
Recycling: pellet manufacturing for plastic industry	4470		4,470,000
Reuse: upcycling	14.7		26,460
Reuse: down cycling	10.9		19,620

Energy recovery: Co-processing at cement kiln		6,948	38,600
Energy recovery: use for industrial boilers		15,904.8	141,100
Landfilling			-
Other			-
Mixed fabric waste			
Energy recovery: Co-processing at cement kiln		73,602	408,900
Energy recovery: Waste to energy plant		25,398	141,100
Landfilling			-
Other			-
Total	**9,041.31**	**220,636.4**	**12733760.8**

*Additional data used for calculation of the economic value of fabric waste

Price of recycled cotton fibre USD 1.5/kg, Price of cotton fabric USD 3.25/kg, Calorific value of coal 27 MJ, Price of 1t of coal USD 150, Price of 1kg of desal (for Industrial boiler operation) USD 1.157, Calorific value of desal generate 45.5 MJ/kg, Calorific value of fabric 20 (MJ/kg), Price of polyester fabric USD 2/kg, Price of nylon fabric USD 1.8/kg, Price of recycled pellets USD 1/kg, 1USD = LKR 315

4 conclusions

The investigation revealed that fabric waste constitutes a notable proportion of the production process, with a waste intensity rate of 9.5 %. The specific types and quantities of fabric waste generated vary significantly based on factors such as industry classification, technology employed, manufacturing processes, and customer specifications and designs. Additionally, this study aimed to identify the prevailing waste treatment and disposal practices adopted by these industries for managing their fabric waste. Furthermore, an estimation was made regarding the extent of material and energy recovery achieved from fabric waste. This assessment encompassed the evaluation of the total economic value derived from the circulation of materials within circular pathways. By considering the recovery rates and economic implications, a comprehensive understanding of the current level of material and energy recovery from fabric waste was attained. This investigation serves as a valuable contribution to the field by shedding light on the magnitude of fabric waste generation and the approaches employed for waste management within various industries. Additionally, it offers insights into the potential economic gains associated with the recovery and reuse of materials, contributing to the development of sustainable and resource-efficient practices within the textile sector.

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