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Fashion and textile waste management in the circular economy: A systematic review

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ABSTRACT

This paper presents a systematic review of waste management within the circular economy (CE) principles, specifically focusing on the fashion and textiles industry. It examines the current state of waste generation, and management strategies in fashion and textiles, emphasizing the environmental impacts and underscoring the need for sustainable practices. The study explores the potential opportunities for waste reduction, resource conservation, and stakeholder value creation. An initial selection of 243 research papers was narrowed to 104 for in-depth analysis. Five primary research methodologies—case studies, surveys, reviews, reports, and book chapters—were identified, spanning seven key research areas within the fashion waste management. Findings indicated that around 70 % of studies concentrated on waste management strategies, including reuse and recycling and transition to a circular economy. The analysis also identifies major challenges, drivers and barriers to implementing fashion waste management policies, addressing the technical implications of waste management across various aspects, including design, manufacturing, supply chains, policy, economic factors, consumer behavior, and business models. Manufacturers are looking to implement CE strategies in fashion and textile waste management, demonstrating significant potential for innovation and benefits such as reduced environmental impact, cost savings, and enhanced brand reputation engaging stakeholders from different dimensions. The paper concludes by discussing the implications for theory, policy, practice, and future research directions. It argues that, although notable challenges persist, there are substantial opportunities to advance waste recycling within the fashion and textiles sector.

1. Introduction

1.1. Present scenario, research problems and statement

Every year, more than 100–150 billion pieces of garments are produced, consuming 93 billion cubic meters of water, yielding 1.2 billion tons of CO_2 as atmospheric emission, and 500 thousand tons of microplastic fibers dumped into oceans (Gazzola et al., 2020). Moreover, globally around 92 million tons of textile waste are accumulated at different phases of their life cycles; amongst those, 50 % of trash is mustered at a post-consumption level. With only 15–20 % of waste is collected for reuse and recycling and more than 80 % of clothing waste is discarded in landfills for dumping and/or incineration leading to higher carbon footprint, energy, and raw material losses (Gupta et al., 2022; Shamsuzzaman et al., 2023).

The fashion industry has undertaken numerous efforts to meet the demand for sustainability such as launch of eco-friendly products, transparent supply chain, reduction of environmental consequences, recycling, reuse, and manufacture of new waste-based products (Kim et al., 2021; Li et al., 2021). Supporting zero-waste design, reuse, reparability, and resource-sharing practices also maximizes a product's life cycle, from origin to manufacturing, and from consumption to disposal (Chen et al., 2021). Specific laws are mandatory to implement for proper waste disposal, since it negatively affects the landfills, emitting

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methane, and polluting groundwater from toxic leachate (Han et al., 2017). During processing and post-consumption, clothing waste management must be checked with circular economy (CE) regimes as waste is considered a resource, and by adopting reverse logistics, the waste materials can potentially be added back to their supply chain at various points (Islam et al., 2025). Fashion industry must promote sustainability by emphasizing longer-lasting products, utilizing and recycling resources, and appropriately disposing any item at the end of their useful lives (Durham et al., 2015; Semba et al., 2020). Upcycling or material recycling techniques is also gaining popularity as customers' concerns about sustainability issues are rising in recent days (Wang et al., 2020).

Over 50 % of clothing waste is generated during post-consumption period, and effective recycling policy can substantially reduce the environmental impact caused by waste (DeVoy et al., 2021). Furthermore, research in this area could create employment opportunities in recycling and upcycling industries, benefiting local economies. However, fashion industries on a global scale lack strategic plans in place and their implementations for sustainability in supply chains of waste collection and distribution, manufacture of waste-based products, technological advancements, automation, and adequate infrastructure. Socio-economic and behavioral aspects of waste recycling and their impact on employment still have challenges to overcome.

Despite an increased focus on clothing waste recycling, numerous areas still need to improve. Apart from the clothing industry, there are other areas of applications for technical/ functional purposes such as medical textiles, smart textiles, automobiles, etc. Moreover, high-performance fibers, for instance, carbon and glass fibers are widely used in fiber-reinforced composites. Composite materials are gaining widespread adoption across diverse industries from household items to components for spacecraft or nuclear power plants due to their prolonged service life coupled with lower maintenance costs and, in the case of lightweight composites, lower energy consumption throughout a product's life (Pakdel et al., 2021). Common materials used in textile composites are high-performance fibers such as carbon, glass, Aramid, Kevlar, ceramics, surface-modified natural fibers, etc along with polymer matrix. According to Statista, the global market value of advanced composite materials is projected to reach USD 59.6 billion by 2026 and USD 144.5 billion by 2028. It is estimated that a total of 43 million tonnes of composite waste will be generated by 2050. This escalation raises significant environmental concerns and underscores the pressing need for effective composite waste management solutions. However, managing the end-of-life disposal of composite materials presents significant challenges. Current disposal methods including landfilling and various recycling techniques, have their limitations (Statista, 2021). Innovative approaches are essential to integrate composites into a circular economy, maximizing their value and minimizing environmental impact. Despite these challenges, research works are ongoing to identify effective recycling technologies to ensure sustainable practices in composite material usage. Nevertheless, the majority of CE (Ellen MacArthur Foundation, 2017) concepts aimed at textiles are focused on reusing, recycling, and repurposing both natural and synthetic textile waste via mechanical and chemical recycling methods. Mechanical recycling is suitable for natural-based fiber (i.e. cotton) though silk and wool fibers are suitable for chemical treatment. Synthetic fibers are suitable for both types whereas mechanical recycling is fit for polyester fiber recycling. Few companies are introducing PET recycling to mitigate the environmental issue and reduce the dependency on virgin polyester fiber.

However, discussions on a CE model for textile materials and clothing are very limited when the issues of advanced manufacturing and novel materials are raised. Recently, wearable electronics or smart clothing have become popular among users as they get smarter, more flexible, and more fashionable (Chae and Hinestroza, 2020; Park et al. 2019). In smart clothing, electronics are integrated inside the flexible textile structure to introduce innovative functionalities in apparel that aim for the wearers to seamlessly interact with devices connected to it for heart-rate monitoring, blood pressure measurements, and others. Research on smart textile-based clothing has been growing in the last few decades, with a primary emphasis on health monitoring, mobility, and improving comfort (Younes, 2023). Consequently, this is gaining space in redefining the future of the fashion and apparel industry, as these textiles and their features can be customized to reflect the wearer's identity. In addition, by application, the hygiene segment is expected to be the largest segment in the technical textiles market. Nonwoven fabrics are used as an alternative to conventional textiles in hygiene products due to their excellent properties, and cost-effectiveness. However, there is a lack of study in waste recycling/management for technical/ functional textiles. Hence technical textiles need to be discussed in the context of a circular economy.

1.2. Research gaps, aims and objectives

The fast fashion tendency has doubled the production over the decade where over 50 % of apparel are thrown away within a year (Ellen MacArthur Foundation, 2017; Dissanayake and Weerasinghe, 2021). Roughly 90 million tons of abandoned clothing are produced annually, with nearly 70 % of the clothing being reusable, however, recycling rate is still under 10 % (Yavari, 2019; Fan et al., 2024; Xu et al., 2022). The types, qualities, and volumes of waste as well as the recycled industry and management regulations are important factors in recycling (Li et al., 2021; Gu et al., 2021). The technological advancements, cost benefits analysis, understanding of market dynamics, comprehensive business models, public awareness, and standardized policies and regulations are still a matter of concern for implementing CE in fashion waste management (Dissanayake and Weerasinghe, 2021; de Aguiar Hugo et al., 2021; Takacs et al., 2022; Leal Filho et al., 2019; Hole and Hole, 2020). Moreover, material innovation, creative techniques for recycling or repurposing can increase the rate of recycling (Kazancoglu et al., 2020). Closing these knowledge gaps could have a major impact on the fashion and textile industries' circular economy by encouraging sustainable practices and lessening environmental impacts. This could have a major impact on fashion and textile circularity by encouraging sustainable practices and lessening environmental impacts. Driven by key literature analysis, we have formulated the following research aims and objectives.

i. To critically analyze existing scenarios of fashion and textiles waste generation and management strategies
ii. To analyze the recycling potentials of fashion waste in the context of economic, commercial feasibility, and environmental sustainability
iii. To explore diverse applications of textile waste and how these benefit wider stakeholders
iv. To understand the roles of stakeholders in fashion and textiles waste management in the transformation to Circular Fashion Economy model

The remainder of this article is organized as follows: explanation of the SLR methodology, discuss the results including descriptive, and thematic analysis of the contents of reviewed resources. Finally, findings are discussed and followed by a conclusion that includes the implications, limitations and future research directions.

2. Methodology

This research paper employs Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to conduct a systematic literature review. A range of sources were analyzed for this systematic literature review (Liberati et al., 2009). These sources were accessed using databases like Web of Science, Elsevier, Science Direct, Scopus, Springer, MDPI, Wiley, ACS, and Google Scholar. The maximum results appeared on Web of Science followed by Elsevier Science Direct, Springer, MDPI, Wiley, and others, respectively. Various databases were utilized to avoid any bias within the identification and selection process which has in return maintained the excellent quality and reliability of this mini systematic review. The sources analyzed were selected using a transparent selection process based on PRISMA to refine the process undertaken for this systematic review. The terms and keywords scrutinized as Circular Economy, green marketing, greenwashing claims, organic, eco-friendly, circular economy, fashion industry, and textile industry. Boolean Syntax, AND, and, OR along with punctuation marks, were utilized to find the most relevant work by researching these terms. The keywords were searched within the titles and abstracts of the research outcomes. The classification was then narrowed down to the scholarly research work to the peer-reviewed and cited research papers. In total, 280 research resources were identified, which were further narrowed down to 243 based on their relevance to the topic by examining the abstract. Further to shortlist 104 research resources to produce this systematic review, 139 research resources were excluded. Finally, 104 papers were considered for analysis including journal articles 73, book chapters 9, and news, reports, websites 22. It was found that 2021 witnessed the highest increment of research in the field of Circular Economy within the context of the fashion and textile industry within the context of waste management. Therefore, the conceptual framework extends beyond the period from 2010 to 2024, determined for the PRISMA methodology. The inclusion and exclusion criteria for this systematic review is based on relevancy, language and other factors which are mentioned in Table 1.

Fig. 1 illustrates the PRISMA refinement process undertaken to build the research library for this review. Due to irrelevancy and duplicity, the initial 280 research resources were narrowed down to 243. After sources were screened for titles and abstracts, another 82 research resources were excluded. Further sources were assessed for eligibility and another 57 papers were excluded from review lists and finally, 104 research items were filtered and finalized for the review.

3. Results and discussion

This section is divided into three analytical approaches: (i) descriptive, (ii) content, and (iii) thematic analysis. The descriptive analysis provides an overview of published research paper patterns, methodology, and contribution areas between 2015 and 2024, demonstrating a greater emphasis on fashion and textile waste reduction. Content study looked at major approaches, goals and contributions, and waste management solutions. Furthermore, thematic analysis divides findings into

Table 1
Inclusion and exclusion criteria of the review.

Keywords	"Circular Economy" AND "Textile Waste" AND "waste management" OR "Recycling" OR "waste" AND "fashion industry" OR "textile industry"		
Timespan	2000–2024		
Search Systems	Elsevier Science Direct, Google Scholar, Web of Science, Scopus and others		
Criteria	Source	No. of exclusions	No. of inclusions
	Journal Articles	79	73
	Book Chapters	16	9
	Conference Papers	4	0
	News Articles, Industry reports, Websites	38	22
	Masters/Doctorate Thesis	1	0
	Legal and Policy Articles	1	0
	Others	0	0
Language	English	139	104
	Translated to English	0	0
	All other languages	0	0
Others	Irrelevant to the research area	0	0
	Inapt or irrelevant to the topic	37	0
	Not accessible	0	0
	Duplicates	0	0

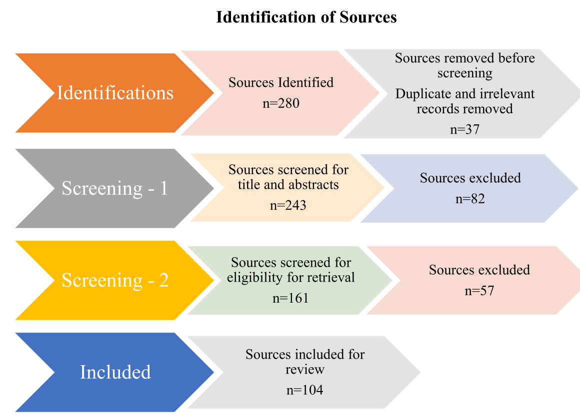

Fig. 1. Refinement process based on PRISMA guideline.
Adopted from Moher et al. (2009).

circular economy practices, recycling technologies, and supply chain sustainability. The analysis, taken together, provides useful insights for future research as well as practical applications.

3.1. Descriptive analysis

A total of 104 papers were considered for this systematic literature review from 38 nations relevant to waste management, recycling potentials and circular economy. The key findings including research methods, year of publications, research focus areas, research findings, gaps/limitations, and name of the published journal are shown in Table 2. Mostly five types of research methods were identified such as (i) case studies (28), (ii) reports (21), (iii) review papers (45), (iv) surveys (10), and (v) book chapter depicted in Fig. 3. Over 70 % papers focused waste management, reuse and recycling strategies, and the shift to a circular economy. We identify seven distinct types of key research focus depicted in Fig. 4 including, fast fashion production (FFP), environmental sustainability (ES), waste management (WM), life cycle assessment (LCA), reuse and recycling strategy (RRS), composite recycling (CR), and transition to circular economy (TCE).

3.1.1. Yearly distribution of reviewed research

For systematic literature review, the selected papers were published between 2010 and 2024. Initially, the fashion and textile waste management-related resources were identified narrowly, however, gained prominence from 2017 when the United Nations (UN) announced 17 Sustainable Development Goal (SDG). The abundance of relevant and updated sources reviewed for this paper is from the 2017s to 2024s. Within the context of this systematic review, maximum 26-articles utilized were analyzed in 2021s. It is critical to note that most of the research articles used in this review were published during the last four years (2020–2024), which accounts for over 70 % of the articles. The growth in the number of research articles reveals the heightened interest of the researchers in this specific area of study ensuring sustainable practices in fashion and textile waste management. Fig. 2 shows detailed distribution of the reviewed papers yearly.

3.1.2. Types of research methods used

The literature evaluation revealed five types of research approaches: reviewed articles (37), case studies (28), reports (21), surveys (10), and book chapters (8) (Fig. 3). The majority of the reviewed articles (37) summarized existing data and gave in-depth insights into the studied domains. The analysis of 28 case studies highlights the importance of practical, contextual, and real-time implications. In our analysis, we have identified the practices including Patagonia's Worn Wear Program (USA), H&M's Garment Collection Initiative (Global), H&M's Garment Collection Initiative (Global) etc. that are successfully implementing

Table 2
List of analyzed resources in terms of research methods, focus, findings, gaps, journals.

Sl. No	Authors and year of publication	Research methods	Research focus	Key findings	Research gap/ limitations	Journal Name
1	(United, 2020)	Report	FFP	Investigated the global fashion production facts, scenarios, and challenges	Need diversification	Website
2	(Ellen MacArthur Foundation, 2017)	Report	FFP	Fast fashion production aligns with circular manufacturing	Lack of appropriate circular design in fiber, fabric and cloth	Website
3	(Gazzola et al. 2020)	Survey	FFP	Influences of sustainability and circularity on perception of fashion world	Lack of consumer concern design on circularity	Sustainability
4	Connecticut's, 2021	Report	FFP	Emphasizes hybrid fashion organization and possible impacts	Inappropriate policies	Website
5	Jia et al., 2020	Review	FFP	Focused on practices, enablers, barriers, and indicators to evaluation of sustainable performance	Barriers to sustainable practices	Journal of cleaner production
6	Hossain et al., 2024	Review	FFP	Collaboration and knowledge exchange on innovation	Higher cost and modern technologies	Journal of Open Innovation: Technology, Market, and Complexity
7	Kim et al., 2021	Survey	FFP	Emotional values affect product attitudes	Need product attitudes and behavior intention	Sustainability
8	Kohler et al., 2021	Book chapter	FFP	Value chains in the manufacturing and retailing of apparel products in EU	Consumer awareness, technical disability	Website
9	Blackburn, 2015	Book chapter	FFP	Sustainable production, processing, and recycling	Regular design	Elsevier
10	Subramanium, 2018	Book chapter	FFP	Sustainable business strategies	Technology, policies and design	Textile Institute
11	Younes, 2023	Review	FFP	Smart application of fashion product	Policies, methodologies	Journal of Industrial Textiles
12	EPA, 2024	Report	RRS	Analyzed data on reuse and recycling prospects	Poor policies and supply chain	Website
13	Awgichewe al., 2021	Case study	RRS	Effects of recycled fibers and yarn on weaving	Recycled yarn are less suitable	Journal of Modern Materials
14	Collective Responsibility, 2018	Report	RRS	Focuses on standardized regulation on reuse and recycling	Significant changes are required for collection and recycling	Website
15	Durham et al., 2015	Book chapter	RRS	Technical design for recycling	More rigorous research	Sustainable Apparel
16	Pakdel et al., 2021	Review	RRS	Recycling of carbon fiber-reinforced materials	Lack of strategies to deal with expensive materials	Resources, Conservation and Recycling
17	European Commission, 2016	Report	RRS	Impact of digital application	Technology	Website
18	Gu et al., 2021	Case study	RRS	Practices recycling policies in zero waste potential	Consumer awareness and income level	Journal of cleaner production
19	Haule et al., 2016	Case study	RRS	Regenerated cellulose fiber from waste garment	Policies	Journal of cleaner production
20	Hole and Hole, 2020	Review	RRS	Policies and incentives within recycling and reuse resources	Policies and legislations.	Sustainable Production and Consumption
21	Juanga-Labayen et al., 2022	Review	RRS	Challenges and opportunities in recycling	Policies and technologies	Textiles
22	Linn Lofling, 2022	Report	RRS	Focused on resource reuse and recycling	Take responsibility by manufacturers, and consumers	Website
23	Li et al., 2021	Case study	RRS	Supply chain of raw materials among factories	lack of technical support, government, brands, and qualified recycling contractor	Journal of cleaner production
24	Mathews, 2016	Report	RRS	Reuse and recycling prospects and consumer engagement	Consumer awareness	Website
25	Patagonia, 2017	Review	RRS	Garment recycling technique	Supply chain	Website
26	Pavarini, 2021	Report	RRS	Recycling of cotton waste	Barriers are regulators and investors	Website
27	Aus et al., 2021	Report	RRS	Upcycling design process	Policies	Fashion and Textiles
28	Feleke Fera, et al., 2022	Case study	RRS	Cotton woven recycling for eliminating sound pollution	-	International Journal of Sustainable Engineering
29	USEPA, 2022	Report	RRS	Global reuse and recycling potential	Policies and awareness	Website
30	Wang, 2010	Review	RRS	Fiber and textile recycling	Product diversification	Waste and biomass valorization
31	Yavari, 2019	Case study	RRS	Simulation approach for textile recycling	Lack of alternative methods	Leddy Library
32	Alom, 2016	Survey	ES	Waste management practices and NGO engagement	Poor concern on environmental strategies and hazards	American Journal of Civil Engineering
33	Amato et al. 2019	Case study	ES	Waste management approach could reduce up to 200 times the impact of the climate change	Primary resources are poorly designed and utilized	Renewable and Sustainable Energy Reviews
34	Gupta et al., 2022	Book chapter	ES	Impact of zero waste pattern cutting on environment and society	Complex supply chain	Emerging Trends to Approaching Zero Waste

(continued on next page)

Table 2 (*continued*)

Sl. No	Authors and year of publication	Research methods	Research focus	Key findings	Research gap/ limitations	Journal Name
35	Shamsuzzaman et al., 2021	Case study	ES	Identified unsustainable practices in denim manufacturing	Faulty ETP practices	Journal of cleaner production
36	Shamsuzzaman et al., 2023	Case study	ES	Worst practice areas are air pollution and greenhouse gas emissions.	Poor policies on chemical usages and reuses	Journal of cleaner production
37	DoE Department of Environment, 2016	Report	ES	Concerned with manufacturing, and disposal practices	Inappropriate policies	Website
38	Emin, 2021	Review	ES	Emissions released from textile industry	Crisis of sources and energy utilization	Euro Economica
39	Eurostat, 2024	Report	ES	Renewable energy sources that can be utilized in fashion and textile manufacturing	Lack of policies on energy use and practices	Website
40	International Air Transport Association, 2022	Report	ES	Textile industry air quality	Poor willingness	Website
41	Islam et al., 2021	Review	ES	Environmental sustainability standards and practices	Negligence in incorporating environmental standards	Journal of Fashion Marketing and Management,
42	Leal Filho et al., 2019	Review	ES	Socio-economic, environmental, and ecological advantages of safe mansufacturing	Technology, policies	Journal of cleaner production
43	Payet, 2021	Case study	ES	Carbon footprint	Hampering environmental elements	Sustainability
44	Plakantonaki et al., 2023	Review	ES	Eco-friendly textiles, restricted substances, and eco-labeling	Existing design process	Sustainability
45	Xu et al., 2022	Review	ES	Environmental protection and sustainable development	Recycling supervision mechanism's imperfections, the trust crisis and a lack of recycling channels	Sustainability
46	Shamsuzzaman et al., 2023	Book chapter	WM	Focuses waste management policies including reuse and recycling	Need upgrading/advanced recycling methodologies	Springer Nature
47	Bukhari et al., 2018	Case study	WM	Focuses on EPR policy in waste management	Challenges to identifying new market for waste-based cloth	Waste Management & Research:
48	Czajczyńska et al., 2017	Review	WM	Applicability of pyrolysis in recycling	Poor technological improvement	Energy Procedia
49	Dissanayake and Weerasinghe, 2021	Review	WM	Resource recovery and detrimental environmental impact	Lack of effort toward physical recycling	Circular economy and sustainability
50	Euromonitor International. 2022	Report	WM	Focused on stakeholders' awareness	Lack of awareness and policies	Website
51	European commission. 2022.	Report	WM	EU clothing consumption, disposal, and circularity	Standardized policies and practices	Website
52	Fan et al., 2024	Case study	WM	Fabrication of denim felt from waste	Methodological	Nano Micro Letters
53	DeVoy et al., 2021	Review	WM	Post-consumer waste management	Wealthier communities generate more waste	Waste Management
54	Noman et al., 2013	Survey	WM	Economic and employment potential in waste management sector	Policies	Waste management & research
55	Paco et al., 2021	Survey	WM	Sustainable clothing consumption	Disparities in use and disposal behavior	Textile Research Journal
56	Park et al., 2019	Survey	WM	Clothing comfort	-	Ergonomics
57	Pensupa et al., 2017	Review	WM	Waste recycling for environmental sustainability	Appropriate recycling method	Chemistry and Chemical Technologies in Waste Valorization
58	Perry et al., 2017	Survey	WM	Product designer's motivation	Appropriate methods	International Journal of Fashion Design, Technology and Education
59	Tanvir and Mahmood, 2014	Survey	WM	Waste management in knit industry	-	Journal of Environment and Earth Science
60	Tecchio et al., 2017	Review	WM	Impact reduction, lifetime extension and residual waste reduction	Standards and regulations	Journal of Cleaner Production
61	Textile Exchange, 2020	Report	WM	Focuses on utilization of raw materials	Supply chain	Website
62	Utebay et al., 2020	Book chapter	WM	Management methods and process	Policies	Waste in textile and leather sectors
63	Wagaw and Babu, 2023	Review	WM	Textile waste statistics, its contribution to pollution and recycling	Scarcity of resources, consumer excessive purchase behavior	AATCC Journal of Research
64	Koszewska, 2018	Review	TCE	Transition of linear to circular impacting production and consumption methods	linear economy model still extremely apparent	Autex Research Journal
65	Mathews, 2016	Report	TCE	Tackling misconceptions in circular textiles	Technological shortages	B2B magazines
66	Chae and Hinestroza, 2020	Case study	TCE	Proposed materials circularity index (CI) and clothing utility (CU)	Poor technological improvement	Materials Circular Economy
67	Chen et al., 2021	Review	TCE	Redesign linear economy to circular	Poorly waste management of post-consumer clothes	Materials Circular Economy

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Table 2 (*continued*)

Sl. No	Authors and year of publication	Research methods	Research focus	Key findings	Research gap/ limitations	Journal Name
68	de Aguiar Hugo et al., 2021	Review	TCE	Identified obstacles and barriers in implementing CE	Poor consumer awareness	Sustainability
69	Dissanayake and Weerasinghe, 2021	Review	TCE	Product design, research and business innovation	Design, technology, methodology	Circular economy and sustainability
70	Dumee, 2022	Review	TCE	Focused on greener fabrication and recycling routes	Technical and societal challenges	Circular economy and sustainability
71	Fashion for good, 2019	Report	TCE	Focused on transition linear to CE	Multidisciplinary approach is needed	Websites
72	Han et al., 2017	Case study	TCE	Upcycling for sustainable design	Poor design on economic and societal	The Journal of Design, Creative Process & the Fashion Industry
73	Hartley et al., 2022	Case study	TCE	Oriented circular supply stream	CE design options	Journal of Industrial Ecology
74	Idiano, 2019	Review	TCE	Implementation of CE model	Policies and awareness	Social Sciences
75	Kazancoglu et al., 2020	Case study	TCE	Circular supply chain for sustainability	Identified 25 barriers	Sustainable development
76	Korhonen et al., 2018	Review	TCE	Environmental sustainability in implementing CE	Rigorous research required	Ecological Economics
77	Saha et al., 2022	Survey	TCE	Challenges and opportunities of implementing CE	Lack of financial, technological and human resources	Supply chain sustainability in small and medium sized enterprises
78	MacArthur, 2015	Report	TCE	Focused on implementing CE methodologies	Technical instability	Website
79	Akter et al., 2022	Case study	TCE	Scopes of circular economy to achieve Sustainable Development Goal (SDG)	Lack of policies create loss in profit	Cleaner Environmental Systems,
80	Malinverno et al., 2023	Survey	TCE	Circular work wear in textile waste management	Little research on categorized material waste flows of work wear	Resources, Conservation and Recycling
81	Piippo et al., 2022	Case study	TCE	Understanding of garment quality in a circular economy.		Sustainability
82	Reserve Resources, 2017	Review	TCE	Circular transition in supply chain	Policies	Websites
83	Schroder, 2020	Book chapter	TCE	Transition from linear to circular	Existing supply chain, product design	Royal University Press
84	Takacs et al., 2022	Case study	TCE	Sustainable circular strategic management framework	Unwillingness to engage in trade-offs, shortage of resources, and lack of knowledge	Journal of Cleaner Production
85	Wang et al., 2020	Case study	TCE	Blockchain in CE	Lack of policies	Computers in Industry
86	Daystar et al., 2019	Case study	LCA	Asian countries reported the highest values of clothing disposal	Consumer's attitude matters	Journal of Textile and Apparel, Technology and Management
87	Veske and Ilén, 2021	Review	LCA	End of life of textile product	Serious lack of legislation	The Journal of The Textile Institute
88	Earley., 2017	Case study	LCA	Circular design opportunities through LCA	Systems and user perspectives	The Design Journal,
89	Resta et al., 2016	Review	LCA	LCA methodology on decision-making	Existing designing process of product	Journal of cleaner production
90	Semba et al., 2020	Case study	LCA	Circular design opportunities through LCA	Systems and user perspectives	Sustainability
91	Xie et al., 2021	Review	LCA	Life cycle evaluation through recycling	Existing clothing-recycling system cannot be fully utilized	Sustainability
92	Huang et al., 2024	Review	LCA	Circular design and recycling opportunities through LCA	Systems and user perspectives	Journal of Cleaner Production
93	Wondmagegnehu. et al., 2021	Case study	CR	Fabrication of textile composite production, their disposal, and remanufacturing process	Need improved composite recycling technique	Materials today
94	Chatziparaskeva et al., 2022	Review	CR	Composite material waste management	Poor recovery strategies, design aspects,	Microplastics
95	Das et al., 2021	Review	CR	Potential solutions for recycling medical textiles	Lack of advanced technology and research	Materials Circular Economy
96	Krauklis et al., 2021	Case study	CR	Recycled-based composite materials applicability and their potential manufacturing steps	Require optimal recycling methods	Journal of Composites Science
97	Mativenga et al., 2017	Case study	CR	Generation of composite waste from production operations, and recycling prospects	Poor manufacturing operations	Procedia Cirp,
98	Shiferaw et al., 2023	Review	CR	Sustainable recycling procedures of composite materials	Poor recycling methods	Materials Engineering Research
99	Statista, 2021	Report	CR	Focused on the composite materials value from 2015 to 2028	Policies, technologies	Website
100	Uddin et al., 2022	Case study	CR	Environmental impact of PPE and recycling	Policies and methodologies	Advanced Sustainable Systems
101	Cetin and Tayyar, 2017	Case study	CR	Recycling of non-woven and their applications	Methodology	Materials Science and Engineering
102	Wong et al., 2017	Review	CR	Compared existing policies and procedures of composite recycling	Policies and methodologies	Science China Technological Sciences

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Table 2 (*continued*)

Sl. No	Authors and year of publication	Research methods	Research focus	Key findings	Research gap/ limitations	Journal Name
103	Zhang et al., 2020	Review	CR	CE on carbon-reinforced composite materials	Need more radical recycling strategies	Composites Part B: Engineering
104	Kamble and Behera, 2021	Review	CR	Upcycling technologies on composite waste recycling	Application of techniques of upcycling waste	Textile Progress

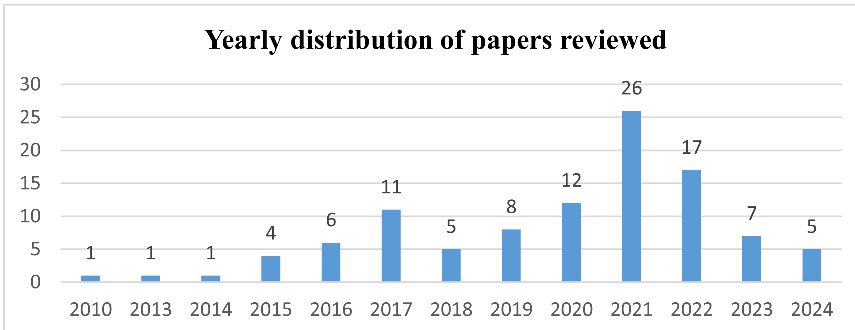

Fig. 2. Annual distribution of the sources included in the systematic review.

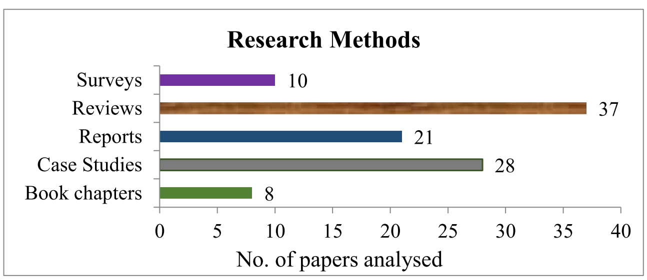

Fig. 3. Types of research methods used.

waste management practices. Report analysis from news, thesis, or any other organization that contributed relies on methodical, factual documentation and results identifying fast fashion movement and waste crisis, environmental and social impact and challenges of CE practices, consumers consciousness and government policies etc. Survey articles argued for a limited use of primary data and its implications focusing on corporate sustainability practices, brand initiatives, and impact. The examination of various types of research papers helped to identify trends, gaps, and breakthroughs in the practical application of sustainable solutions in fashion and textile waste management.

3.1.3. Key research areas

Combining TCE (22) and RRS (20) occupied 40 % of the analyzed research publications, emphasizing the need to extend material lifespans and shift from linear to circular production. WM (18) and ES (14) addressed current sustainability concerns while emphasizing waste reduction and environmental effects. Analysis of CR (12), FFP (11), and LCA (7) revealed considerable insufficient research in these fields, urging quick action for waste management in fashion and textiles. Almost 70 % of the papers assessed were associated with circular models, waste management, and reuse and recycling potentials (Fig. 4).

3.1.4. Country-wise distribution of papers

Bangladesh has the highest number of research publications (13) among 36 nations and has made significant contributions to tackling sustainability challenges in this industry. The United Kingdom, China, and America contributed 11, 11, and 10 articles, respectively, reflecting their strong emphasis on circular economy approaches in the textile industry. The Netherlands, Italy, and Germany made moderate contributions, replying to four, four, and three evaluated papers, respectively. Poland, the United Arab Emirates, Sri Lanka, Hong Kong, and Australia submitted two evaluated articles, whereas others had very limited access to only one. Furthermore, cross-regional collaborations involving EU countries, the United Kingdom, and South Asia produced eight and one publication, respectively. This distribution highlighted the importance of broader spatial implications for inclusive sustainable solutions.

3.2. Content analysis

3.2.1. Overviews of global fashion and textiles waste

Due to the fast fashion production, the global consumption of clothes

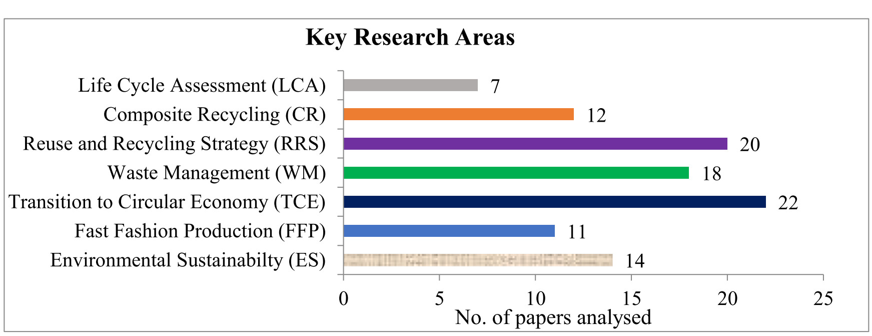

Fig. 4. Key research areas.

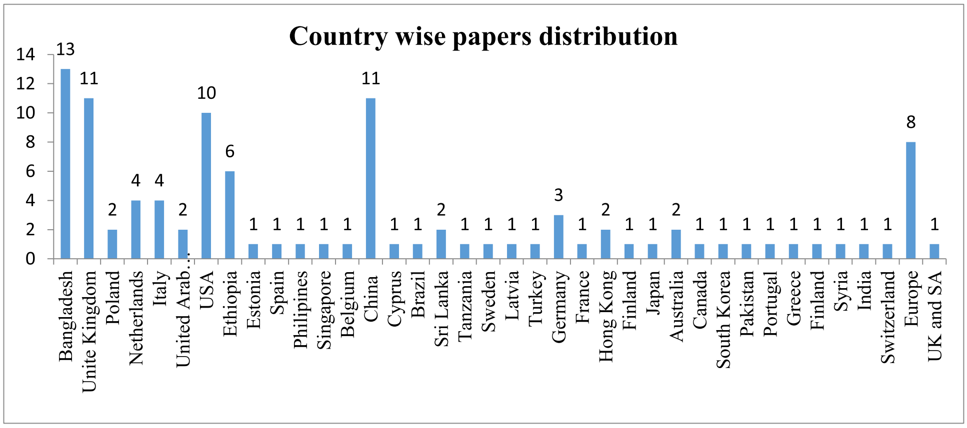

Fig. 5. Country wise distribution of papers analyzed.

will increase to 102 million tons by 2030 which will be accounted for 47 % of extra waste from fibers entering into the fashion value chain (Textile Exchange, 2020). This waste amount may be increased to 148 million tons by 2050 yearly within this domain (Reserve Resources, 2017). Fig. 6 shows the generation of textile waste globally between 2000 projecting towards 2030.

This staggering quantity of waste comes from clothing, fabrics, curtains, blankets, stuffed animals, and other cloth materials. A recent survey conducted by Connecticut, Canada showed that approximately 4 % or 96,500 tons of Connecticut's waste stream came from textile waste; 74 % (71,800 tons) of total disposed textiles are from residential sources and 26 % (24,700 tons) are from non-residential sources such as universities, state agencies, and businesses (Connecticut's Official, 2021). This scenario represents the pattern of waste generation from textiles in Europe or northern America. In terms of global phenomena, Fig. 7 shows the segmentation of solid waste generation from different stages of textiles during manufacturing. Almost 70 % solid waste generated from consumption stages such as apparel 37 % and fabric 34 %. Rest of the waste comes from resin (15 %), fiber (12 %) and dyeing (2 %) (DoE Department of Environment, 2016).

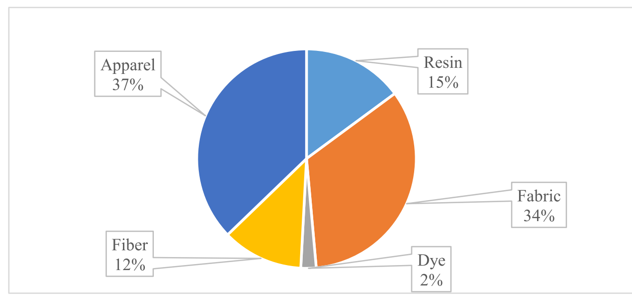

Fig. 7. Percentage of solid waste generated from textile industries.

3.2.2. *Geographically biggest waste generator*

Worldwide, trash generation per person ranges from 0.11 to 4.54 kg, with an average of 0.74 kg. The high-income countries are the responsible for the biggest waste creator, around 34 %, of the world's fashion garbage, though only 16 % lives there (Pavarini, 2021). Fig. 8 illustrates the annual landfill trash production (kg/capita) for several nations whereas Fig. 9 showing the solid clothing waste generation in 2022.

China is producing about 26 million tons of textile and clothing waste where only 3.5 million tons from that are recycled or utilized afterwards. Others country like USA, EU, Hong Kong, Bangladesh, India and Pakistan are also generated almost 17 million, 15 million, 5.8 million, 5.77 million, 7.8 million and 8.7 million tons of waste

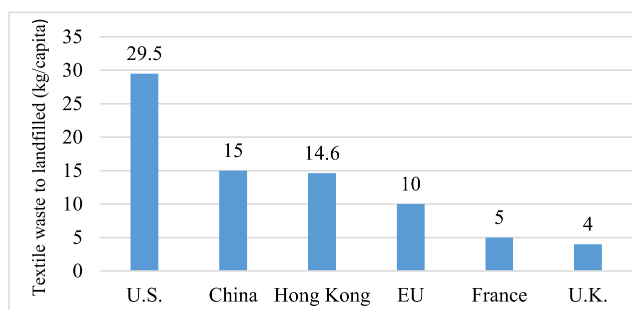

Fig. 8. Annual generation of landfill textiles (kg/capita) in 2021.

respectively (Euromonitor Internation, 2022; European commission, 2022). However, China have taken a pilot program under which almost 55 % of textile waste will be collected and recycled by 2025 (Collective, 2018). Nearly 500,000 tons of textile waste are generated in Canada

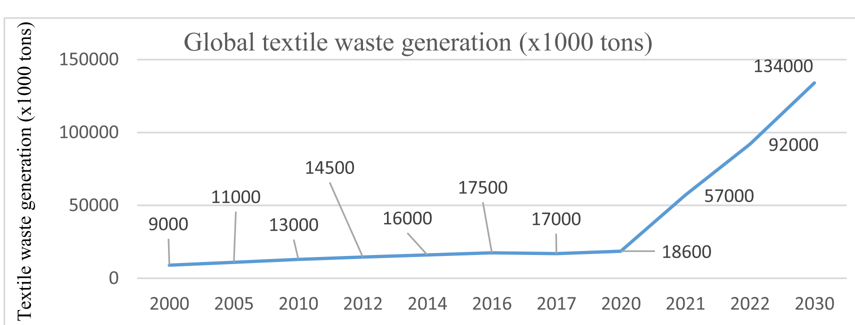

Fig. 6. Global textile waste generation in recent years (x1000 tons) (USEPA, 2022).

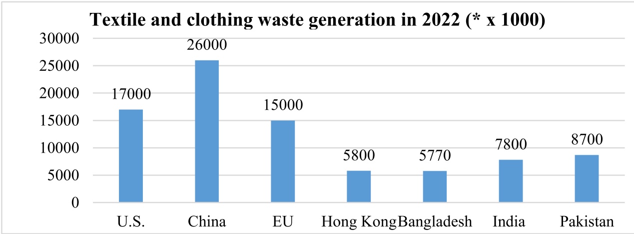

Fig. 9. Solid textile and clothing waste generation (Country wise in 2022).

each year, with 30–55 CAD estimated to be disposed of per person. Unfortunately, only 10–15 % of those clothes are reprocessed, even though, about 95 % of them can be recycled or reused.US is responsible for 169 million tons of textile waste annually where 140 million tons are discarded to landfills (USEPA, 2022). The scenario is grim in Bangladesh as well. It generates over 577,000 tons of waste every year (Pavarini, 2021; Paco et al., 2021). Surprisingly, for all the cases, 80–90 % of waste are recyclable though only 5–10 % are recycled. Besides, the cost of disposal of 1 ton waste requires $45 which results in an expenditure of hundreds of millions of dollars annually (Linn, 2022).

3.2.3. Sources and types of fashion and textile waste

Mainly textile waste comes from production and consumption stages where 30–40 % generated from different manufacturing operations including spinning, weaving, dyeing, finishing, and clothing production; rest (50–60 %) is collected from post consumption stages (DeVoy et al., 2021). Table 3 showing the varieties of sources of fashion and textile wastes generated, and Fig. 10 showing the types of textile and fashion waste generated.

Table 3
Sources and types of textile waste generation in fashion manufacturing.

Sources	Variety of wastes
Ginning	Scrap metal, cotton dust fly, cotton wastes and dust.
Spinning	Blow room cotton dust, floor sweep, scrap iron, cone made of paper, plastic scrap, ball bearing, scrap of rubber, cotton droppings, cotton flat waste, flat strips, Licker-in waste, Sliver cut, filter waste, noils, lap wastages, card fly cotton dust, sweep spinning, Tubes, pallets, cones, containers, drums, Seam waste, paper waste
Sizing of warp yarn	Polypropylene bags, tota (thread ropes), iron scrap, discharged sizing chemicals, cotton dust, cardboard, paper cone,
Modern power looms	Thread ropes of 5 ft, brass bora, paper cone, scratched paper cone, bags of polypropylene, cotton dust, dropper iron hoops, kara iron wire, and metal scrap.
Knitted fabric section	Oily discard products, iron and plastic scrap, paper cone, polythene bags, Type-B garments, wastage yarn, ragged white and colour garments.
Nonwoven section	Trimmed fibres, roll ends, plastic wraps, cardboard, nonwoven residue in production machinery.
Textile coloration	Iron barrels, containers of plastic, flat cardboard, coloured threads, plastic pieces, polypropylene and brass bag, discharge effluent dyes, and chemicals.
Packing of finished products	Both white and colored cutting rags, over lock, polypropylene bags, cardboard, fusing (petroleum based), bag made of brass.
Stitching	B-category and cut piece garments, cutting rags, polypropylene bags.
Textile materials except apparel	Sweep spinning, cut pieces of different fibers, open end sweep, cotton dirt and dust, noil, hard waste, iron container, plastic scrap, colour damage, drum and can bucket of plastic, cutting rags, polypropylene and brass bags, paper cone, rubbery scrap, ball bearing.
Post-consumption	Old and outdated-fashioned garments, distorted and defective apparel.
Fiber-reinforced Composites	Scraps, Fibers, resins, additives, offcuts, and end-of-life components.
Medical textiles	Disposable gowns and drapes, personal protective equipment (PPE), surgical textiles, bandages and dressings, hospital linens, disposable bedding and curtains
Technical Textiles	Specialized fabrics for industrial medical, and automotive applications

Fibre, yarn, and fabric scraps, as well as chemical effluents from dyeing, printing, and finishing processes, are all examples of fashion and textile production waste. These wastes are caused by material inefficiencies, overproduction, and manufacturing flaws and are 30–40 % of total waste. They contribute significantly to resource depletion and environmental damage, particularly the release of untreated chemicals into water systems. To reduce production waste, greater material optimization, advanced manufacturing techniques, and the adoption of sustainable production practices are necessary. Pre-consumer waste is made up of unsold or damaged goods that are discarded before they reach customers. Unsold items are typically the result of bad inventory management, fast fashion trends, or overproduction, whereas damaged items are the result of manufacturing quality difficulties. This trash frequently ends up in landfills or incinerator plants, wasting valuable manufacturing resources. To address pre-consumer waste, inventory management processes must be improved, demand-driven production developed, and mechanisms for reusing unsold or defective goods devised (Shamsuzzaman et al., 2025). Post-consumer waste includes clothing that people discard due to wear and tear, outgrown sizes, or changing fashion trends. Much of this waste ends up in landfills or adds to microplastic contamination, particularly synthetic fibers. Increasing recycling efforts, expanding secondhand clothing marketplaces, and encouraging customers to embrace sustainable consumption practices like donating or upcycling old clothing can all contribute to effective post-consumer waste management. In China, pre-consumption waste amounted to over 100 million tons in 2015 (Mathews, 2016). Moreover, post-consumer waste is the solid garment waste that is collected after the end of the product life cycle. It includes clothes, footwear, fashion accessories, towels, beds, and curtains. On average, these two types of waste together are around 50–60 % (Payne, 2015). Another type of waste can come from technical textiles and composites in the form of fibers, resins, additives, and specialized fabrics for industrial, medical, and automotive applications (Temesggen et al., 2022). The majority of this waste is composed of fibrous waste and washed-off chemicals, which are generally blends of natural and synthetic polymeric materials. The exact amount of this waste has not been substantiated yet (Shiferaw et al., 2023; Wondmagegnehu. et al., 2021).

3.2.4. Waste management hierarchy and techniques

A viable and effective waste management policy is crucial for minimizing environmental footprint, energy recovery, and sustainable production. In fashion industry, this could reutilize around 60–80 % of post-consumer trash that could save up to $200 billion in total (Daystar et al., 2019). In such case, effective waste management hierarchy could discuss, research, invent etc. for sustainable circular ecosystem inside fashion management. Most textile companies execute their waste management system using a waste hierarchy, zero waste principles, and a 10 R waste hierarchy (Akter et al., 2022). The hierarchy is categorized into three specific stages including (i) Design (refuse, rethink, and reduce), (ii) Consumption (reuse, repair, refurbish, remanufacture, and repurpose), and (iii) Return (recycle and recovery) (Fig. 11) –

First segment **design** depends on the smarter purchasing decisions by the end users, emphasizing the consumers to refuse to buy wasteful or non-recyclable products and establishing standards and early expectations. This could make manufacturers rethink their operations, and sourcing of materials and force them to design/implement circular fashion model. This effort will reduce waste from manufacturing operations and majority of the manufacturers adopt this policy to maintain the quality of the product. The second section **Consumption** is much critical. Reusing the products that are no longer required for their original usage are being utilized by the manufacturers to produce new products through modifications. Day by day, the popularity of the reuse

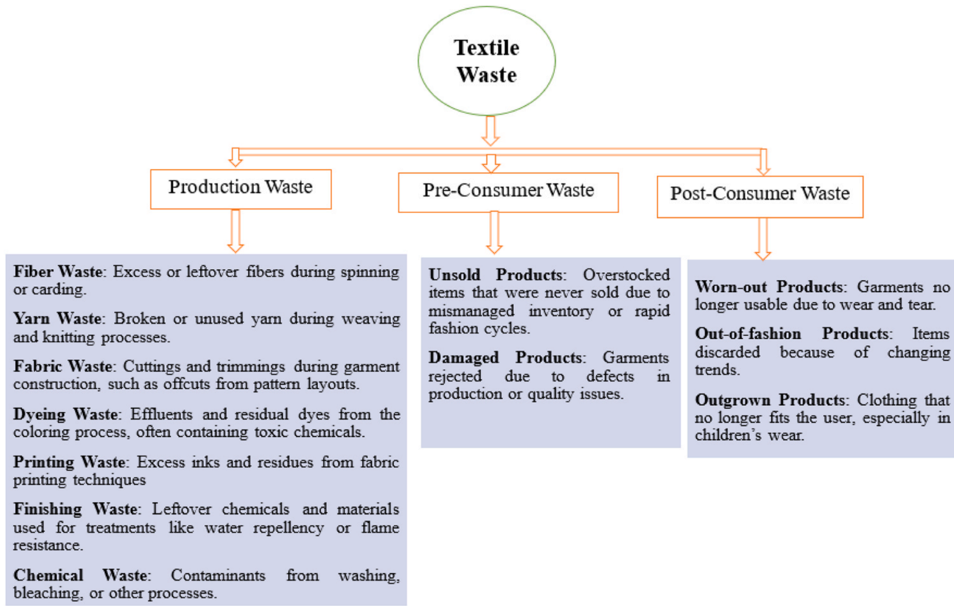

Fig. 10. Types of textile wastes.

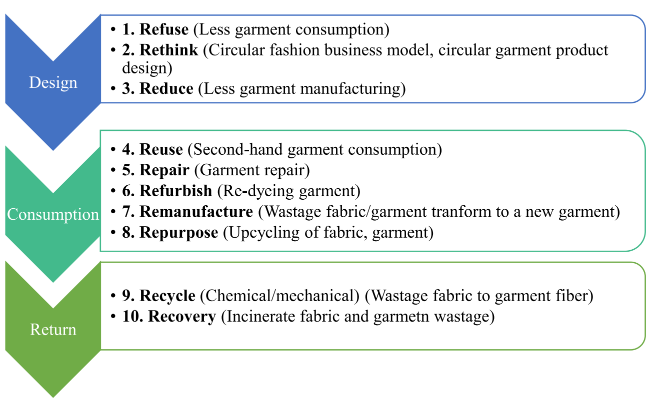

Fig. 11. Hierarchy of textile waste management.

of damaged or used garments is rising through repair, redistributed/refurbished, or remanufactured for resale. Repurpose indicating upcycling policies of the products that cannot be refused, reduced, or reused. Embracing technology may help to find new ideas and ways for repurposing the same items. The third segment **return** is the combination of recycling and recovery processes. Recycling of textile waste involves mechanical and chemical procedures whereas recovery involves incinerating fabric and garment waste. By prioritizing tactics such as decreasing manufacturing waste, prolonging garment life through reuse and repair, and recycling materials at the end of life, manufacturers can significantly assist in adopting waste management hierarchy decreasing environmental effects, conserves resources, and promoting a sustainable future for the fashion industry.

Mainly three types of recycling techniques are available in Fig. 12 and Fig. 13 showing the percentage of application.

Mechanical/physical recycling is the best way to eliminate textile waste (Payet, 2021). Here, either recoveries or commingled waste treatment policy is implemented where defective or worn-out garments are transformed into fibers and yarns. These can be used to make

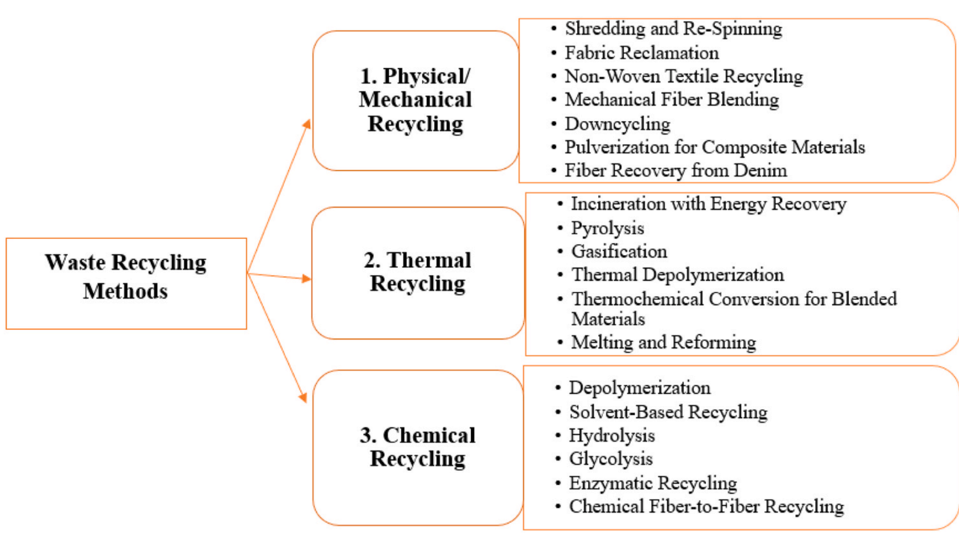

Fig. 12. Types of textile waste recycling.

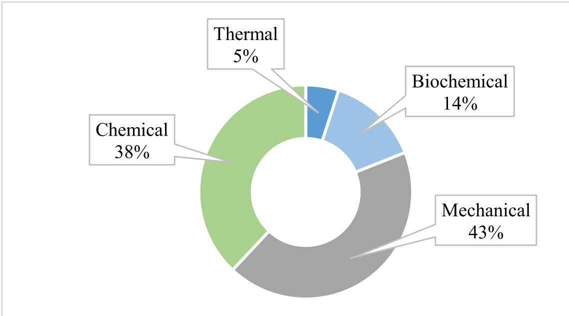

Fig. 13. Application of recycling techniques by percentage.

carpets, nonwovens, materials for insulation, filtration, geotextiles, and more. As new product is produced without complete change of materials origin (reclamations), this technique is environmentally friendly, cheaper, and easier (Pensupa et al., 2017). Physical or mechanical recycling methods including **(i) Shredding and Re-Spinning:** discarded textiles are shredded into fibers, cleaned, carded, and re-spun into fresh yarn, **(ii) Fabric recycling,** large unused or mildly damaged fabrics from pre-consumer trash, such as off-cuts and surplus materials, are gathered, processed, and recycled for new goods. These materials can be utilized directly in garment production without considerable changes, **(iii) Non-Woven Textile Recycling**- Waste fibers are compressed and processed into non-woven materials like felt or insulation. **(iv) Mechanical fiber Blending-** recovered cotton fibers are frequently blended with virgin polyester to generate durable fabrics while retaining sustainability, **(v) Downcycling-** converted into lower-value goods, such as cleaning rags, padding, or filling for cushions, beds, or toys, **(vi) Pulverisation for Composite Materials-** Textile waste is pulverized into small particles and incorporated into composite materials for industrial purposes, such as construction panels or automobile components. **(vii) Fiber Recovery from Denim**-Denim trash, including pre-and post-consumer waste, is shredded into fibers and reused to make new denim fabrics or other products.

In **chemical recycling,** synthetic fibers are processed through polymerization reactions where synthetic fibers are dissolved and spun to form new ones. Besides, acid and alkali hydrolysis can remove the dust from the waste fibers (Reserve Resources White Paper, 2017). World-class fashion brands such as Nike, Teijin Fiber etc. uses chemical synthesis for manufacturing their products whereas dimethyl terephthalate (DMT), polyethylene terephthalate (PET) etc. the outputs (Haule et al., 2016). Chemical recycling includes **(i) Depolymerisation**, which breaks synthetic fibres into monomers and then re-polymerizes them into new synthetic fibres. **(ii) Solvent-Based Recycling-** nontoxic solvents dissolved cellulosic fibres and then regenerated new fibres like lyocell, which is highly sustainable and biodegradable. **(iii) Hydrolysis-** uses water, heat, and catalysts to break down synthetic polymers into their fundamental components; this is especially useful for recycling blended textiles or clothes with coatings and finishes. **(iv) Glycolysis-** A chemical reaction that uses glycols and heat to degrade polyester-based materials into monomers. The recovered monomers can be purified and reused to produce high-quality polyester. **(v) Enzymatic Recycling-** employs enzymes to selectively degrade particular materials, such as cotton or polyester, into their natural or synthetic monomers; **(vi) Chemical Fiber-to-Fiber Recycling-** uses chemical reaction Cotton-polyester mixtures are split into new fibres.

Thermal recycling process mainly uses heat or electricity to break down the fiber molecules into smaller ones through pyrolysis process (Czajczyńska et al., 2017). This breakdown occurs at 450°C and 700°C (Strahle and Philipsen, 2017) where cloth loses 74 % of its original weight (Juanga-Labayen et al., 2022). This technique is utilized to recycle carbon-based goods (Patagonia, 2017). Thermal recycling methods, such as **(i) incineration with energy recovery,** utilise burning garbage to reduce quantities. However, advanced emission control systems are needed to minimise the production of dangerous gases including CO_2 and toxic pollutants. (ii) In the absence of oxygen, the **pyrolysis process** breaks down synthetic fibres into new raw materials. **(iii) Gasification**, like pyrolysis, uses heat to convert waste to syngas (a mixture of hydrogen and carbon monoxide). **(iv) Thermal depolymerisation**- breaks down synthetic polymers into monomers and assists in repolymerization into new fibres. **(v) Thermochemical Conversion for Blended Materials-** Textiles with fibre blends, such as cotton-polyester, can be separated and recovered utilising thermochemical methods. For example, polyester can be melted and reused, whereas cotton cellulose can be converted into charcoal or other byproducts. **(vi) Melting and Reforming** - Thermoplastics like polyester and polypropylene can be melted and reformed into new products like plastic pellets, which are subsequently used in manufacturing. This technology is economical, but it requires contamination-free feedstock for optimal results.

Most of the composite wastes are reused or recycled through mechanical, thermal, or chemical recycling (Krauklis et al., 2021; Zhang et al., 2020). Some of the Western countries are imposing laws and legal fees to incorporate reuse of recycled composite waste commercially. These techniques decompose composite materials into hydrocarbon products and recover the reinforces such as fibers and preforms. Further, reinforcement materials can also be recovered from the EOL composites using solvents. In the UK, ELG Carbon Fibre Ltd. has a recycling capacity of 2000 t/yr (Bledzki et al., 2021) through pyrolysis.

3.2.5. *Present scenario of waste recycling*

In 2022, around 92 million tons of fashion and textile waste was generated that will rise to 150 million tons by 2050. Only 15 % of them are collected, unfortunately, only 5–10 % are reuse or recycled for further use, rest are dumped or incinerated (Gupta et al., 2022). However, there is a possibility to claim almost $4.5 billion opportunity of recycling textile waste from Vietnam, Turkey, India, Malaysia, and Indonesia market which is a hope now (Resta et al., 2016; Wagaw and Babu, 2023). However, specific data on waste collection and supply chain is still unknown.

Figs. 14–17 highlight the present scenarios of global fashion and textile waste recycling. Fig. 14 displays the percentage of several waste management practices found globally, with landfills accounting for 57 %, indicating the reliance on direct disposal that has a detrimental environmental effect, identifying inadequate recycling infrastructure, limited adoption of circular fashion practices, and the complexity of separating blended fibers. Incineration (25 %) is next, contributing to carbon emissions while only 10 % of waste undergoes recycling processes showcasing major gaps in resource recovery. Reuse accounts for only 8 %, demonstrating the underutilization of second-hand consumption and garment life extension options. This might be technological and economic challenges in repurposing materials efficiently. These statistics highlight the critical need to implement circular economy

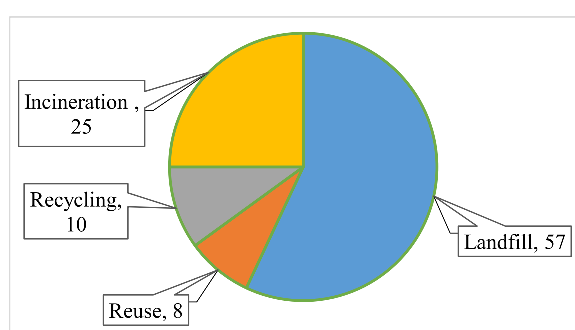

Fig. 14. Present waste management prospects (%) in textiles and apparel sector.

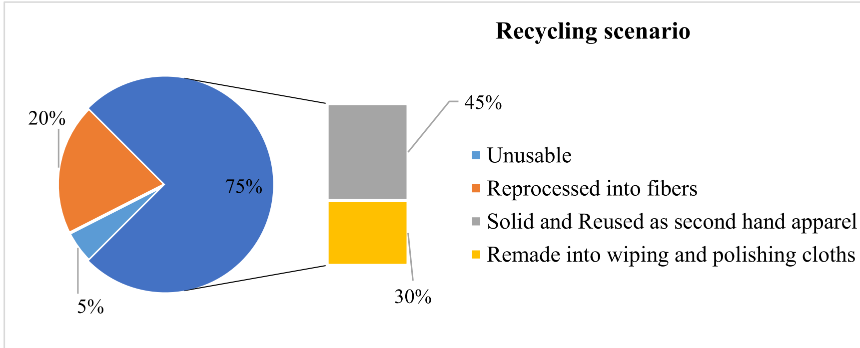

Fig. 15. Textile waste recycling scenario (by percentage).

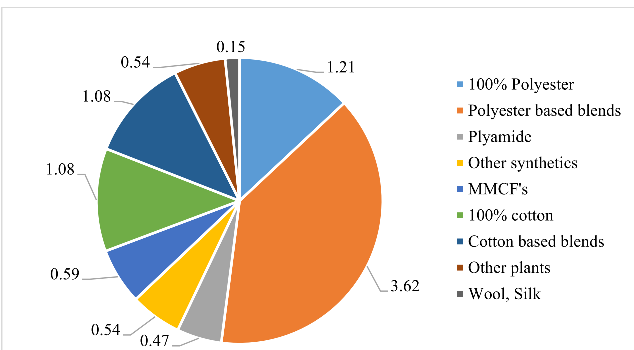

Fig. 16. Recyclable textile waste globally.

principles and invest in novel recycling and upcycling technology to reduce waste and environmental damage.

Among all the collected clothing almost 45 % of solid clothing is reused as secondhand apparel after minor modifications, 30 % are remade into wiping and polishing cloths, 20 % are reprocessed into fiber and 5 % remains unusable (Fig. 15). These figures emphasize the need for advanced recycling technologies and innovative reuse strategies to reduce unusable waste and maximize material recovery.

Fig. 16 identifies the recyclable textile fibers whereas all of those 20 % reprocessed fibers (Fig. 16) show the actual quantity in Fig. 17. Fig. 16 shows the global distribution of recyclable textile waste, with polyester-based blends accounting for 3.62 (%) and 100 % polyester (1.21 %). Other significant contributors are 100 % cotton and man-made cellulosic fibers (MMCFs), both with 1.08 %. Wool, silk, and other plant-based materials provide minor contributions, underlining the need to tackle the problem of recovering mixed and synthetic fibers. This breakdown emphasizes the importance of specific recycling methods for different fiber types.

The American Apparel and Footwear Association conducted a critical analysis between 1970 and 2018 using data on the generation of textile waste, its disposal in landfills, its use for energy production, and its recycling (EPA, 2024). Fig. 17 displays the results of it. Textile waste production has soared, surpassing 16,000 thousand tonnes by 2018, while recycling remains insignificant. Landfilling is the most popular method of disposal, followed by combustion with energy recovery, highlighting the significance of improved recycling techniques and long-term waste management solutions in the textile industry.

3.3. *Thematic analysis*

3.3.1. *Contextual factors (barriers, opportunities, drivers) in fashion waste circularity*

From the investigation, the main barriers, opportunities, and drivers are identified, and summarized in Table 4. Key barriers including escalating costs, inadequate infrastructure, complexities of raw materials; lack of efficient recycling techniques, and consumer awareness. Several key drivers promoting the adoption of CE practices have been identified including collaborative consumption, material traceability, green chemistry; digitalization; recognition, appreciation, incentives, and cost support. Key opportunities including material innovation; diversification in value creation, market demand, and cost savings.

3.3.2. *Key challenges of waste management and implementing CE in fashion manufacturing*

However, these industries are facing multiple challenges of strategic plans for sustainable supply chain of clothing waste collection and distribution (Gupta et al., 2022; Patagonia, 2017), poor recovery strategies (Chatziparaskeva et al., 2022), poor buyers' initiatives regarding environmental standards, lacking technological advances and automation (Dumee, 2022; Chae and Hinestroza, 2020), poor infrastructure and consumer engagement (Kohler et al., 2021; Kim et al., 2021; Hartley et al., 2022), and standardized policies and regulation (Uddin et al.,

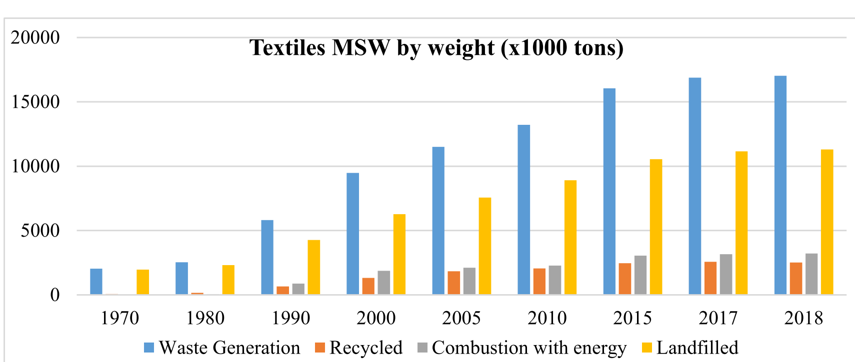

Fig. 17. Comparison among waste generation, recycle, combustion and landfill.

Table 4
Barriers, opportunities and drivers impacting fashion waste circularity.

Factors in circularity adoption	Recommendation	References
Barriers: Dominance of take-make-disposal economy; complexities of blended raw materials; lack of efficient recycling techniques, infrastructure; consumer awareness; cost of recycling	Circular product design; innovative recycling methods, infrastructure, consumer education; standardized regulations and collaboration with stakeholders	Daystar et al., 2019; de Aguiar Hugo et al., 2021; European commission. 2022; Emin, 2021; Hartley et al., 2022; Hole and Hole, 2020; Kazancoglu et al., 2020; Li et al., 2021; Paco et al., 2021; Veske and Ilén, 2021; Shiferaw et al., 2023; Xu et al., 2022; Takacs et al., 2022
Opportunities: Sustainable material innovation; diversification in value creation, market demand, and supply chain; cost savings	Investment in sustainable technologies; product LCA assessment; development of closed loop system; green marketing; campaigns for awareness; certifications on traceability	Fashion United, 2020; EPA, 2024; Chae and Hinestroza, 2020; Das et al., 2021; DoE Department of Environment, 2016; Gu et al., 2021; Hossain et al., 2024; Korhonen et al., 2018; Kohler et al., 2021; Linn Lofling, 2022; Perry et al., 2017; Statista,2021; Subramanium, 2018;
Drivers: Circular product design; upcycling; waste minimization and environmental sustainability; stakeholder's responsibilities; materials innovation	Collaborative and sustainable consumption; biodegradable materials, material traceability and green chemistry; product life cycle; digitalization; environmental sustainability	Shamsuzzaman et al., 2023; Wondmagegnehu. et al., 2021; Bukhari et al., 2018; Connecticut's, 2021; Dumee, 2022; Pakdel et al., 2021; Islam et al., 2021; DeVoy et al., 2021; Kim et al., 2021; Leal Filho et al., 2019; Mativenga et al., 2017; Plakantonaki et al., 2023; Earley., 2017; Aus et al., 2021; Semba et al., 2020.

2022; Juanga-Labayen et al., 2022). Moreover, social, economic, and behavioral aspects of clothing waste recycling including attitudes and the impact on employment are still a challenge (Khan and Islam, 2015; Dissanayake and Weerasinghe, 2021; Han et al., 2017; Hartley et al., 2022). The circular fashion model focuses on sustainable production, consumption, and disposal practices, making them a vital area of research. Investigating circular fashion models and their effectiveness in reducing clothing waste remained a critical research area compared with successful economic countries like China and European countries. Adopting this model has made significant progress driven by robust policies, advanced technologies, and consumer awareness by those countries. Few successful models including (i) Zhuanzhuan, and (ii) European Green Deal and the Circular Economy Action Plan need to be assessed and implemented properly (Saha et al., 2022).

Besides, the technical challenges on recycling textiles for material recovery should fit within sustainable framework where (i) separation of cotton and polyester blends is still a challenge because of intricated bonds between natural and synthetic fibers that limit the recycling efficiency and reduced quality of recycled outputs, (ii) recycled textiles should match current production prices otherwise inability to match current production prices discourages large-scale adoption by manufacturers., (iii) emissions and resource usage should not exceed current levels unless it would create counteract the environmental benefits of recycling, (iv) current manual practices need to be automated for scalability and cost-effectiveness, (v) unsustainable supply chain including logistics and procurement of raw materials are hindering the progress of transformation to CE, (vi) poor consumer awareness on recycled products exacerbating the value and quality of the recycled based products, (vii) Chemical recycling of waste fibers causes toxicity and sensitivity and may release harmful substances, posing risks to human health and the environment.

Mainly four types of recycling textiles are incorporated such as (i) secondhand clothing reuse enhances product lifespan and lower the demand for new production, (ii) mechanical recycling converts textiles into fibers or lower-grade materials, (iii) chemical recycling degrades them into raw materials for higher-quality reuse, and (iv) biological recycling decomposes natural fibers using enzymes or microbes, providing a more environmentally friendly waste management alternative (Piribauer and Bartl, 2019). However, existing technologies lack proper recycling of blended cloths, chemical recycling could be a viable alternative but dissolved cellulosic portion. Nowadays, a few steps on textile waste recycling like digital receipts, documentation, transparency, material scanning for easy and commercial sorting, radio frequency identification (RFID), etc. are employed (Sandvik and Stubbs, 2019).

3.3.3. Changing the paradigm: Linear economy to CE of textile waste

The key points to transit the linear economy into a circular fashion economy includes (i) Using fewer virgin materials, (ii) working for recyclable materials, (iii) recapturing garment offcuts to packaging for reuse, and (iv) implementing the possibilities for using, reusing and recycling. This focuses on the longevity and life cycle of the possessions, including designing waste and pollution that emphasizes the values of the end products and repurposing those into something useful products (Koszewska, 2018; Amato et al. 2019). In this transition, three principles for CE is developed including (i) Designing out waste and pollution, (ii) Keeping products and materials in use, and (iii) Regenerate natural systems (shown in Fig. 18). These reduces both virgin material inputs and waste outputs, and to exchange the typical cycle of take-make-waste in favor of reusing and recycling with sustainable and ethical fashion (Awgichew et al., 2021; Korhonen et al., 2018). Therefore, CE model support sustainable development and gain attention among policy makers, scholars, and practitioners (Idiano, 2019). According to European Agency, CE considers the core Green Economy perspectives that ends it approach from waste and material to human wellbeing and Eco balance (European Commission, 2022; Kohler et al., 2021). The key concepts of CE shown in Fig. 19.

There are examples of successful CE adoption. Several countries, including Sweden, Netherlands, Denmark, Germany, United Kingdom, Finland, France, and Japan, are successfully employing a circular economy in fashion, with an emphasis on sustainability, waste reduction, reuse, and recycling. Sweden, for example, implemented **Siptex** (Swedish Innovation Platform for Textile Sorting), has pioneered textile recycling initiatives, and encourages secondhand shopping, with substantial government backing for sustainable fashion initiatives. Besides, Swedish company Renewcell has innovated **Circulose*** recycling process to transform discarded fashion waste into high-quality biodegradable fibers and become forefront in fashion textile waste management. Netherlands has embraced circular fashion business effectively through innovation hubs and government-backed initiatives to reduce textile waste. The advancement of the shift to a circular textile business is greatly aided by the **Dutch Circular business program and Extended Producer Responsibility (EPR).** This aims to persuade manufacturers and retailers in the Dutch textile sector to alter their business plans and improve textile collection initiatives (Islam et al., 2021; Islam et al., 2025; Shamsuzzaman et al., 2025). Denmark launched the Circular Fashion Lab to promote circular business models, while Germany has pioneered the cradle-to-cradle trend, with many fashion businesses embracing sustainable production processes. The UK and France have also made substantial efforts, with the UK advocating circular design and France establishing regulations prohibiting the disposal of unsold goods, encouraging manufacturers to recycle and donate. These countries demonstrate how CE principles may be applied to the fashion sector, resulting in more sustainable and resource-efficient methods.

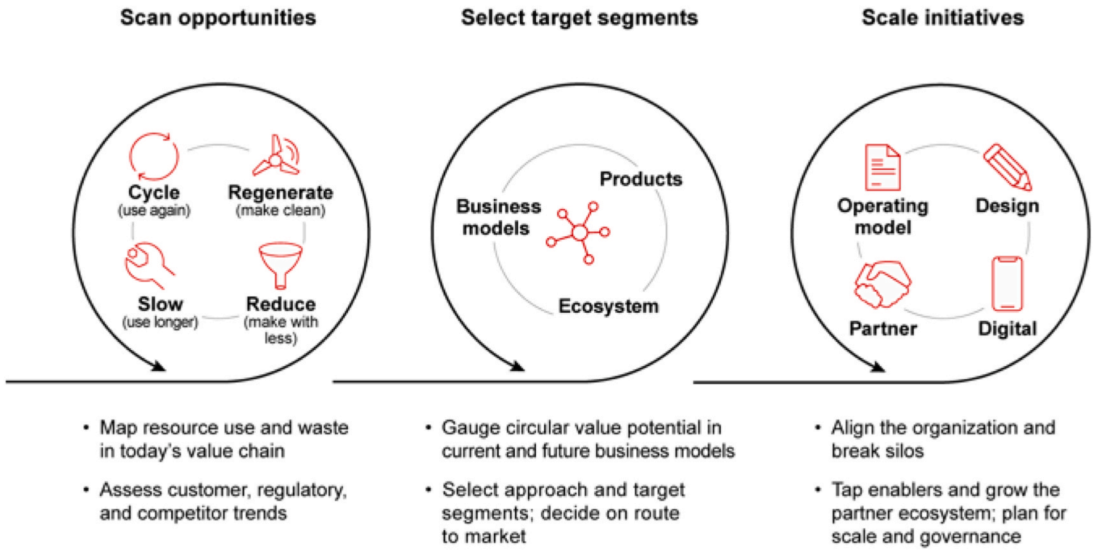

Fig. 18. CE model (Idiano, 2019).

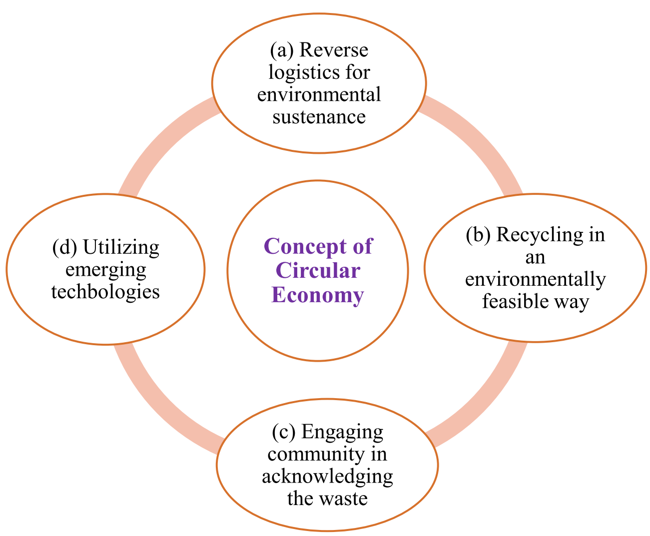

Fig. 19. Concept of circular economy (Idiano, 2019).

Besides, China has successfully adopted circular economy (CE) approaches in the fashion sector by combining robust government legislation, technological advancement, and industry partnership. The Chinese government has incorporated CE concepts into its national policy, supporting sustainable fashion with legislation that requires waste reduction and optimising resources (Habib et al., 2021; Saha et al., 2022).

3.3.4. Application of CE-led waste management to the fashion and textiles value chain

The application of CE-led waste management ideas addresses the fashion industry's sustainability issues that offer economic benefits by reducing the waste and environmental hazards. Besides CE attempts to maximize resource efficiency by designing out waste, reusing products and resources, and regenerating natural systems. This translates into new techniques in the fashion and textile industries, such as designing for lifetime, recyclability, and disassembly, as well as encouraging reuse, repair, and recycling. Therefore, CE guidelines will implement product stewardship programs to encourage take-back schemes and end-of-life recycling to keep textiles in circulation rather than being dumped after use. Furthermore, adopting collaborative business models, such as leasing or rental services, promotes longer product lifespans and a shift towards more sustainable consumption patterns. Moreover, CE-led waste management will promote innovation and investment in sustainable technology and practices, hence offering chances for circular business models and green jobs. Finally, by shifting to a circular fashion and textile economy, the sector would progress towards a more sustainable and resilient future in which waste is eliminated, resources are conserved, and environmental impacts are greatly reduced. The following model (Fig. 20) is a good example of CE implementation from design to disposal.

Adopting circularity in fashion involves a shift from the traditional "take-make-dispose" model to a more sustainable and regenerative approach. This transition requires a comprehensive rethinking across all areas of the fashion industry, including material sourcing, production methods, product design, and consumer engagement. Designers are now tasked with creating products that are durable, versatile, and easy to recycle or repair, thereby minimizing waste and environmental impact. Material selection becomes critical, emphasizing recycled and eco-friendly fabrics along with innovative bio-based materials. Close collaboration with suppliers and other stakeholders throughout the supply chain ensures material traceability and recyclability. Furthermore, circular fashion design promotes the principles of "slow fashion," encouraging business models like rental, resale, and repair services to reduce demand for new clothing. For smart textiles, integration levels directly affect recyclability and end-of-life (EOL) management. Specified EOL treatment methods and standardized waste policies are essential, and new design guidelines for functional textiles can reduce waste and support reuse and recycling efforts.

Incorporating circularity necessitates a transformative approach to clothing manufacturing. Sustainable material choices, such as recycled and eco-friendly options, are prioritized to reduce environmental impact. Circular fashion emphasizes product longevity and reparability, encouraging manufacturers to design items that are easy to maintain and refurbish. To effectively minimize textile waste, manufacturers may need to invest in recycling and upcycling facilities. Collaborative supply chain efforts are vital for maintaining product traceability and supporting a closed-loop system. The circular economy model calls on producers to adopt more ethical practices, from raw material sourcing to final production stages, reducing the fashion industry's environmental footprint and promoting a more sustainable future. A key aspect of circular waste management in technical textiles is rethinking the design, production, consumption, and end-of-life management processes (Ustiln Çetin and Tayyar, 2017). Emphasizing durability, repairability, and

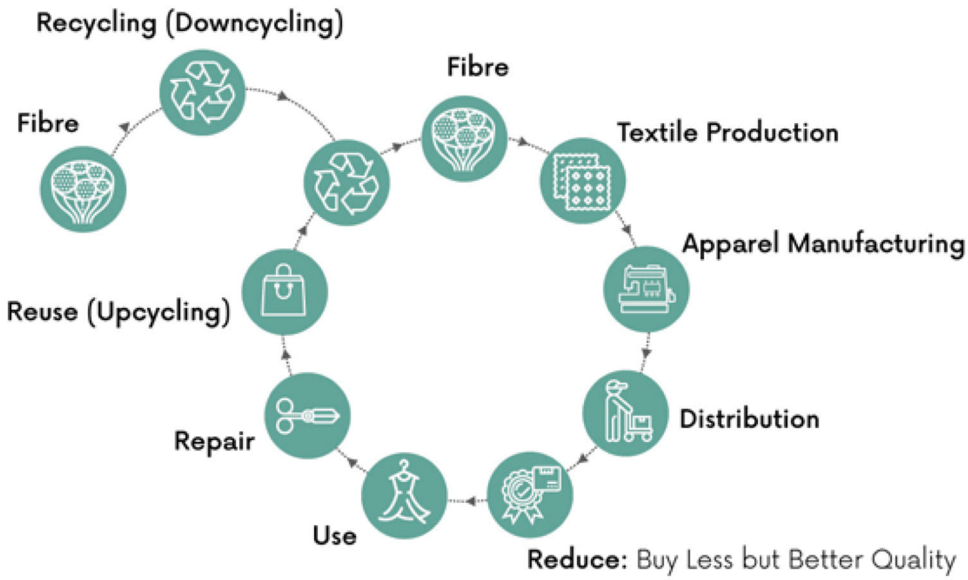

Fig. 20. CE model for fashion industry waste recycling.
Adopted from Koszewska (2018).

recyclability enables longer-lasting products and reduces waste. For example, smart apparel can be designed to allow easy disassembly, conserving materials and minimizing energy loss. This shift requires significant efforts toward understanding and standardizing sustainable manufacturing practices.

Embracing circular economy principles in branding and retailing can enhance a company's reputation by demonstrating a commitment to product quality, safety, and sustainability. In a competitive market, circular branding can differentiate a business by offering consumers the assurance that its products meet high safety and environmental standards, fostering customer loyalty and increasing sales. CE certification can serve as an effective marketing tool to highlight a brand's commitment to ethical and environmentally responsible practices. By actively communicating their dedication to quality and sustainability through various marketing channels, brands become more appealing to consumers who prioritize responsible consumption.

Finally, in adopting CE principles may provide consumers with a trusted standard for responsible consumption, encouraging safer and more environmentally conscious purchasing decisions. Products bearing CE certification assure customers of compliance with rigorous safety and environmental standards, empowering them to choose items that align with their values of sustainability. Additionally, CE certification guides consumers toward products designed with longevity and environmental responsibility in mind, supporting a shift towards more conscientious fashion choices. For functional textiles, raising consumer awareness about circularity can foster prolonged use, further extending a product's lifespan. New strategies for implementing the circular economy in smart textiles, clothing, and future wearables are also being developed, with innovative design and structural guidelines at both personal and societal levels (Chae and Hinestroza, 2020) (Fig. 21). In sum, integrating circularity within the fashion industry offers substantial environmental and economic benefits. By restructuring design, manufacturing, retailing, and consumption practices to prioritize resource efficiency, recyclability, and waste reduction, the industry can move towards a sustainable, closed-loop system that meets consumer demands while minimizing ecological impact.

Fig. 21. Ambitions for New CE lifestyle and ecology with smart clothing.

3.3.5. Looking forward: role of key stakeholders

The successful transition to a sustainable fashion industry hinge on the proactive engagement of key stakeholders throughout the value chain. Each group—consumers, producers, policymakers, brands, retailers, designers, NGOs, media, and trade associations—plays a critical role in fostering systemic change toward a more sustainable and circular fashion model.

Consumers are at the forefront of this shift, influencing change through their purchasing decisions. By favoring products that are ethically produced, environmentally sustainable, and socially responsible, consumers can motivate brands and retailers to adopt sustainable practices. Educating consumers on the environmental and social impacts of their choices and empowering them to make informed decisions will be essential for shaping the future of fashion consumption.

Producers, including manufacturers, suppliers, and textile mills, bear responsibility for integrating sustainable practices within their operations. This involves optimizing resource use, reducing waste, and implementing eco-friendly production processes. By adopting circular economy principles and innovative technologies, producers can minimize their environmental footprint while enhancing operational efficiency and competitiveness.

Policymakers can drive sector-wide adoption of sustainable standards through legislation, incentives, and enforcement measures. By promoting transparency and traceability in supply chains and encouraging investment in sustainable materials and technologies, policymakers can create a regulatory environment conducive to sustainable development.

Brands and retailers have significant influence over consumer behavior and market trends. By embedding sustainability into their brand identity, product offerings, and marketing strategies, companies can cultivate a culture of conscious consumerism and increase demand for sustainable fashion. Embracing circular business models, such as product-as-a-service or resale platforms, can also extend product lifespans and reduce waste.

Designers play a vital role in shaping the aesthetics and functionality of fashion products. By prioritizing durability, repairability, and recyclability, designers can significantly reduce the environmental impact of their creations. Additionally, fostering innovation in sustainable design can inspire new, eco-friendly approaches to fashion production and consumption.

Non-governmental organizations (NGOs) and advocacy groups are crucial in raising public awareness of the fashion industry's environmental and social implications. Through research, advocacy, and public engagement, NGOs can hold stakeholders accountable and promote systemic change. By establishing best practices, standards, and certification programs, these organizations can encourage responsible business conduct across the industry.

Media platforms, including traditional outlets and social media influencers, play a pivotal role in shaping public discourse and consumer behavior. By highlighting sustainability issues within the fashion industry and showcasing innovative solutions, the media can raise awareness, stimulate demand for sustainable products, and hold industry participants accountable.

Trade associations and industry groups offer collaborative platforms for knowledge sharing and joint initiatives in the fashion sector. By fostering dialogue, promoting best practices, and facilitating stakeholder collaboration, these associations can advance industry-wide sustainability goals and cultivate a culture of ongoing improvement.

4. Conclusion and research implications

This research provides state of the arts of research and valuable insight into the waste management in the circular economy with a focus on fashion and textiles industry. Textile waste presents a significant environmental challenge due to its contributions to landfill overflow, water pollution, and greenhouse gas emissions. Addressing this issue requires robust strategies for integrating textile waste into a circular economy, focusing on methods for reuse, recycling, and upcycling. The practical implications of this research will support a shift toward a more sustainable and circular textile ecosystem, involving key changes across production, design, consumption, regulation, and collaboration within the industry. Adopting circular economy (CE) principles in fashion waste management will fundamentally reshape the textile sector, placing a strong emphasis on resource efficiency and waste reduction. Designers will prioritize creating products that are easy to recycle, repair, or adapt for multiple uses, aiding manufacturers in rethinking production processes and incorporating advanced recycling and upcycling techniques for textile waste. Initiatives like take-back programs and rental services offered by fashion brands and retailers will extend garment lifespans, helping to significantly reduce waste. This approach will also shape consumer behavior, promoting conscious consumption, proper garment care, and participation in circular practices such as clothing swaps and resale markets. Further, researchers will focus on enhancing existing technologies to improve product traceability, making circular practices more efficient. Collaborative efforts across stakeholders—including NGOs, media, and trade associations—will play a critical role in promoting awareness, education, and advocacy for sustainable textile practices. The theoretical contributions of this study will resonate across diverse academic disciplines. Researchers will engage in advancing materials and designs that enable indefinite recycling without value loss, explore sustainable consumption patterns, investigate psychological drivers of consumer behavior, and examine social dynamics around eco-friendly textile choices. Various stakeholders, including governments, NGOs, and manufacturers, will be prompted to develop comprehensive and current regulations that encourage the widespread adoption of sustainable practices. Together, these theoretical frameworks establish a robust foundation for researchers, policymakers, and industry practitioners, enabling the development of strategies that drive a more sustainable and circular textile industry.

4.1. Future research directions

Circular economy initiatives for textile reuse and recycling are essential to reducing the industry's environmental footprint. Fig. 22 is highlighting the future directions for circular transformation of fashion and textile wastes. To transition from linear to circular systems, producers must apply extended producer responsibility (EPR), which holds them liable for their products' whole lifecycle, including post-consumer waste. By implementing these strategies, we conserve resources, decrease greenhouse gas emissions, and advance toward a more sustainable future. Increasingly, manufacturers are voluntarily adopting circular economy principles by incorporating recycled raw materials instead of virgin ones, although challenges remain. Take-back programs, where customers receive discounts for returning unwanted clothing, are gaining popularity, encouraging responsible disposal and reuse.

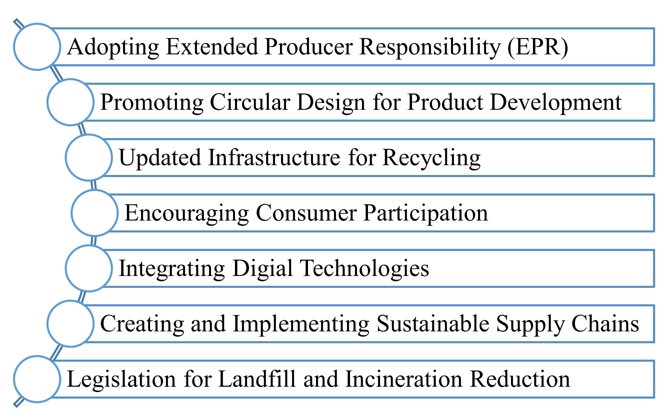

Fig. 22. Future directions for circular transformation.

Upcycling is an effective approach, transforming discarded fabrics into new, higher-value items. This can include repurposing textiles for insulation, soundproofing, or creating new apparel, accessories, and home goods from pre-existing materials. By extending the life and utility of textile products, upcycling reduces waste and promotes sustainability. Recycling offers another valuable method for managing textile waste by breaking down used fabrics into fibers, which are then spun into new yarns and textiles. This process lessens dependence on virgin materials and significantly reduces the volume of textile waste ending up in landfills. Recycling innovations, including automated separation of blended fibers and scalable chemical or biological recycling, may contribute to higher material recovery percentages. The circular economy, which seeks to establish closed-loop systems, is gaining traction in the textile industry as it enables continuous reuse and recycling of materials. Under this model, textiles are designed with end-of-life recycling in mind, allowing products to re-enter the production cycle post-use. As the demand for second-hand fashion rises, fashion industry business models will need to adapt to emphasize durability and resale opportunities. While transitioning to a fully circular model presents challenges—particularly given the industry's reliance on rapid production cycles and consumer demand for newness—moving toward circularity offers notable benefits in reducing waste and pollution. Future research should expand on technical and functional textiles, particularly focusing on sustainable composite materials.

Policies that encourage eco-design, such as developing garments that are durable, repairable, and recyclable, can help to reduce waste during the manufacturing process. Furthermore, using digital technologies such as blockchain for supply chain transparency and AI-powered sorting technology could boost recycling efficiency and traceability. Public awareness campaigns are crucial for persuading customers to adopt ecologically friendly practices like donating, reusing, and recycling textiles. Governments and businesses must collaborate to establish a robust recycling infrastructure and encourage closed-loop systems such as take-back programs and green pricing. Furthermore, international cooperation can help to bridge the waste management gap between industrialized and developing countries. The fashion business may contribute to a more sustainable future by encouraging innovation, policy alignment, and consumer participation.

4.2. Limitations

This study identifies certain constraints while addressing sustainability issues related to waste management and CE adaption. The complicated and fragmented nature of the textile supply chain, which includes varied materials, production processes, and global distribution networks, complicates universal solutions. The lack of standardized measurements and procedures for analyzing the environmental impact of textile goods across their full life cycle makes meaningful comparisons and extensive assessments challenging. Furthermore, researchers aiming to measure and evaluate the performance of waste management systems and circular practices face challenges due to restricted data availability and transparency. Economic factors, such as the cost-effectiveness of circular practices and potential resistance from enterprises accustomed to linear models, impede the practical implementation of sustainable methods. Finally, poor regulatory frameworks of the textile industry, often impede the implementation of effective policies to promote circular practices. Researchers anticipate overcoming these constraints by interdisciplinary collaboration, research flexibility, and an understanding of the linked difficulties in the textile waste management and CE research landscape.

CRediT authorship contribution statement

Shamsuzzaman Md: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Islam Mazed:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rayyaan Rishad:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Formal analysis, Data curation. **Mamun Md. Abdullah Al.:** Writing – original draft, Visualization, Software, Investigation, Formal analysis, Data curation. **Islam Saniyat:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Formal analysis. **Sowrov Kazi:** Writing – review & editing, Writing – original draft, Software, Resources, Investigation, Formal analysis, Data curation. **Sayem Abu Sadat Muhammed:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Methodology, Investigation, Data curation, Conceptualization.

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.

Data availability

Data will be made available on request.

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