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REVIEW

Cotton Industry Fashion and Sustainable Development: A Review

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ABSTRACT

PURPOSE: This study critically investigates the sustainability challenges linked to cotton production and the fashion industry, with a specific focus on the systemic impacts of fast fashion. It aims to evaluate the environmental pressures generated by cotton cultivation and textile manufacturing processes, while exploring emerging institutional initiatives and technological innovations that may facilitate more sustainable production and supply-chain practices.

DESIGN/METHODOLOGY/APPROACH: A qualitative, literature-based analytical methodology is employed, synthesising evidence from peer-reviewed academic publications, industry reports, and established sustainability frameworks relevant to cotton agriculture, textile manufacturing, and fashion supply chains. The analysis emphasises key sustainability dimensions, including water consumption, chemical input intensity, energy use, and the role of policy, institutional mechanisms, and technological interventions in enhancing environmental performance.

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FINDINGS: The findings indicate that increasing global demand for cotton, driven largely by fast fashion, has intensified environmentally unsustainable practices across both agricultural and industrial stages of the value chain. Key challenges include excessive water withdrawal, high dependence on agrochemicals, and inefficient energy utilisation, collectively contributing to water scarcity, ecosystem degradation, biodiversity loss, and potential human health risks. Sustainability initiatives such as the Better Cotton programme, the expansion of organic cotton systems, and the adoption of improved agronomic practices demonstrate measurable potential for mitigating these impacts. In addition, advancements in precision agriculture, particularly sensor-based monitoring and GPS-enabled technologies, emerge as effective tools for optimising resource efficiency and reducing environmental burdens.

ORIGINALITY/VALUE OF THE PAPER: This study contributes to the literature by offering an integrated perspective that connects agricultural sustainability challenges with the structural dynamics of the fashion industry, particularly fast fashion. By examining the interdependencies between cotton farming, textile processing, and consumption patterns, the paper highlights the combined influence of institutional initiatives and technological innovation in advancing system-level sustainability transitions.

RESEARCH LIMITATIONS/IMPLICATIONS: The study is constrained by its reliance on secondary sources; this may limit the representation of regional heterogeneity in cotton production systems and recent industry-specific developments. Future research should incorporate empirical case studies, field-based assessments, or quantitative modelling to evaluate the effectiveness of targeted sustainability interventions across diverse geographic and socio-economic contexts.

PRACTICAL IMPLICATIONS: The results offer practical guidance for policy-makers, cotton producers, and fashion brands by emphasising the importance of water-efficient management, reduced chemical input use, and investment in precision agriculture technologies. For the fashion sector, the findings support the adoption of sustainable sourcing standards and responsible production strategies as critical measures for reducing the environmental footprint of cotton-based apparel.

KEYWORDS: *Cotton Industry; Water Scarcity; Sustainable Development; Fertilisers; Contaminates; Fashion; Ecosystem.*

INTRODUCTION

Sustainable development seeks to meet the needs of the present without compromising the ability of future generations to meet their own needs. It involves balancing environmental integrity, social equity, and economic viability. The Sustainable Development Goals (SDGs) are a widely accepted framework for this balance. The cotton industry refers to all the activities involved in growing, processing, and producing products from cotton. It includes every stage from the farm to finished goods (Ahmed, 2010; Pillah, 2023):

- **Spinning:** Converting cotton fibres into yarn or thread;
- **Weaving or knitting:** Turning yarn into fabric;
- **Finishing and dyeing:** Treating the fabric to give it colour, texture, or strength;
- Garment and textile manufacturing, producing clothes, home, and industrial fabrics;
- Trade and export, selling raw cotton, yarn, or finished textiles locally or internationally.

In short, the cotton industry covers the entire chain from cotton farming to textile production. Cotton is the most widespread profitable non-food crop in the world. Its production provides income for more than 250 million people worldwide and employs almost 7% of all labour in developing countries. The cotton industry is blamed for excessive use of water that can lead to water scarcity, ecosystem degradation, heavy reliance on pesticides and fertilisers that contaminate soil and water sources, harming biodiversity and human health (WWF, 2025). Other environmental concerns and sustainability in the cotton industry encompasses social and economic factors. This includes ensuring fair labour practices, improving working conditions, and providing economic stability for the millions of smallholder farmers who depend on cotton for their livelihoods. By integrating these environmental, social, and economic aspects, the cotton industry can move towards a more regenerative and ethical model, fostering a circular fashion economy that benefits both the planet and its people. The fashion industry, particularly the "fast fashion" model, has a significant and often negative impact on sustainable development. This is due to its heavy consumption of resources, pollution, waste generation, and social issues within its supply chain. Addressing these challenges is crucial for the industry to align with the United Nations' SDGs (UN, 2025). Here, we have to mention that the Better Cotton Initiative (BCI) aims to promote measurable improvements in cotton cultivation to make it more economically, environmentally, and socially sustainable. The BCI's philosophy is to develop a market for 'Better Cotton' and thereby bring long-term benefits for the environment, farmers, and other people dependent on cotton for their livelihood. The BCI aims to promote measurable improvements of cotton cultivation to make it more economically, environmentally, and socially sustainable. The BCI's philosophy is to develop a market for 'Better Cotton' and thereby bring long-term benefits for the environment, farmers and other people dependent on cotton for their livelihood (Solidaridad, 2023; 2025).

NEGATIVE IMPACTS OF COTTON PRODUCTION ON SUSTAINABLE DEVELOPMENT

Here are some the negative effects of the cotton chain management production on the SDGs described in Table 1 with more details. These factors need to tackled in harmony by all the stakeholders.

Table 1: Impact of the cotton production on the SDGs

Type of Impact	Description	Examples / Evidence	SDGs Affected
Environmental degradation	Production often uses large amounts of raw materials, energy, water, etc., generating pollution (air, water, soil), greenhouse gas emissions (GHG), and habitat destruction.	A critical review of manufacturing shows that manufacturing is one of the highest contributors to greenhouse gas emissions (especially CO_2) in the EU (second only after the energy sector) (Panagiotopoulou *et al.*, 2022). Industrial agriculture contributes to deforestation, land degradation, loss of biodiversity, desertification, aquatic pollution, and is responsible for up to 37% of greenhouse gas emissions in some assessments (Driscoll, 2021). Also, the FAO documents how overexploitation, unclear land tenure, resource depletion, and forest cover loss are negative consequences in many production chains.	SDG 13 (Climate Action), SDG 15 (Life on Land), SDG 6 (Clean Water), SDG 12 (Responsible Consumption and Production)
Biodiversity loss and habitat destruction	Clearing land for agriculture, industry or resource extraction destroys ecosystems; runoff, pollution and monocultures reduce species diversity.	For example, cleaning land for mechanised farming: numerous case studies show major negative effects on ecosystem services and biodiversity(Ayompe *et al.*, 2021).	SDG 15 (Life on Land), SDG 14 (Life Below Water) if water ecosystems are affected
Resource depletion and soil/land degradation	Overuse of soil, water, nutrients; deforestation; conversion of forests or natural landscapes to agriculture or industrial sites; unsustainable harvesting.	UNDP notes that agriculture drives overexploitation, poor agricultural practices that lead to soil erosion, depletion of freshwater (UNDP, 2025). Manufacturing that uses plastic packaging, etc., contributes to pollution and waste; plastics are derived from fossil fuels and often disposed of poorly, also contributing to soil/water contamination.	SDG 2 (Zero Hunger, via soil fertility), SDG 6 (Water), SDG 12, SDG 15
Pollution (air, water, soil)	Emission of pollutants from factories, runoff from agriculture (fertilisers, pesticides), industrial waste, chemical by-products. These harm human health, ecosystems, food safety.	The manufacturing sector's carbon footprint review mentions not just CO_2 but environmental emission factors (Panagiotopoulou *et al.*, 2022). Industrial agriculture is a major source of water and soil pollution (Driscoll, 2021).	SDG 3 (Good Health & Well-being), SDG 6, SDG 14, SDG 15

Type of Impact	Description	Examples / Evidence	SDGs Affected
Climate change acceleration	Production based on fossil fuel energy, deforestation, methane emissions, etc., adding to greenhouse gases.	As above: the manufacturing sector contributes high GHG emissions (Panagiotopoulou *et al.*, 2022). Industrial agriculture is responsible for large share of emissions (Driscoll, 2021).	SDG 13 (Climate Action)
Social impacts: labour, equity, land rights, displacement	Production sometimes causes land grabbing, displacement of communities, poor labour conditions, inequality, lack of fair income.	In palm oil production, many studies show direct negative social impacts, such as land disputes, housing issues, land grabbing. The FAO noted that unclear land tenure and exploitation rights often hurt the poorest actors in the supply chain. In "light industries" (e.g., garment industry), low wages, poor working conditions, lack of social protection are often present (Glasson and Therivel, 2019).	SDG 1 (No Poverty), SDG 8 (Decent Work & Economic Growth), SDG 10 (Reduced Inequalities), SDG 5 (Gender Equality) in some cases
Unstable or inequitable economic outcomes	Some producers or labourers may benefit, but many others suffer from volatile markets, low or uncertain incomes, dependency, weak bargaining power.	FAO: unstable markets and low income for many smallholder producers; fragmentation of actors in supply chains; poorest link gets least benefit. In palm oil: while income generation is a positive outcome, many negative outcomes are social and environmental, often unevenly distributed (Abideen *et al.*, 2023).	SDG 1, SDG 8, SDG 10
Pressure on infrastructure, urbanisation and local systems	Rapid industrialisation can lead to unplanned urban growth, pollution of cities, inadequate services, etc.	The "Problems of Sustainable Development" (light industry) article notes rapid expansion of industries leading to unplanned urbanisation, strain on infrastructure, environmental and social problems (APEC, 1999; Grainger-Brown *et al.*, 2022; Ripka *et al.*, 2024).	SDG 11 (Sustainable Cities & Communities), SDG 6, SDG 3

Source: Constructed by authors

COTTON PRODUCTION ENERGY BALANCE

Agricultural production and the use of production inputs have increased substantially in the recent years. This intensified input utilisation has contributed to significant environmental challenges, underscoring the need for more efficient and sustainable input management within agricultural systems (Pretty, 2008; Khan *et al.*, 2021; Seleiman and Hafez, 2021). Energy balance refers to the relationship between the energy inputs and energy outputs in a system (Baran *et al.*, 2021). It helps determine whether a process is energy-efficient, sustainable, or wasteful. It is the accounting of how much energy enters a system (as fuel, electricity, sunlight, etc.) and how much leaves it (as useful work, heat, waste (2005).

Definitions

- **Energy input:** the total energy used to produce cotton (all stages up to harvest or bale) including direct inputs (fuel, electricity, labour, irrigation, pesticides, machinery) and indirect inputs (embodied energy in seeds, fertiliser manufacture, machinery, etc.).
- **Energy output:** energy in the product produced often as the calorific or market value output, or more commonly, just expressed in mega joules (MJ) of cotton fibre yield times some conversion.
- **Energy use efficiency/energy ratio:** ratio of output energy to input energy (>1 means net gain).
- **Other metrics:** net energy gain (output − input), specific energy (MJ per kg of product), energy productivity (kg product per MJ input).

What "Energy Output" Means

- "Energy output" is typically the energy embodied in the harvested cotton (seed cotton or lint) based on some standard conversion. It does not account for downstream processing (ginning, spinning, weaving, dyeing, finishing), nor the energy used in use phase or disposal. So the energy balance figures are typically only for cultivation/field to harvest/bale stage (Figure 1).
- Also, many studies do not count environmental externalities (health costs, carbon emissions beyond direct inputs, subsidies) in the energy accounting.

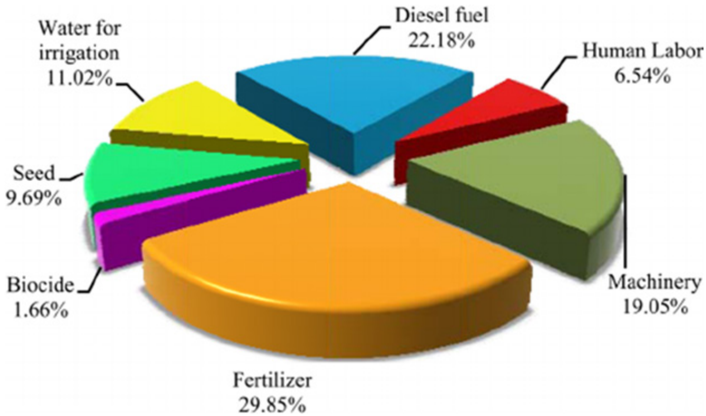

Figure 1: Cotton Energy Consumption
Source: Pishgar-Komleh *et al.*, 2012

A summary of what is known about the energy balance of cotton production how much energy goes in vs what comes out plus key numbers, drivers, and variation, based on recent studies is given below.

Key Findings: Energy Balance of Cotton Production

Figure 2 and Table 2 show numbers and variation in different regions and different types of cottons.

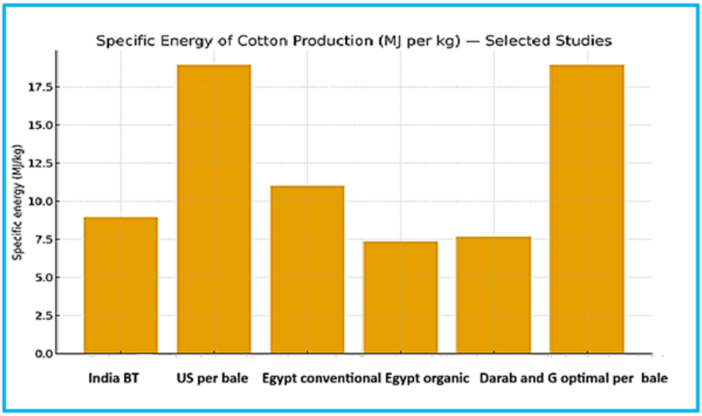

Figure 2: Comparative Histogram of Energy Consumption of Cotton Production in Different Regions of the World
Source: Kazemi *et al.*, 2018

Table 2: Energy Balance of Cotton Production in Different Regions

Location / Study	Inputs (MJ/ha)	Output (MJ/ha) or Equivalent	Energy Ratio or Efficiency (Output/Input)	Specific Energy (MJ per kg cotton)	Key notes/ Drivers of variation
Beheira, Egypt (conventional vs organic cotton) (Mehmeti *et al.*, 2024)	Conventional: ~37,472 MJ/ha; Organic: ~24,763 MJ/ha (Mehmeti *et al.*, 2024)	Conventional: ~40,120 MJ/ha; Organic: ~39,699 MJ/ha (Mehmeti *et al.*, 2024)	Conv.: ~1.07; Org.: ~1.60	Conv.: ~11.02 MJ/kg; Org.: ~7.36 MJ/kg	Organic got much higher efficiency because of lower input energy, less synthetic fertiliser, etc.
Darab & Gorgan, Iran (cotton cultivation) (Abbas *et al.*, 2022)	Darab: ~36,189 MJ/ha; Gorgan: ~31,860 MJ/ha	Darab: ~34,090 MJ/ha; Gorgan: ~35,237 MJ/ha output	Energy use efficiency: ~1.106 at Gorgan; slightly less in Darab (i.e. output just ~10% higher than input)	Specific energy ~7.69 MJ/kg for region studied in this case; energy productivity ~0.13 kg per MJ input	Variation depends heavily on region, irrigation requirements, types of inputs (fertiliser, fuel), etc.
Beşiri district, Batman, Turkey (Abbas *et al.* 2022)	Inputs: ~52,302.62 MJ/ha	Output: ~60,341.03 MJ/ha	Energy use efficiency: ~1.15	Specific energy ~10.23 MJ/kg cotton	Large share of inputs comes from non-renewable sources (electricity, fertiliser, diesel).
Australia (Keytah farms, various systems) (Khabbaz, 2010.)	With "optimum" practices (zero tillage, efficient irrigation, reduced chemicals): ~**4.3 GJ per bale** (≈4,300 MJ per bale) in best case; higher in typical systems.	—	—	Given per bale; depends on bale weight, but shows big reductions possible under improved systems.	

Source: Constructed by authors

Several factors strongly influence the energy balance:

1. **Farming system type:** Organic systems tend to have lower energy inputs (less synthetic fertiliser, pesticides, less mechanisation) and so often show better energy efficiency ratios. However, outputs may sometimes be lower (Beheira, Egypt study) (Mehmeti *et al.*, 2024).
2. **Inputs mix:** Fertilisers (especially nitrogen), diesel/fuel, electricity (for irrigation) are among the largest shares of energy input. Regions that rely heavily on irrigation (especially pumping water) or synthetic fertiliser have much higher input energy.
3. **Renewable vs non-renewable energy sources:** Some systems (organic in Egypt) draw more from renewable or less fossil fuel dependent inputs; conventional systems tend to depend heavily on non-renewable energy. That shifts both the sustainability and the environmental burdens (Yu *et al.*, 2016; Schnidrig *et al.*, 2024).
4. **Yield per hectare:** Higher yield improves the ratio, because output energy goes up while many inputs may stay similar or scale less than proportionately. Regions with poor yields suffer worse energy specific costs. So soil fertility, climate, water availability, pest pressures matter.
5. **Mechanisation and technology:** More efficient machines, optimised labour/fuel usage, improved irrigation, etc., reduce the energy input per unit output. Systems with older, inefficient machines or poor irrigation lose energy efficiency. (Australia's example shows gains by zero tillage & optimised machinery (Khabbaz, 2010.)
6. **Climate/water conditions:** Regions needing more irrigation, or with long dry seasons, will have high energy demands for pumping water. Also if climate change forces more pest control or crop protection, this adds to energy costs.

Typical Energy Efficiency and Costs

- Many systems show modest energy efficiency outputs, only 1.05-1.5× the energy inputs. In other words, net energy gain is small unless conditions are favourable (e.g., Egypt organic ~1.60; conventional just ~1.07)
- Specific energy (how much MJ needed per kg cotton) often ranges from ~7 MJ/kg in more efficient systems to 10-12+ MJ/kg in less efficient ones. Examples: Egypt conventional (~11 MJ/kg), organic (~7.4 MJ/kg) (Semerci *et al.*, 2019).
- In some high-input regions, energy input per hectare can be very high (30,000-50,000MJ/ha or more) depending on irrigation, fertiliser rates, diesel use (Aytop, 2023; Mehmeti *et al.*, 2024).

Implications for Sustainable Development

- When input energy is high relative to output, cotton production may contribute significantly to greenhouse gas emissions (through fertiliser manufacture, diesel combustion, electricity) and to fossil fuel depletion.
- Systems with low energy efficiency are more vulnerable to energy price fluctuations, which affects farmer profitability and risk.
- Better energy balance generally aligns with more sustainable development: reduced environmental impact, lower carbon footprints, improved resource use, better resilience for farmers.
- Country-level (and system-level for Egypt) values for energy input (MJ/ha), energy output (MJ/ha) were reported, energy ratio (output/input), specific energy (MJ/kg) were available, short notes and source for every row.

Summary

- Values vary widely by region and farming system. Reported inputs range from ~18,000 MJ/ha (some Indian Bt cotton trials) up to ~83,000 MJ/ha (a Turkish study reporting high inputs), with specific-energy values commonly falling in the ~7-12MJ/kg range were reported.
- Organic systems (Egypt example) often show lower input energy and higher energy ratios (better efficiency) because they avoid energy-intensive synthetic fertilisers and agrochemicals; local conditions can moderate net outcomes.
- Many studies report energy use efficiency close to 1.0 (output ≈ input), indicating narrow net energy gains and strong sensitivity to input use and yields. Irrigation pumping, fertiliser manufacture and diesel are consistently large contributors to input energy.

Bale Weight Variation

- Bale-weight varies by country and reporting convention; this study used 227 kg/bale as a single conversion assumption to convert per-bale energy (4.3GJ) into MJ/kg specific-energy for USA and Australia estimates.

The Negative Impacts on Sustainability

- They undermine the resilience of natural systems; these are needed for food, water, climate regulation, etc.
- They can impose long-term costs (health, environmental restoration, loss of ecosystem services) that may outweigh short-term economic gain.
- They can lock societies into unsustainable paths (e.g., dependence on fossil fuels, weakened ecosystems, poverty traps).
- They often affect the most vulnerable populations disproportionately.

Mitigation/How to Reduce Negative Impacts

What does "sustainable production" aim to correct?

- Using cleaner technologies, renewable energy, and waste minimisation.
- Better regulation, transparency, enforcement of environmental and labour standards.
- Supporting small producers, ensuring fair trade, secure land tenure.
- Circular economy models (recycling, reuse, designing out waste).
- Sustainable agriculture (agro-ecology, diversified cropping, soil conservation (FAO, 2022; Rikhter *et al.*, 2022).

Focus: Negative Impacts of Production on Sustainable Development

Industrial and agricultural production are not only central drivers of economic growth but also principal sources of negative impacts that undermine sustainable development. On a global scale, agrifood systems alone account for approximately one-third of anthropogenic greenhouse gas (GHG) emissions, with farm-gate emissions and land-use change remaining major contributors; livestock and fertiliser use are repeatedly highlighted as emission hotspots. These sectorial emissions have trended upward in recent decades, complicating climate mitigation and food security objectives (FAO, 2022).

Manufacturing industries contribute a substantial share of CO_2 emissions and exhibit clear "hotspots" in energy-intensive sub-sectors. Bibliometric reviews indicate that research and monitoring efforts have identified consistent sectorial contributors (steel, cement, chemicals, textiles) and emphasise the persistent research gaps around supply-chain emissions accounting and regionalised emission factors gaps that also limit policy design and corporate reporting. This concentration of emissions ties production directly to SDG 13 (Climate Action) and illustrates how production decisions cascade into long-term climatic risks (Zhao *et al.*, 2025).

Production practices also drive biodiversity loss and land-use conversion. With commodity-driven expansion for example, mechanised cotton farming has been linked to deforestation, habitat fragmentation and reductions in ecosystem services in major producing regions. Certification and sustainability initiatives (e.g., Roundtable on Sustainable Palm Oil (RSPO) (see Figure 3) and corporate stewardship reports) show mixed results: certified operations can reduce new deforestation risks, but structural issues (market demand, enforcement, leakage) continue to undermine systemic change. Such land-use impacts directly threaten SDG 15 (Life on Land) and intersect with livelihoods and tenure security for local communities (Alhaji *et al.*, 2024).

Figure 3: System for Certified Sustainable Palm Oil
Source: Meijaard *et al.*, 2017

Fashion and textile production create persistent pollution pathways. Life-cycle assessments (LCAs) of textiles repeatedly identify production and end-of-life management as lifecycle hotspots; limitations in data and methodological choices (functional unit, system boundaries) often lead to divergent conclusions about net benefits of recycling or alternatives. Microfibres released from textile washing are now established as globally pervasive contaminants; emerging research quantifies shedding rates and links manufacturing/design choices to downstream microfibre loads, raising concerns for aquatic ecosystems and potentially human exposure through food and water. These findings spotlight the limits of incremental waste management without upstream production changes (Witczak *et al.*, 2024).

Finally, social and governance harms accompany environmental damage. Supply-chain investigations and benchmarks (e.g., KnowTheChain) document ongoing labour rights risks, forced labour exposure and weak governance in apparel and other labour-intensive sectors. This shows that economic gains from production often fail to distribute equitably and can exacerbate inequalities, undermining SDGs 1, 5, 8 and 10 (KnowtheChain, 2023).

Collectively, the literature indicates that addressing production's negative impacts requires more than technical fixes: robust data and LCA standardisation, systemic demand-side interventions, stronger governance (local to global), finance to support just transitions, and incentives for redesigning products and supply chains. Without integrated policies that couple environmental limits to social protections, production will continue to both fuel economic development and erode the resource base upon which future development depends (Nordahl and Scown, 2024).

The Impact of Cotton Fashion Industry on Sustainable Development

The fashion industry represents an important part of our business, with a value of US$1.3 trillion and employing over 300 million people along the value chain foundation. In the last 20 years, global fibre production has almost doubled from 58 million tonnes in 2000 to 116 million tonnes in 2022; it is expected to continue to grow to 147 million tonnes in 2030 if business as usual continues. While people bought 60% more garments in 2014 than in 2000, they only kept the clothes for half as long (EMF, 2025). While the fashion sector is booming, increasing attention has been brought to the impressive range of negative environmental impacts for which the industry is responsible. The fashion industry is the second-biggest consumer of water and is responsible for 2-8% of global carbon emissions (see Table 3).

Table 3: Impact of Fashion Industry on SDGs

Impact Category	What Happens	Examples/Quantitative Data	Implications for Sustainable Development (SDGs, etc.)
Water use & stress	Cotton is a very water-intensive crop. Large volumes of water are used in cultivation and in the processing (washing, dyeing, finishing) of cotton textiles.	• To produce one cotton T-shirt ≈2,700 litres of water. • Globally, cotton production accounts for ~3-4% of global water consumption. • Cotton farming in water-stressed regions reduces available fresh water for local communities.	Threatens access to clean water (SDG 6), food security (if water is diverted from food crops), community health; undermines resilience in drought-prone areas.
Chemical use & pollution	Heavy use of pesticides, insecticides, synthetic fertilisers. Run-off of these chemicals into waterways, soil contamination, harm to local biodiversity and human health.	• Cotton uses approximately 24% of the world's insecticides and 11% of all pesticides despite using only ~2-3% of global cropland. • Fertiliser use leading to nitrogen/phosphorus run-off, causing eutrophication, aquatic toxicity. Worker exposure risks, etc. (Okafor, 2021).	SDGs impacted: SDG 3 (Health & Well-being), SDG 15 (Life on Land, biodiversity), SDG 14 (Life Below Water), SDG 12 (Responsible Consumption & Production)
Greenhouse gas emissions & climate change	Emissions arise from: land conversion (CO_2 release), fertiliser/N2O emissions, energy used in irrigation, processing and transport.	• The cotton sector contributes a portion of global CO_2e; estimates (e.g. from Soil Association) put cotton's production emissions globally at ~220 million tonnes CO_2e per year. • Synthetic fertilisers and nitrogenous fertilisers contribute to nitrous oxide emissions (potent greenhouse gas) (Vandepaer, 2024).	Climate action (SDG 13) is undermined; cotton fashion contributes to fossil-fuel dependency; risk of unstable yields with climate change.
Soil degradation, land use change & biodiversity loss	Monoculture cotton farms, expansion into natural ecosystems, deforestation, depletion of soil fertility, erosion.	• Expansion of cotton into new land degrades soil; continuous cotton cultivation in monoculture systems reduces soil organic matter, increases erosion (Okafor, 2021) • In Brazil's Cerrado region, cotton cultivation (for brands such as H&M, Zara) has been linked to deforestation and land appropriation (Garnier, 2024).	Loss of ecosystem services, habitat destruction (SDG 15), decreased resilience of ecosystems; risk to local food systems.

Impact Category	What Happens	Examples/Quantitative Data	Implications for Sustainable Development (SDGs, etc.)
Social/labour issues	Workers and farmers often face poor working conditions, low pay, sometimes forced or child labour, especially in cotton picking or in textile factories; unequal power relationships; exposure to toxic chemicals.	• Uzbekistan: until 2017, nearly 2 million adults and children were mobilised yearly to hand-pick cotton; 15% of pickers forced labour (World Bank, 2025). • Smallholder cotton farmers may incur debt from costs of seed, fertiliser, pesticides, equipment; low farm gate prices (Bhogi and Rastogi, 2025). • Worker exposure to harmful pesticides and health risks (Solidaridad, 2025).	Affects SDG 1 (No Poverty), SDG 8 (Decent Work), SDG 10 (Reduced Inequalities), SDG 3 (Health). Also undermines human rights and wellbeing.
Waste (textile waste, processing waste, inefficiencies)	Overproduction leads to excess inventory; dyeing and finishing processes produce water pollution and chemical effluents; discarded cotton garments still generate waste, even though they are more degradable than synthetic fibres, they are often blended or treated.	• Substantial textile waste globally; untreated wastewater from dyeing most problematic. • Clothing being discarded quickly (fast fashion cycles) means cotton products also contribute to landfill burden.	Impacts SDG 12 (Responsible Consumption & Production), SDG 3 (health via pollution), SDG 11 (Sustainable Cities & Communities)

Source: Constructed by authors

Fair Trade and Ethical Considerations

Ethical treatment of cotton industry workers involves fair wages, safe working conditions, and respect for labour rights. Ensuring decent living standards and prohibiting child labour are essential. Ethical practices contribute to the social sustainability of the cotton industry, fostering a responsible and humane work environment for those involved in the production process. Transparent supply chains in the cotton industry are vital for accountability and ethical practices. They enable consumers to make informed choices, promoting sustainability. Visibility into the supply chain ensures fair labour conditions, environmental responsibility, and adherence to ethical standards, fostering trust and driving positive change in the global cotton market (Harper, 2025).

Traceability Solutions

Ensuring the sustainability of cotton is fundamentally tied to traceability, i.e., the comprehensive tracking of materials or goods across the entire supply chain, from their origin to the point of sale. In the context of cotton, this entails tracing the journey from the farm or farmer, through the production and manufacturing processes, to the final product on the shelf. For brands or manufacturers engaged in upcycling cotton products, traceability extends to monitoring the trajectory of upcycled materials and determining the percentages of recycled materials in the end products. Through traceability, the assurance of fair pay for farmers, avoidance of harmful chemicals, and the reduction of water waste become tangible commitments (Sim *et al.*, 2022).

Mitigating the Risk of Cotton Processing

Eco-friendly cotton processing involves adopting practices such as water recycling, using non-toxic dyes, and energy-efficient machinery. Also, the use of closed-loop systems minimise water waste, eco-friendly dyes to reduce chemical pollution, and implementing renewable energy sources for processing reducing carbon footprints. These sustainable methods aim to mitigate environmental impact, aligning with an holistic approach to eco-conscious textile production. Energy-efficient manufacturing in the cotton industry is crucial for reducing environmental impact; utilising renewable energy sources and implementing energy-saving technologies minimise carbon emissions. This not only addresses climate concerns but also enhances overall sustainability, ensuring the cotton manufacturing process aligns with eco-friendly practices and contributes to a greener, more resource-efficient industry.

CONCLUSIONS

The cotton and fashion industries face a complex array of interlinked environmental, social, and economic challenges that threaten their long-term sustainability. Intensive cotton cultivation contributes to excessive water consumption, soil degradation, and pesticide pollution, while the energy-intensive processes of textile manufacturing generate substantial carbon emissions. Moreover, the acceleration of fast fashion trends has intensified resource use and waste generation, leading to unsustainable production cycles. Social concerns, including low wages, unsafe working conditions, and limited supply chain transparency, further exacerbate the industry's sustainability deficit.

Mitigating these challenges requires a multidimensional and collaborative approach. The adoption of sustainable agricultural practices, such as organic cultivation, water-efficient irrigation, and integrated pest management, can substantially reduce the environmental footprint of cotton production. Embracing circular economy principles, including textile recycling, eco-design, and extended product lifespans, offers viable pathways to minimise waste and resource depletion. Transitioning to renewable energy sources, enhancing energy efficiency, and integrating digital innovations such as traceability technologies can further strengthen environmental and operational performance. Additionally, enforcing ethical labour standards and promoting transparency throughout the supply chain are essential to addressing social sustainability concerns.

Ultimately, the transformation of the cotton and fashion industries into a sustainable model depends on co-ordinated action among policy-makers, industry stakeholders, researchers, and consumers. Through innovation, regulation, and education, the sector can progress towards a resilient, low-impact, and socially responsible future aligned with the United Nations Sustainable Development Goals (SDGs).

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