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Advancing Circularity in India's Textile sector: Challenges, Opportunities, and the Role of Digital Transformation in Sustainable Production

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ABSTRACT

Although India's "Make in India" campaign has driven rapid growth in the Micro, Small, and Medium Enterprise (MSME) sector, it has led to severe environmental degradation. India's resource extraction rate exceeds the global average by 251%, with industrial SMEs consuming nearly 25% of industrial energy and contributing to the country's high greenhouse gas emissions. Transitioning to a Circular Economy (CE) is essential for decoupling economic growth from environmental harm and achieving India's Nationally Determined Contribution (NDC) goals. However, CE adoption among Indian SMEs remains low due to technological gaps, regulatory uncertainty, missing inter-sectoral collaboration, and a lack of data-driven strategies.

This study examines circularity preparedness within India's textile sector, a major contributor to global exports and regional economic specialization across states like Gujarat, Tamil Nadu, Karnataka, and West Bengal. Despite its economic significance, the textile industry generates 7.7 million tons of waste annually and remains heavily polluting due to intensive water, chemical, and dye usage. Crucially, less than 1% of textile waste in India is currently recycled, constrained by poor infrastructure, product complexity, technological limitations, and low top-management commitment. Existing literature lacks micro-level diagnostic frameworks to guide firms across the design, production, consumption, and end-of-life stages.

To address this gap, this paper conducts a comprehensive literature review to identify the critical barriers hindering circularity in the Indian textile value chain. The study presents a strategic roadmap and actionable recommendations for CE implementation. Furthermore, it explores the integration of cross-disciplinary digital technologies to overcome these barriers, offering targeted technological requirements to accelerate the sector's scalable transformation toward net-zero and circular operations.

INTRODUCTION

The "Make in India" campaign has, over the years, served as a strong stimulant for growth and progress of India's Micro Small and Medium Enterprise (MSME) sector (Chhimwal et al., 2022). The ecosystem of MSMEs, which is home to approximately 48 million enterprises is a backbone of Indian economy and employs more than 106 million people with making efficient contribution for 6.11% share in manufacturing GDP and accounting for about 24.63% of the service sector GDP (Nudurupati et al.,2022). However, this economic boom has come at the expense of the environment in India. The resource extraction rate of the country is 1,580 tonnes per acre in comparison with the world average of 450 tonnes per acre recorded by Sarma et al. (2023), thus it is 251% more than the global average production. Moreover, SMEs contribute almost 25% of the industrial energy consumption and are also one of the prominent sources of employment in India whereas India has third highest contributor to GHGs (about 9.2% into global emissions) along with China and USA combined (Varun Boralkar, 2023).

With this background, environmental sustainability has become a national priority and joint responsibility shared by SMEs in addressing it is vital. The strategic answer of India to such sustainability challenges has largely been the steady mainstreaming of Circular Economy (CE) principles — an ideology that works towards separating the act of economic growth from resource use and threat to nature. CE promotes the creation of waste free products, retention of products and materials in use as long as possible, and generation of natural systems (thus helping India fulfil its Nationally Determined Contribution [NDC] goals under the Paris Agreement) (Ellen MacArthur Foundation, 2016; Gedam et al., 2021; Varun Boralkar; Gambhir, 2023).

Moving to a circular economy calls for systemic change – not only must there be coordination and control of flows of resources throughout the value chain, but forward and reverse logistics (whereby products are returned in order to extract materials or components) must be integrated; design innovation needs to be multiplied; ecosystems need to work together and new business models enabling the return-creation of value loop need to emerge. While initiatives like the Swachh Bharat Mission and Mission LiFE (Lifestyle for Environment) reflect India's commitment to sustainable and circular practices, the uptake of CE models among SMEs is low.

Several obstacles have stood in the way of that transformation. These gaps include technology gap, lack of strategical informational input/ information for decision, regulatory uncertainty and collaboration missing while education, policy bodies, industry players and consumers are concern is also lacking in various fields (Das et al., 2024). To overcome these challenges, there is a need for the generation and accumulation of CE data specific to various industries that can be employed in devising industry-specific strategies responsive to their peculiarities, challenges and opportunities (Badhotiya et al., 2022; Bag et al., 2022; Nudurupati et al., 2022).

Such data- driven information would provide a guide both for sectoral strategy and as a benchmark that organisations may choose to assess their compliance with best practices or industry standards. This will

help to enable the application of CE approaches within India's industry in an efficient and scalable manner that reconciles eco-performance with economic development.

This article explores the circularity preparedness of India's textile sector that has grown remarkably during the last 15 years. In the same duration, India has increased its apparel production by two fold, and is the sixth largest exporter of textiles and clothing in the world and positioned for further growth (Kanupriya, 2021). Indian textile industry is a unique example of regional specialization where each state has made its own contribution to the national textile value chain. The state of Karnataka, which comprises major regions such as Bangalore and Mysore, is famous for its silk sarees and cotton textiles to both the local market and foreigners. "The handloom textiles, knitwear and cotton fabrics found in Tamil Nadu have made a mark in Tirupur being the leader for knitwear exports in India while cities like Coimbatore and Kanchipuram contributing to our textile history," it noted. Gujarat, with its hubs in Surat, Ahmedabad and Vapi, produces almost 30% of India's cotton - Surat churns out 30 million metres of raw material each day. Rajasthan's cities like Jaipur, Ajmer and Bhilwara are known for their colourful block-printing styles and handloom work. Maharashtra - Bhiwandi in particular - contributes significantly to power loom production and pocket-friendly fabric aimed to the garment manufacturers all over India. Production of luxury silk items is also Uttar Pradesh's forte, and Varanasi in Uttar Pradesh the famous Banarasi sarees. Punjab (with Ludhiana and Amritsar leading), is the unchallenged leader in woollen textiles and hosiery, while West Bengal (especially in Kolkata and Murshidabad) accounts for 75% of the world's jute production alongside high quality silk workmanship (Ankita Sharma, 2020; CII, 2023; Sanjay Bakshi, 2024).

However, despite its wide-ranging economic and cultural diversity, the textile field is globally considered one of the most polluting sectors in both production and consumption because it uses toxic dyes, water, chemicals (as well as auxiliary materials). India produces about 7.7 million tons of textile waste every year (Dwivedi et al., 2023; Ponnambalam et al., 2023). Despite lucrative prospects of recycling and recovery from pre- as well as post-consumer textile waste, the present rate of recycling in India is less than 1% (CII, 2023; NCAER, 2009). This is low circularity which seems to be influenced by various TAS obstacles, such as poor infrastructure, lack of technology ability and tools or method to implement CE, complexity of the product, and weak top management commitment to sustainability. Ponnambalam et al. (2023) listed various challenges (or barriers) limiting the extent of textile recycling in India, and although there is literature on CE adoption describing such barriers, this literature does not offer a structured way for companies to diagnose their current processes with respect to CE principles. As a result, many companies are left confused about where to start with transitioning themselves to a circular way of working.

Although Dwivedi et al. (2023) measured circular capabilities within the industry their findings do not include explicit measures and therefore fail to cover multiple aspects of circularity – such as design, production, consumption and end-of-life – leading to unclear direction on how to provide for net-zero ambitions. Thus, assessing circularity at the micro-level is vital in order to focus actions and enhance CE implementation in textile value chains. To fill this research gap, the following question is explored in this

paper: Which are these obstacles that are acting against enhanced circularity in the Indian textile industry?

Figure 1: Circularity Gaps in Indian Textile Sector



To address this, we have undertaken a literature review to explore the barriers preventing CE adoption and to consolidate the understanding of India's textile sector was progressing towards circularity. According to this evaluation, we offer a roadmap and hands-on recommendations on the successful implementation of CE. In addition, at the intersection of different disciplines, we investigate digital technologies that could remove identified barriers and push circularity in the sector. With the listing of digital requirements, required for facilitating CE practices, this paper provides an orientation to how technological solutions can be best innovated in order to expedite the transformation of the sector towards circularity.

Table 1: Key Statistics of the Indian Textile Industry and Circularity Context

Category	**Statistic / Fact**	**Value / Description**	**Source**
Global Position	India's rank in global textile & apparel exports	6th largest exporter	Kanupriya (2021)
Industry Growth	Apparel production growth	Doubled in last 15 years	Kanupriya (2021)
Regional Contribution (Gujarat)	Cotton production share	30% of India's cotton	CII (2023)
Regional Output (Surat)	Textile raw material production	30 million meters per day	CII (2023)
Regional Contribution (West Bengal)	Global jute production	75% of world's jute output	Sanjay Bakshi (2024)
Environmental Impact	Annual textile waste generated in India	7.7 million tons	Dwivedi et al. (2023); Ponnambalam et al. (2023)
Recycling Rate	Textile recycling (pre & post consumer)	<1%	CII (2023); NCAER (2009)
SME Sector (for broader CE context)	Number of enterprises	48 million	Nudurupati et al. (2022)
SME Employment	Workforce size	106 million people	Nudurupati et al. (2022)
SME Contribution (GDP)	Manufacturing GDP share	6.11%	Nudurupati et al. (2022)
SME Contribution (GDP)	Service sector GDP share	24.63%	Nudurupati et al. (2022)
Resource Extraction (India)	Extraction per acre	1,580 tonnes/acre	Sarma et al. (2023)
Global Benchmark	Global average resource extraction	450 tonnes/acre	Sarma et al. (2023)
Environmental Ranking	India's position in global GHG emissions	3rd largest emitter (9.2% share)	Varun Boralkar (2023)
Industrial Energy Use	SME share in industrial energy consumption	≈25%	Nudurupati et al. (2022)

METHODOLOGY

We attempt in this paper, to explore and list the barriers that exist in implementing CE practices by Indian textile industry taking recourse of a narrative literature review methodology. A narrative review is less

rigid in its structure than a systematic review, and provides freedom to search and synthesize literature that pertains closely to the issue of interest (Chaney, 2021). This method has been utilized extensively by researchers investigating sustainability and CE topics (Chofreh et al., 2019; Upadhyay et al., 2021; Ardolino et al., 2022), due to allowing expansive interpretive understanding of complex, multidimensional issues.

Using this approach, we identified literatures looking at the Indian textile sector to better understand and contextualize the barriers faced by certain sectors in large scale CE adoption. Its use for the fragmented, interdisciplinary, and evolving field of CE research provides valuable insights into externalities impacting on structural, technological and organisational constraints limiting circularity within India's textile industry.

KEY BARRIERS TO CIRCULAR ECONOMY ADOPTION IN THE INDIAN TEXTILE INDUSTRY

Our literature review examined the poor state of circular economy (CE) readiness in India's textile sector looking at barriers from other Indian manufacturing industries and mapping them to CE-readiness tool scores across macro-, meso-, and micro-levels. The main challenges include sustainability issues, behavioral and cultural barriers, and legal restrictions (Das et al., 2024), alongside a lack of competence in technology and knowledge, and low consumer awareness among SMEs (Nudurupati et al., 2022). Digital infrastructure gaps, cybersecurity risks, and inadequate leadership training also hinder adoption (Bag et al., 2022). There are also financial, organizational, supplier, operational, and reverse-logistics constraints (Dutta et al., 2021; Yadav et al., 2020). These hurdles are complex, multilayered, and interlocking – such as regulatory uncertainty suppressing market demand and technology investment – and, therefore, simple classifications are inadequate; a methodical approach is required (Badhotiya et al., 2022; Chhimwal et al., 2022).

The literature shows that the barriers to circular economy (CE) are highly context-specific, depending on sector, geography, and culture. Some key obstacles include a traditional business mindset, low CE literacy, perceived risks of transitioning from linear models, and weak supply chain collaboration that leads to laggard behavior – particularly among Indian SMEs (Mangla et al., 2018; Sharma et al., 2024): within both firms and consumers, knowledge deficits persist (Dutta et al., 2021; Sharma et al., 2023). Economic hurdles like high initial investments, volatile raw material prices, and inadequate recycling facilities show noticeable sectoral disparities across metals, mining, automotive, and plastics (Badhotiya et al., 2022; Bag et al., 2022; Gedam et al., 2021; Manoharan et al., 2022). IP loss risks, product competition, and lower perceived quality of recycled goods thwart adoption even further (Fiksel et al., 2021). Additionally, there are technological bottlenecks. These include limited advanced recycling capacity and ineffective take-back and waste management systems (Parida et al., 2023); this is worsened by weak governance and lack of regulatory enforcement (Yadav et al., 2020), pointing to the need for continuous re-evaluation as these situational barriers change over time.

Based on this review, nine broad categories of CE barriers faced by Indian manufacturing were seen. While studies on barriers to CE accumulate, little information on the Indian textile sector exits.

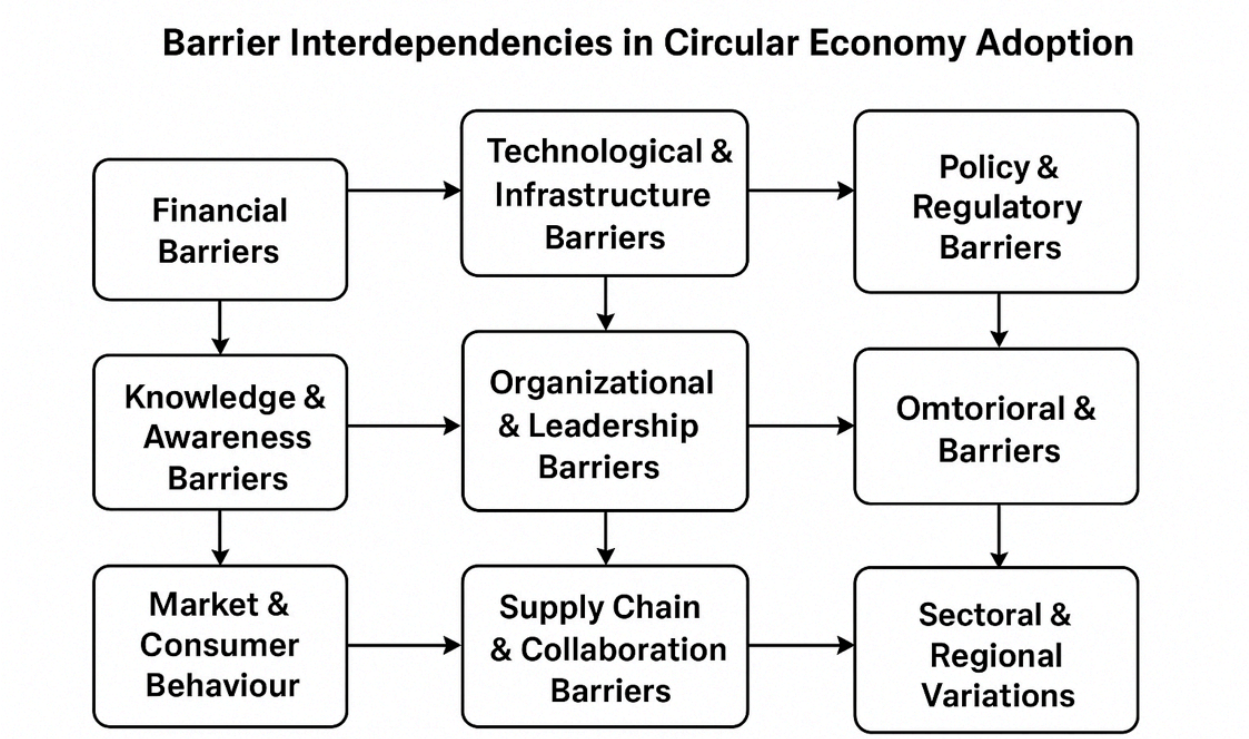
The major issues faced in the manufacturing sector include huge upfront costs, a lack of tech know-how, and poor infrastructure (Badhotiya et al., 2022; Nudurupati et al., 2022). Moreover, textile waste often gets mislabeled as "special waste," which stops companies from reusing it and leads to low-quality downcycling instead (Saccani et al., 2023). Policy-wise, there are voids when it comes to national quality standards and incentives for stakeholders to collaborate (Mhatre et al., 2023; Ponnambalam et al.; Yadav & Majumdar, 2024). Low use of renewable energy, poor supply chain communication, and new data security risks with smart textiles are additional challenges (Khan et al., 2022).

Figure 2: Key Barriers to Circular Economy Adoption in Indian Textile Industry



While fast-moving trends make it hard to adopt longer-life CE-aligned textile products, consumerist skepticism on recycled/made of sustainable textiles closes off the market even more (Yaduvanshi et al., 2016). Taken together, these findings indicate how complex and connected the barriers to CE in the Indian textile industry are. That is why multilevel interventions are critical.

Figure 3: Barriers Interdependencies in Circular Economy Adoption



Barrier Category	Core Issues Identified	Key Sources (from your text)
1. Financial Barriers	• High initial investment for CE technologies	Badhotiya et al. (2022); Nudurupati et al. (2022); Saccani et al. (2023); Sharma et al. (2024)
	• Limited financial resources, especially for SMEs	
	• High cost of recycling infrastructure	
	• Perceived low returns, cost–benefit mismatch	

2. Technological & Infrastructure Barriers	• Limited access to advanced recycling systems	Bag et al. (2022); Parida et al. (2023); Fiksel et al. (2021); Ponnambalam et al. (2023)
	• Difficulty maintaining fiber quality in post-consumer recycling	
	• Poor digital infrastructure, digital literacy gaps	
	• Lack of tools for managing return flows	
	• Risks in outsourcing remanufacturing	
3. Policy & Regulatory Barriers	• Absence of national quality benchmarking system	Yadav & Majumdar (2024); Ponnambalam et al. (2023); Mhatre et al. (2023); G. Yadav et al. (2020)
	• Misaligned or unclear CE regulations	
	• Weak enforcement of sustainability policies	
	• Lack of coordinated governmental support	
4. Organizational & Leadership Barriers	• Unclear digital/CE strategies	Bag et al. (2022); Rajput & Singh (2021); Saccani et al. (2023)
	• Leadership deficiencies in driving CE adoption	
	• Limited workforce training and competency gaps	
	• Inefficient process management	
5. Knowledge & Awareness Barriers	• Low CE knowledge among employees	Dutta et al. (2021); Sharma et al. (2023); Saccani et al. (2023)
	• Lack of consumer education about CE products	
	• Misclassification of textile waste as "special waste" instead of secondary raw materials	
6. Market & Consumer Behavior Barriers	• Low consumer trust in recycled/sustainable products	Fiksel et al. (2021); Yaduvanshi et al. (2016); Manoharan et al. (2022)

	• Perceived risks and quality concerns	
	• Fear of cannibalizing existing product lines	
	• Rapid fashion cycles conflicting with durability	
7. Supply Chain & Collaboration Barriers	• Weak coordination and communication among partners	Dutta et al. (2021); Zaidi & Chandra (2024); Chhimwal et al. (2022); Yadav et al. (2020)
	• Poor information sharing across supply chains	
	• Limited reverse logistics readiness	
	• Supplier resistance to new CE standards	
8. Cultural & Behavioral Barriers	• Resistance to shift from linear to circular models	Mangla et al. (2018); Sharma et al. (2024)
	• Traditional business practices dominating operations	
	• Low stakeholder perception of CE benefits	
9. Sectoral & Regional Variations	• Textile industry-specific recycling limitations	Gedam et al. (2021); Badhotiya et al. (2022); Bag et al. (2022)
	• Infrastructure gaps vary widely across clusters	
	• Sector-dependent regulatory and market constraints	

Table 2: Summary of Key Barriers to Circular Economy Adoption in Indian Textile Industry

DIGITAL TECHNOLOGIES SUPPORTING CE IMPLEMENTATION

Industry 4.0 have potential to create new avenues that can address different barriers hindering Circular Economy (CE) transitions in Indian textile sector (Kanupriya, 2021). The greatest challenge here is the lack of traceability across its value chain that prevent this enormous amount of more than a million tons

textile waste produced every year in India to be handled effectively (Dwivedi et al., 2023). Recent traceability systems – based on digitalisation tools (such as the internet of things (IOT), blockchain, or data analytics) are able to control material flows through value chain i.e., from "sourcing to end-of-life" more efficiently uncovering substantial potential for improving transparency and optimizing recycling processes with waste treatment system in general (Saccani et al.; 2023).

However, companies frequently face challenges in the integration of digital tools with their existing operational infrastructure. Integration complexity can lead to interoperability challenges, especially when attempting to bring together disparate technologies and legacy infrastructure (Bressanelli et al., 2022). Furthermore, the majority of such advanced and digital solutions tend to rely significantly on accurate data inputs, which raises a number of questions regarding data generation, quality, accuracy and management (Bag et al., 2020). These data problems are frequently exacerbated by economic instability as firms, especially SMEs risk-averse to investing into new technologies without a proven ROI (Ingemarsdotter et al., 2021).

It is therefore critical to know the maturities of digital technologies mature, niche, and emerging. The maturity of technology has obvious effects for risk, investment planning and anticipated results. Mature technologies present less implementation risk, more proven use-cases and allow firms to assign budgets with higher confidence (Neri et al., 2023). New technologies on the horizon: New entrants may hold strategic value added in the long run, but these have a higher investment requirement and less of an established framework. A good understanding of the technology landscape enables companies to collaborate and plan strategic roadmaps for migrating to CE, and also take advantage of the government's Digital India programme.

In fact in the textile industry there are perhaps a variety of mature technologies that already have promising potential. Thereby IoT networks and data analytics systems lead to end-to-end lifecycle monitoring, mass-customization and process optimization as well as coordination amongst supply chain partners (Gupta et al., 2021; Jamwal et al., 2022). Through analysing and predicting energy demand, particularly in inventory and return-flow management, artificial intelligence contributes to sustainability (Liang et al., 2018).

Novel technologies open up new avenues for circular transformation. Advanced manufacturing, vitally, is possible with robotics, cyber-physical systems and additive manufacturing which allows for precision manufacture in order to minimize waste of material and energy wastage; improved digitalization of logistics; increased productivity (V. S. Yadav & Majumdar, 2024). For example, automated cutting machines result in reduced amount of waste fabric and cyber-physical systems support efficient transportation routes, as well as reusable packaging. Additive manufacturing (3D printing) as an on demand personalized strategy, has been identified as a shale technology to transform textiles in minimising over consumption and material waste noted for the same (Hettiarachchi et al., 2022).

Another potential option is applying blockchain technology to solve the transparency, data protection and trust issue in a circular supply chain. Its tamper-proof and decentralized nature allows secure transfers of data, traceability and incentive mechanisms (e.g., for end users as well as supply chain partners) such as loops in the CE concept (Esmaeilian et al., 2020; Prajapati et al., 2022).

Niche technologies AR, VR, horizontal and vertical integration platforms fulfill the more special use-cases. Such solutions may enhance the cross-industry coordination, communication between parties in chains and cooperation across stages in a chain (cf., Schöggl et al., 2024). The SME community in particular, may benefit significantly from utilizing tailor-made niche tools that accommodate to their individual organisational limitations and resource constraints.

Adoption of CE-technologies, according to the stage of commercialization and organization's preparedness could potentially accelerate momentum toward CE in the textile industry. Unite for Circular: An organized tech journey from digital analysis, financial feasibility to sustainable goals can be a powerful catalyst for adopting circular practices in the sector.

Table 3: Summary of Mature, Niche, and Emerging Technologies Supporting CE in the Textile Industry

Technology Category	Key Technologies	Primary CE Functions	Application in Textile Industry	Key References
Mature Technologies	Internet of Things (IoT)	Real-time monitoring, lifecycle tracking	RFID tags for fabric tracking; monitoring production waste; machine health monitoring	Gupta et al., 2021; Jamwal et al., 2022
Mature Technologies	Data Analytics & AI	Predictive modelling, waste reduction, demand forecasting	Improved energy efficiency; return-flow prediction; inventory optimization	Liang et al., 2018
Mature Technologies	Cloud Computing	Centralized data storage and sharing	Integrated CE reporting systems; shared supply chain dashboards	Bag et al., 2020

Mature Technologies	Enterprise Resource Planning (ERP)	Integration of process and material flows	Traceability of materials from sourcing to recycling; enhanced process transparency	Bressanelli et al., 2022
Niche Technologies	Horizontal & Vertical Integration Platforms	Supply chain synchronization	Aligning suppliers–manufacturers –retailers for circular flows; better coordination of reverse logistics	Schöggl et al., 2024
Niche Technologies	Augmented Reality (AR) & Virtual Reality (VR)	Design optimization, communication	Reduced prototyping waste; immersive design testing; virtual sampling	Schöggl et al., 2024
Niche Technologies	Digital Twins	System simulation and optimization	Modelling material loops; testing recycling scenarios; optimizing cutting patterns	Neri et al., 2023
Niche Technologies	Collaborative Platforms	Knowledge sharing, stakeholder coordination	Sharing recyclable material specs; consumer–producer CE engagement platforms	Mangla et al., 2018
Emerging Technologies	Blockchain	Immutable data, traceability, transparency	Fiber-to-retail traceability; anti-counterfeiting; reward tokens for recycling	Prajapati et al., 2022; Esmaeilian et al., 2020
Emerging Technologies	Additive Manufacturing (3D Printing)	On-demand production, waste minimization	Printing textile accessories (buttons, trims); reducing overproduction	Hettiarachchi et al., 2022

Emerging Technologies	Cyber-Physical Systems (CPS)	Automation, process control	Automated cutting/sewing; optimized transportation routes; waste reduction	V. S. Yadav & Majumdar, 2024
Emerging Technologies	Robotics & Smart Manufacturing	Precision processing, productivity	Automated sorting of textile waste; robotic cutting for accuracy	Nudurupati et al., 2022
Emerging Technologies	Advanced Recycling Technologies (Chemical Recycling)	Fibre regeneration, material recovery	Converting waste textiles into high-quality fibers; reducing downcycling	Parida et al., 2023

DISCUSSION

While it is helpful to document individual barriers and digital tools, our study is focused more on understanding how these elements interact across the Indian textile value chain (Kanupriya, 2021; Saccani et al., 2023). To bridge the divide between the 7.7 million tons of textile waste generated annually and the country's disheartening recycling rate of under 1% requires us to look at systemic bottlenecks that currently trap Indian manufacturers in linear production models frankly (CII, 2023; Dwivedi et al., 2023; NCAER, 2009; Ponnambalam et al., 2023).

There are three closely connected structural issues at the root of this under-1% recycling bottleneck (CII, 2023; NCAER, 2009):
First, material complexity is always a problem (Saccani et al., 2023). Most domestic post-consumer waste consists of intricate fiber blends, such as poly-cotton or elastane mixtures, heavily treated with chemical finishes and synthetic dyes. Standard mechanical recycling shreds these fibers, making them so weak and short that they can only be downcycled into low-value items like industrial rags, padding, or insulation (Saccani et al., 2023). Without accessible, high-speed optical sorting technologies capable of identifying fiber chemistry on the factory floor, high-value fiber-to-fiber recovery simply cannot take off (Parida et al., 2023).

Second, up to 80% of waste collection and primary sorting across major hubs like Surat, Panipat, and Bhiwandi is handled by informal waste aggregators. Relying entirely on manual, visual sorting without digital tracking creates huge information gaps between scrap collection networks and industrial recycling facilities (Dutta et al., 2021; Zaidi & Chandra, 2024).

Third, the sector is stuck in a classic small-business capital trap. Over 90% of Indian textile facilities operate as cash-strapped MSMEs that cannot afford expensive chemical recycling equipment or optical sorting lines without guaranteed buyers (Badhotiya et al., 2022; Ingemarsdotter et al., 2021; Nudurupati et al., 2022). Meanwhile, major brand owners won't commit to signing long-term purchasing contracts until suppliers can prove they can regularly produce high-quality recycled yarn, creating a major deadlock.

Digital tools offer a practical way to break through these operational deadlocks (Kanupriya, 2021; Saccani et al., 2023). Blockchain networks and Digital Product Passports make supply chains more transparent as they create an unalterable record from raw fiber sourcing to garment retail (Esmaeilian et al., 2020; Prajapati et al., 2022). Tagging fabrics lets recyclers and brands instantly check exact material blend and chemical details, which takes the guesswork out of reverse logistics (Bressanelli et al., 2022; Prajapati et al., 2022). AI-powered Near-Infrared sensors solve the sorting problem by quickly scanning scrap compositions (Nudurupati et al., 2022), while Digital Twins let engineers test fiber blends to cut down on trial-and-error waste (Neri et al., 2023). IoT tech also monitors water, energy, and chemical use during dyeing in real time (Bag et al., 2020; Gupta et al., 2021), proving to skeptical buyers that a product is genuinely sustainable (Fiksel et al., 2021).

Since India's textile sector varies across regions quite significantly, circular strategies must also adapt locally. Gujarat's synthetic centers around Surat and Vapi need chemical depolymerization, IoT zero-liquid-discharge systems, and blockchain tracking (Parida et al., 2023; Prajapati et al., 2022). Tamil Nadu's cotton export centers need AI pattern optimization, cloud scrap platforms, and mechanical fiber recycling (CII, 2023; Liang et al., 2018; V. S. Yadav & Majumdar, 2024). Panipat's rag-yarn hub relies on Near-Infrared sorting and digital grading (Esmaeilian et al., 2020; Nudurupati et al., 2022), while West Bengal's jute and silk hubs need digital craft markets and smart sensors (Sanjay Bakshi, 2024; Schöggl et al., 2024).

Finally, we must push circularity from a voluntary goal into an industry standard. India needs a clear Textile Extended Producer Responsibility framework modeled on existing national environmental policies (Sarma et al., 2023; Varun Boralkar, 2023). A policy like this must set mandatory recycled content targets for domestic apparel while imposing eco-modulated fees on brands based on product recyclability, directly funding collection infrastructure (Ardolino et al., 2022). The government should also help intgrate informal scrap collectors into recognized cooperatives with digital tools, while the Bureau of Indian Standards sets clear quality norms for secondary fibers to build trust across the country (Dutta et al., 2021; Ponnambalam et al., 2023; Yadav & Majumdar, 2024).

CONCLUSION

Despite the fact that previous study conducted by various authors ad experts in the field focused on looking at the challenges related to implementing Circular Economy (CE) concepts in a variety of Indian manufacturing sectors, there is still an evident absence of systematic analysis and classification of these barriers in the textile sector. This paper attempts to present a systematic taxonomy that provides

purposeful information for researchers, industry stakeholders, and policymakers by addressing and assessing nine major barrier categories.It offers a more thorough comprehension of the strategic measures required for advancing India's transition to a circular and sustainable textile ecosystem.

The significance of digital technology in addressing CE implementation challenges is underscored in this study. It brings out the importance of industrial sectoral strategies that integrate technology with ground level realities resulting in better planning and tailored interventions. Interestingly, for CE based applications in the context of the Indian textile sector, it is one of the first full-fledged discussions that relate digital solutions to a levels of technology readiness in terms of being mature, niche and emerging. This technology-focused viewpoint aids businesses in comprehending the changing digital environment, upskilling their employees, and coordinating their circularity initiatives with suppliers, consumers, and partners.

The report also underscores the complementarity and interrelationship between digital technologies and CE practices. To achieve this, you need to know how the above interdependencies can be used as a common basis for developing feasible, scalable methods that enhance resource efficiency and mitigate waste while fostering sustainable production.
It's a call to action for players in the Indian textiles sector to apply CE principles and leverage digital progress. The circular textile economy for IndiaA comprehensive, strong and future-proof circular textile economy is facilitated by a comprehensive analysis of this technology and obstacles related to them.

MANAGERIAL IMPLICATIONS

The research has some significant managerial implications to the Indian policymakers and executives within the textile sector, as it provides elaborate insights on the micro-levels of initiatives required to see the successful adoption of the Circular Economy (CE). An acute necessity to increase awareness about CE concepts, associated challenges, and benefits in the long run in all spheres of the industry is one of the main outcomes. The gap in knowledge should be bridged by initiating systematic capacity-building programs by government agencies and business organizations. The initiatives would involve training modules, workshops, seminars and involvement at the community level.

It is still important to involve the government in order to speed up the CE implementation process. The policymakers need to raise financial incentives such as microloans, tax concessions and targeted subsidies to reduce the financial cost of transitioning to circular models. At the same time, the development of unified CE-relevant regulatory frameworks and the development of eco-industrial parks would provide the institutional background needed to integrate sustainable practices across the industry.

This is equally important with the growing awareness of the consumers. Through highlighting the social and environmental values of the products of circular textile, strategic marketing can alter the behaviour of the customers. The increase in demand of sustainable alternatives will make manufacturers adopt more circularity requirements.

The paper also brings out the transformational impact of strategic alliances between large corporations and small and medium-sized enterprises (SMEs). Large companies can be very important in this matter by integrating SMEs into their sustainability-based sourcing strategy and giving them financial assistance, technical guidance, and extended procurement contracts. The partnerships enhance material recovery, resource productivity, and supply chain resilience of bigger companies and at the same time empower SMEs.

Finally, the circularity of the sector should involve SMEs. By collecting, sorting, and using post-consumer and post-production materials in a systematic way, SMEs can reduce their dependence on the virgin resources and contribute greatly to the circular ecosystem. The governments, industry leaders, and SMEs should therefore work together in driving the textile industry in India to a sustainable and circular future.

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