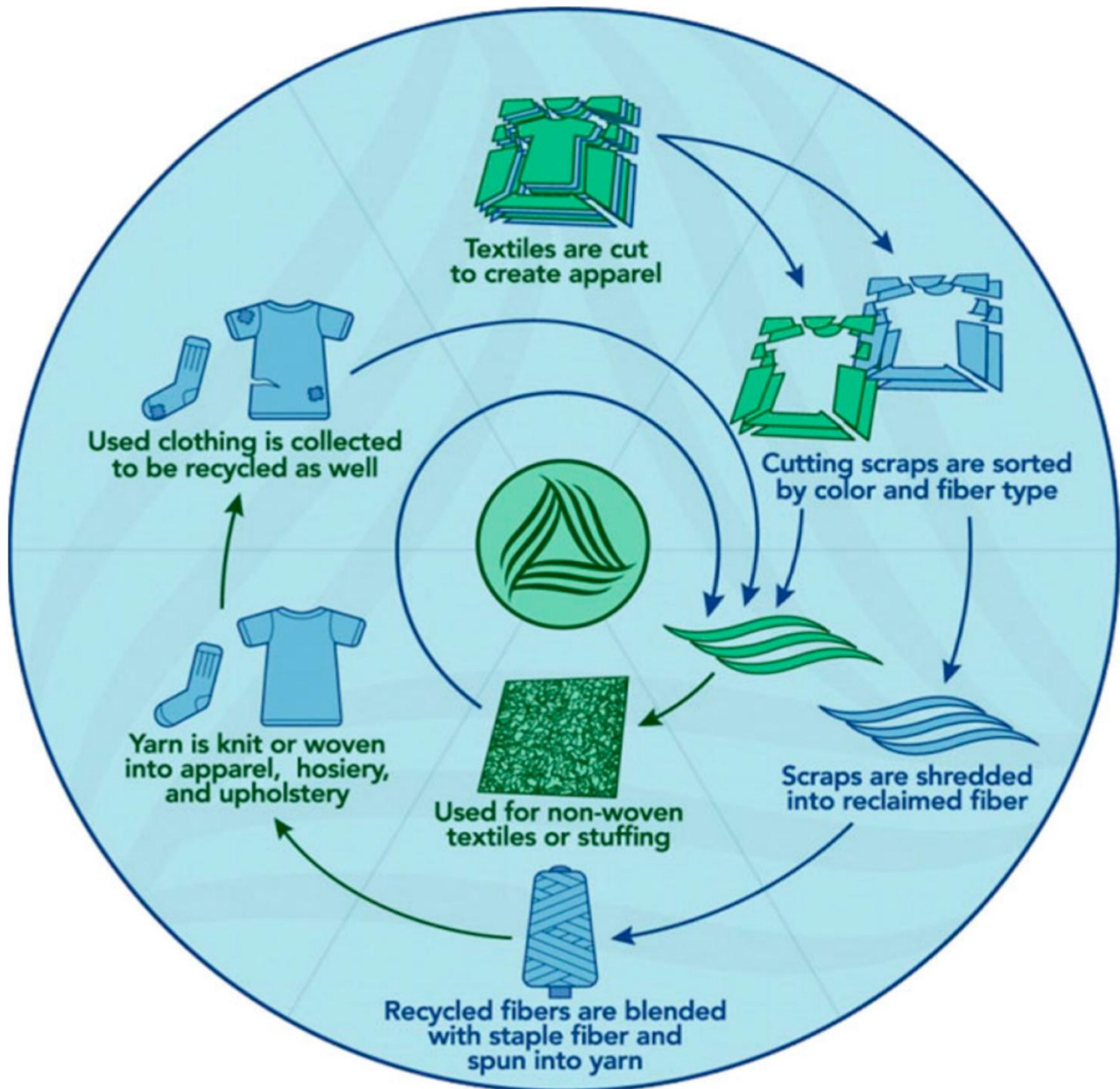


# TEXTILE SUSTAINABILITY

## UNIT-3

### PROCESS AND NEW TECHNOLOGIES IN TEXTILES :

#### 1. The Textile Production Stage



#### A. Overview of the Textile Production Chain

Textile production is a long, interconnected journey that begins with raw fibres and ends with finished garments ready for consumers. Each stage carries environmental and social

implications, from water usage to chemical discharge and energy consumption. The production chain includes spinning, weaving/knitting, dyeing, finishing, and garment

construction — a sequence that shapes both the physical form and ecological footprint of every textile.

## **B. Fibre Preparation and Spinning**

At the very foundation lies fibre processing. Natural fibres undergo cleaning, carding, and combing before being spun into yarns. Synthetic fibres are extruded from polymers before they are stretched and twisted. Traditionally, these processes required significant energy and emitted dust. Today, modern high-efficiency spinning machines reduce waste, conserve energy, and improve worker safety.

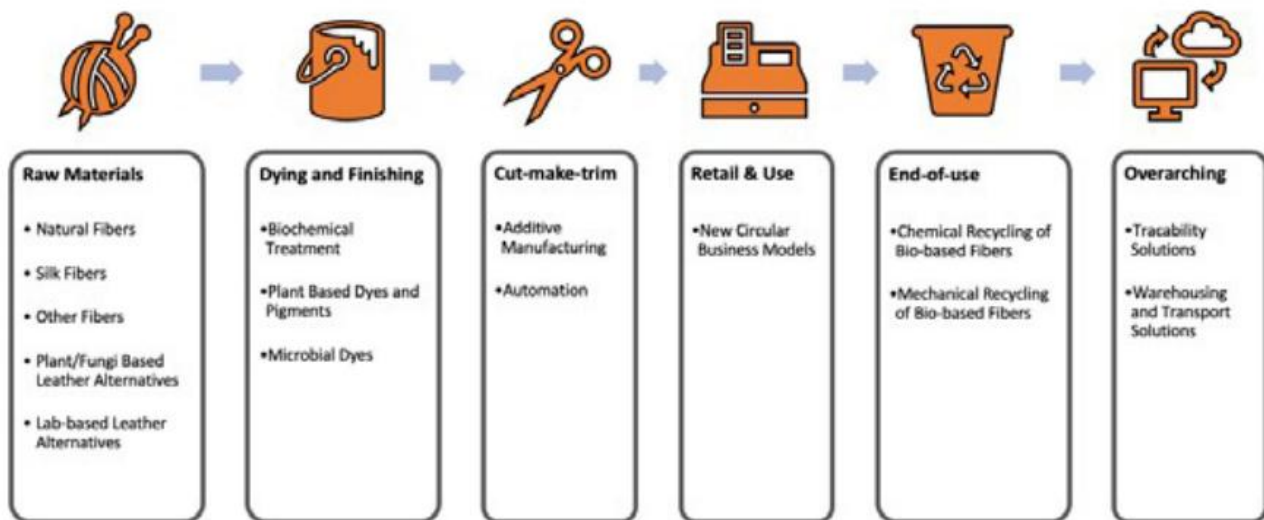
## **C. Fabric Construction: Weaving and Knitting**

Fabric formation determines the strength, stretch, and texture of the textile.

- Weaving, with its interlaced warp and weft, produces durable fabrics.
- Knitting, using loops, generates flexible and breathable materials. Modern looms and circular knitting machines now operate with optimized energy usage and reduced noise pollution. Automated tension control reduces defects, minimizing material waste.

## **D. Wet Processing: Dyeing, Printing, and Finishing**

Wet processing is the most resource-intensive stage, involving huge volumes of water and chemicals. Pre-treatment (scouring, bleaching), dyeing, and finishing determine the fabric's final color, feel, and performance. Historically, this stage created some of the highest environmental burdens, but modern technology now offers greener alternatives such as low-water dyeing and digital printing.



## E. Garment Manufacturing

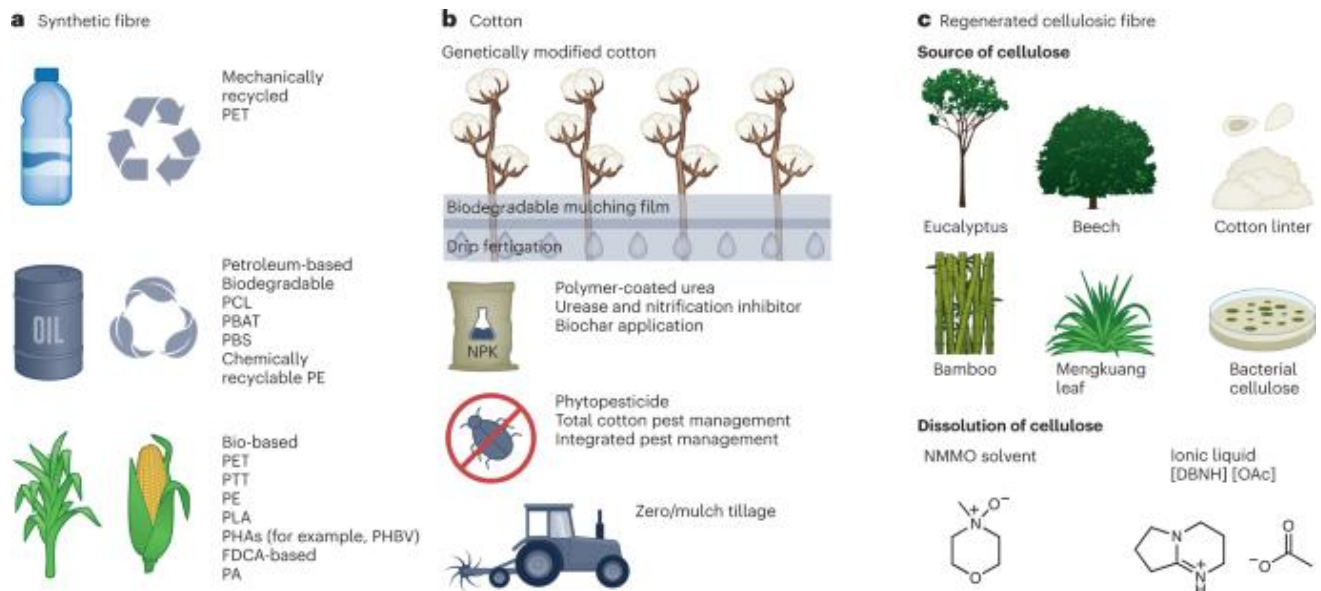
Once fabrics are ready, pattern-making, cutting, sewing, and finishing bring garments to life. Precision cutting, automated sewing systems, and 3D visualization tools help reduce waste and improve product quality. Lean manufacturing principles ensure streamlined workflows and reduced energy consumption.

## F. Environmental Challenges in the Production Stage

The conventional textile chain generates substantial pollution through:

- Effluent discharge from dyeing
- Air emissions from boilers
- Energy-intensive machinery
- Fibre and fabric waste

Understanding this impact opens pathways for sustainable interventions.



## 2. BEST AVAILABLE TECHNOLOGIES (BAT) IN THE TEXTILE INDUSTRY

The best available technologies in the textile industry include AI and automation for design and supply chain management, [digital printing](#) and laser technology for precise and efficient decoration, nanotechnology for creating high-performance fabrics, and 3D printing for customized and sustainable production. Additionally, advanced dyeing techniques like electrochemical and ozone methods are improving sustainability in processing.

### Design and production

- [Artificial Intelligence \(AI\)](#): AI-powered software can forecast trends, streamline supply chains, and optimize resource usage.
- Automation and Robotics: Machines can now handle complex tasks like pleating, cutting, and knitting with high precision.
- [Digital Textile Printing](#): Allows for complex designs, high-speed production, and customization with layered printing capabilities.
- [3D Printing](#): Enables the creation of customized garments and footwear with minimal material waste, with potential future applications for a wider range of clothing.

- **Laser Technology:** Used for precise cutting and engraving to create intricate designs and add unique textures to fabrics.

### **Materials and functionality**

- [Nanotechnology](#): Integrates tiny particles into fibers to create textiles with advanced properties such as self-cleaning, water repellency, fire resistance, and durability, while using less energy.
- [Smart and Bio-Fabricated Textiles](#): These include fabrics with integrated sensors, energy-harvesting capabilities, and those made from bio-materials, with applications in areas like health monitoring and sustainable fashion.

### **Sustainability and processing**

- **Sustainable Dyeing:** New methods like electrochemical and ozone dyeing can reduce water and energy consumption in the dyeing process.
- **Blockchain:** Provides transparency in the supply chain, helping to verify ethical sourcing and track materials from origin to finished product.
- **Optimized Resource Use:** Algorithms can calculate the most efficient use of raw materials, reducing waste

### **A. Understanding BAT in Textiles**

Best Available Technologies (BAT) represent the most advanced, effective, and environmentally responsible processes currently achievable in the textile sector. These technologies aim to reduce emissions, conserve resources, and improve efficiency while remaining economically feasible. BAT is not static — it evolves as new innovations emerge.

### **B. BAT in Wastewater Treatment**

Wastewater from textile industries contains dyes, salts, chemicals, and microfibres. Modern BAT solutions include:

- **Membrane bioreactors (MBR)** for high-efficiency filtration

- Reverse Osmosis (RO) for water recovery
  - Effluent Treatment Plants (ETP) with real-time monitoring
  - Zero Liquid Discharge (ZLD) systems minimizing discharge
- These technologies reduce pollution while enabling water circularity.

### **C. BAT in Dyeing and Finishing**

Technological innovations have transformed dyeing from a resource-heavy process into a more controlled, eco-friendly stage.

#### **Key BAT methods include:**

- Supercritical CO<sub>2</sub> dyeing (eliminates water)
  - Low-liquor ratio dyeing machines
  - Digital textile printing (reduced dye and water use)
  - Cold pad batch dyeing (energy-efficient)
- These ensure deep, consistent coloration with minimal environmental burden.

### **D. BAT in Energy Management**

Energy use accounts for a large share of textile industry emissions. Best Available Technologies include:

- High-efficiency boilers and steam systems
  - Heat recovery units on dyeing machines
  - Solar thermal systems for water heating
  - Variable frequency drives (VFD) on motors
- These technologies significantly reduce carbon footprints.

### **E. BAT in Air Emission Reduction**

Textile factories emit volatile organic compounds (VOCs), dust, and fumes. Advanced solutions include:

- Electrostatic precipitators
  - Bag filters
  - Activated carbon adsorption units
- These ensure cleaner air and healthier working environments.

## **F. BAT for Solid Waste Management**

Solid waste is minimized using technologies such as:

- Fabric scrap shredders
  - Fibre recovery systems
  - Digital pattern optimization
  - Automated cutting machines
- This supports circularity and reduces landfill accumulation.

## **G. Barriers in Adopting BAT**

Despite their advantages, challenges include:

- High initial investment
  - Lack of skilled operators
  - Limited support for small manufacturers
  - Infrastructure and policy gaps
- Yet, industry pressure and consumer demand continue to accelerate adoption.

## **3. LOW ENVIRONMENTAL IMPACT PROCESSES / TECHNOLOGIES**

Low environmental impact processes and technologies focus on energy efficiency, waste reduction, and renewable resources, encompassing sectors like clean energy generation (solar, wind, hydro), sustainable agriculture (vertical farming,

phytoremediation), and resource management (carbon capture, AI-driven optimization, and smart metering). They aim to reduce carbon emissions, conserve natural resources, and minimize pollution throughout their lifecycle, from construction to waste.

## **Energy and buildings**

- Renewable energy: Power from naturally replenishing sources like solar, wind, and hydroelectricity.
- Energy efficiency: Technologies like LED lighting, smart thermostats, and high-efficiency HVAC systems reduce energy demand.
- Energy storage: Batteries are crucial for storing renewable energy for use when needed.
- Self-sufficient buildings: Constructing energy-positive buildings that generate their own power, often through solar panels.
- Low-carbon construction: Using green materials like bamboo, straw, and hemp, which can store carbon, to replace carbon-intensive materials like cement and steel.

## **Waste and water management**

- Waste-to-energy: Converting waste into energy, often through incineration.
- Automated recycling systems: Efficiently sorting and processing recyclable materials.
- Composting: Turning food waste into fertilizer.
- Water purification and recycling: Treating wastewater for reuse, and using smart meters to help monitor and reduce water consumption.
- Phytoremediation: Using plants to remove contaminants from soil and water.

## **Transportation and manufacturing**



- Electric transport: Using electric vehicles like cars, trucks, and buses.
- Green logistics: Optimizing transportation routes and using energy-efficient vehicles to minimize environmental impact.
- Energy-efficient manufacturing: Implementing technologies like AI, automation, and digital twins to optimize energy use and reduce waste.
- Sustainable materials: Developing and using materials like dissolvable support structures in additive manufacturing, which reduces waste from post-processing.

## **Carbon management**

- Carbon capture and storage (CCS): Capturing carbon dioxide emissions from sources like power plants and storing them underground.
- Carbon tracking software: Using software to calculate and monitor a company's carbon footprint, allowing for better management

## **A. Introduction to Low-Impact Technologies**

Low-impact processes focus on reducing water, energy, chemicals, emissions, and waste throughout textile manufacturing. These technologies align with global sustainability goals and help brands meet regulatory and consumer expectations. They represent a shift from “less harm” to “positive impact,” where eco-efficiency becomes the guiding principle.

## **B. Water-Saving Technological Innovations**

Water scarcity influences every part of the textile supply chain. Key low-impact innovations include:

- Waterless dyeing systems (supercritical CO<sub>2</sub>)
- Foam dyeing (minimal water)
- Continuous dyeing with low liquor ratios

- Effluent recycling systems

These technologies drastically reduce freshwater dependency.

### **C. Energy-Efficient Practices**

Energy-efficient solutions lighten the environmental load. Examples include:

- Optimized boilers and steam traps
- Solar-powered dryers and heaters
- LED lighting throughout factories
- Heat recovery from exhaust gases

These reduce greenhouse gas emissions and operational costs.

### **D. Eco-Friendly Chemical Alternatives**

Green chemistry promotes safe and biodegradable chemical substitutes.

Examples include:

- Natural dyes from plants, roots, and minerals
- Enzymatic scouring and bleaching
- Low-impact reactive dyes
- Biodegradable finishing agents

These reduce toxic discharge into water bodies.

### **E. Cleaner Production Techniques**

Cleaner production integrates preventive strategies to reduce pollution at the source.

This includes:

- Automated machine dosing to prevent chemical overuse
- Digital printing with minimal ink wastage
- Zero-waste pattern cutting

- Air-based fabric drying  
Cleaner production improves efficiency and protects ecosystems.

## **F. Circular Production Models**

Circularity focuses on keeping materials in use longer.

Processes include:

- Fibre-to-fibre recycling
- Using industrial textile waste as raw material
- Modular and repair-friendly garment design  
This reduces dependency on virgin materials.

## **G. Robotics and Automation**

Automation minimizes human error, reduces waste, and enhances resource precision.

Examples:

- Automated dye dosing
- Sensor-based quality checks
- Intelligent cutting machines
- AI-based production planning  
These technologies optimize workflow and support sustainability goals.

## **H. Eco-Friendly Finishing Technologies**

Modern finishing can enhance fabric performance while limiting environmental impact.

Key techniques include:

- Plasma surface treatment
- UV-curing finishes
- Ozone bleaching

- Nano-finishes requiring reduced chemicals
- Each method reduces energy, water, or chemical consumption.

## I. Social Benefits of Low-Impact Technologies

Sustainability extends to people as well. Low-impact technologies create:

- Safer working environments
  - Reduced chemical exposure
  - Better health outcomes for communities
  - More efficient, dignified employment
- Thus, the impact becomes both ecological and humanitarian.



## ENVIRONMENTAL SOCIAL GOVERNANCE:

### 1. Environmental Perspective

#### A. Understanding Environmental Responsibility in ESG

The environmental pillar of ESG emphasizes how companies interact with the natural world. It examines resource use, energy consumption, emissions, waste management, biodiversity impact, and climate responsibility. Organizations are expected not merely to avoid harm but to contribute positively to ecological resilience. In a world facing climate shocks, water scarcity and pollution, the environmental pillar becomes the foundation upon which sustainable futures are built.



## **B. Climate Change Mitigation and Adaptation**

Companies today must confront the realities of climate change. Mitigation strategies include reducing greenhouse gas emissions, switching to renewable energy and rethinking processes that rely on fossil fuels. Adaptation focuses on preparing supply chains for climate-related disruptions—heatwaves, floods, droughts and unpredictable weather patterns. Firms that acknowledge climate risks early build stronger, more resilient operations.

## **C. Resource Efficiency and Circular Use of Materials**

Resource conservation is at the heart of environmental sustainability. This includes optimizing energy, reducing water usage, improving machinery efficiency and embracing circular material flows. Technologies such as recycling, regeneration, and waste-to-resource models reduce the strain on natural ecosystems. Companies shift from a “take–make–waste” mindset to “reduce–reuse–renew.”

## **D. Pollution Reduction and Ecological Protection**

Air emissions, chemical discharge, soil contamination and microplastic release are major environmental concerns. The environmental pillar pushes industries to adopt cleaner processes, advanced filtration systems, responsible chemical management, and

nature-based solutions. Protecting biodiversity—rivers, forests, coastal zones—becomes a shared responsibility across the value chain.

## **E. Environmental Transparency & Reporting**

Sustainability reporting frameworks such as GRI, CDP and TCFD require companies to openly disclose environmental performance. This transparency strengthens accountability, encourages improvement, and helps investors make informed decisions. Companies that communicate clearly build greater trust with all stakeholders.

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## **2. Social Perspective**

### **A. Social Wellbeing in ESG**

The social pillar of ESG centers on people—workers, communities, consumers and society at large. It evaluates whether organizations create a fair, safe and inclusive environment. This pillar recognizes that no amount of environmental or financial success can compensate for human exploitation. Social sustainability ensures dignity becomes a non-negotiable part of progress.

### **B. Labor Rights and Working Conditions**

Safe working environments, fair wages, regulated working hours and respect for human rights form the heart of social sustainability. Companies must ensure ethical labor practices throughout their supply chain, from raw material sourcing to retail. Social audits, worker voice platforms, and grievance redressal mechanisms reinforce ethical operations.

### **C. Diversity, Equity and Inclusion (DEI)**

Modern organizations embrace diverse teams, equitable opportunities and inclusive practices. Diversity strengthens creativity; equity ensures fairness; inclusion nurtures belonging. As workplaces become more global, DEI evolves into a key indicator of a socially responsible organization. Leaders are expected to cultivate empathy, respect and cultural understanding.

## **D. Consumer Health, Safety and Ethical Responsibility**

Products must be safe, non-toxic and responsibly marketed. Companies bear a duty to protect customer well-being. Transparency in communication—through labels, certifications, safe chemical use and quality assurance—builds consumer trust. Ethical marketing avoids manipulation and respects consumer rights.

## **E. Community Development and Social Impact**

Businesses are embedded in communities that support them. Through education programs, local employment, skill development and environmental restoration, organizations can uplift the communities they serve. Social sustainability encourages companies to leave a positive footprint.

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## **3. Certifications and Policies**



### **A. Importance of ESG Certifications and Policies**

Certifications act as proof that a company meets defined environmental and social standards. They help distinguish true sustainability from empty claims, while policies

guide organizations toward consistent, ethical decision-making. Certifications strengthen credibility, transparency and market competitiveness.

## **B. Environmental Certifications**

- **ISO 14001:** Environmental management systems
- **OEKO-TEX & Bluesign:** Chemical safety
- **Carbon Neutral/Net Zero Labels:** Climate commitment
- **Energy Star:** Energy efficiency

These certifications validate environmental practices and motivate continuous improvement.

## **C. Social and Ethical Certifications**

- **Fair Trade Certification**
- **SA8000 (Social Accountability)**
- **WRAP (Worldwide Responsible Accredited Production)**
- **B-Corp Certification**

These certifications ensure labor rights, fair wages, safe conditions and ethical business conduct.

## **D. Governance & Responsible Business Policies**

Corporate governance policies include anti-corruption rules, transparency frameworks, board diversity guidelines, whistle-blower protections and compliance mechanisms. Strong governance ensures that environmental and social goals are upheld with integrity.

## **E. International Agreements and Government Frameworks**

Policies such as the Paris Agreement, EU Green Deal, UN SDGs, and national environmental laws shape sustainability strategies. Companies must align with these frameworks to remain compliant, competitive and responsible.



## **4. Barriers to Circularity**

### **A. Understanding Circularity Challenges**

Circularity aims to create closed-loop systems where waste becomes a resource. However, transitioning from a linear model to a circular one is complex. Structural, technological, economic and behavioral barriers often slow the journey. Recognizing these obstacles helps industries craft effective solutions.

### **B. Technological and Material Barriers**

Many textiles are blended materials (cotton-polyester, nylon-elastane), making recycling technically difficult. Recycling technologies are still developing and may be expensive or inconsistent in quality. Lack of large-scale fiber-to-fiber recycling infrastructure further complicates circularity.

### **C. Economic and Market Barriers**

Circular processes often require higher investment and longer return periods. Sustainable materials may cost more than conventional alternatives. Market demand for circular products is growing, but not yet universal. Smaller companies struggle most due to limited capital.

### **D. Supply Chain Complexity**

Global textile supply chains involve multiple actors—farmers, mills, factories, transporters and retailers. Ensuring transparency, traceability and accountability across these layers is challenging. Without reliable data, circular systems remain difficult to implement.

### **E. Consumer Awareness and Behavior**

Even the most sustainable product fails if consumers are unwilling to repair, reuse, return or recycle. Fast fashion culture encourages overconsumption, short garment lifecycles and disposability. Changing behavior requires education, incentives and accessible recycling options.

## **F. Policy and Regulatory Barriers**

Many countries lack strong Extended Producer Responsibility (EPR) systems, circularity standards or waste management frameworks. Without supportive policies, companies find it hard to invest in circular innovations.

## **G. Cultural and Organizational Resistance**

Circularity demands mindset shifts. Traditional manufacturing prefers speed and volume, whereas circularity requires durability, repairability and resource efficiency. Resistance to change—within companies, industries and consumer communities—creates friction.