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CASE STUDY

The Socio-Economic and Environmental Impacts of a Just Transition to a Circular Economy: Sudan's Cotton as a Case Study

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ABSTRACT

PURPOSE: This study examines the socio-economic and environmental implications of transitioning to a circular cotton economy in Sudan, emphasising how recycled cotton integration influences employment, community livelihoods, and resource sustainability.

METHODOLOGY: Using a mixed-methods approach combining policy review with secondary data on cotton production and trade, the research highlights both opportunities and challenges within Sudan's agriculture-dependent context.

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FINDINGS: Results show that circular practices significantly reduce water use, pesticide reliance, and energy consumption, improving environmental performance across the cotton value chain. Socio-economically, the shift creates new green jobs in recycling and repair, although traditional farming and textile roles may be affected. Applying a just transition framework, the study underscores the need for inclusive policies to ensure equitable distribution of benefits among workers and local communities.

ORIGINALITY/VALUE: As one of the first analyses linking circularity and social justice in Sudan's cotton sector, this work informs sustainable policy development despite limitations in local data availability.

KEYWORDS: *Circular Cotton Economy; Just Transition; Environmental Impacts; Sudan's Cotton; Textiles and Apparel.*

INTRODUCTION

The history of cotton cultivation and its associated economic value in Sudan can be traced back to the late 19th century (Yıldız, 2024). The crop was first introduced in the Tokar region of Eastern Sudan, marking the beginning of organised cultivation efforts. Commercial-scale production later took root in 1905 with the launch of the Zeidab Pilot Scheme in Northern Sudan. A major milestone in the nation's agricultural transformation came in 1925 when the construction of the Sennar Dam initiated large-scale irrigated farming (Abushama *et al.*, 2023). These developments reflected not only agricultural ambition but also broader investments in the hydro-political dynamics of the Nile Valley; these have shaped both past and present regional relations (Merem and Twumasi, 2019; Elhance, 1999; Krampe *et al.*, 2020).

Since that period, cotton has retained a central role in Sudan's agrarian and economic systems, despite the challenges tied to water dependency and the political dimensions of resource management (Merem *et al.*, 2020; Merem and Twumasi, 2006; Carlson, 2013). The crop's significance is evident from long-term agro-economic trends, including the expansion of cultivated land and production capacity. The decades spanning the 1960s to the 1980s witnessed considerable growth, establishing cotton as a vital export commodity. The sector's integration into international markets generated substantial fiscal gains and elevated Sudan's position within global trade networks (Puaschunder, 2023; Alhelo *et al.*, 2023). Today, this legacy continues to influence policy directions and investment initiatives aimed at reviving cash crops such as cotton and restoring their pivotal place in the national economy (Merem, 2023).

CIRCULAR ECONOMY

The circular economy is based on the principle of extending the life cycle of materials and products by maintaining them in continuous use through strategies such as reuse, repair, recycling, sharing, and remanufacturing (Figure 1). It further emphasises the regeneration of natural systems, the elimination of waste by design, and the replacement of non-renewable inputs with sustainable, renewable, and bio-based materials. In essence, the circular model represents a fundamental shift from the prevailing linear economy, where resources are extracted, processed into goods, consumed, and ultimately discarded. Unlike the linear system marked by resource inefficiency, significant waste generation, and loss of material value, the circular approach seeks to maximise utility, minimise environmental impact, and create long-term economic resilience.

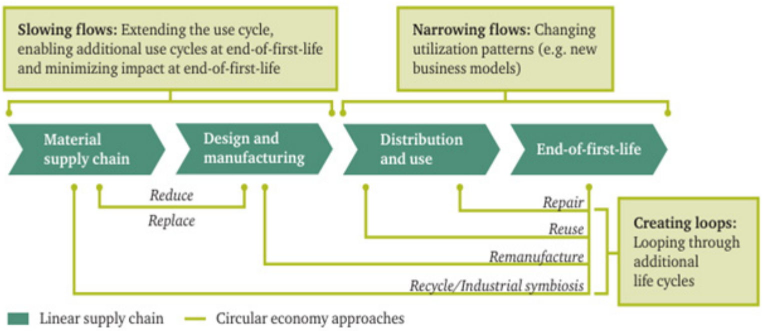

Figure 1: Circular Economy Approaches Slowing Flows, Narrowing Flows and Creating Loops

Source: Schröder, 2020

TEXTILES AND APPAREL INDUSTRY

The textile and apparel sector has long operated under a linear "take-make-dispose" system that prioritises production and consumption over resource efficiency, leading to significant environmental strain. This linear approach contrasts sharply with the principles of a circular economy (CE), seeking to optimise material use and remain within ecological limits (Figure 2). In recent years, growing awareness of sustainability challenges has prompted the industry to reconsider its practices. Increasingly, manufacturers and brands are adopting more responsible production and consumption models. However, the transition towards circularity cannot be realised through isolated corporate efforts alone; it demands a comprehensive, system-wide transformation involving collaboration among diverse stakeholders across the value chain.

The global clothing industry is among the largest sectors worldwide, valued at approximately US$2.4 trillion and providing employment to tens of millions of people. Like many other industries, it is highly concentrated, with a small number of dominant companies, referred to as keystone actors, exerting substantial influence over production and market dynamics. Keystone actors are defined as firms that control large portions of global output, dominate key production segments, and maintain extensive networks of subsidiaries, thereby linking ecosystems and shaping international governance and industry standards. Globally, there are 20 such keystone actors in the clothing sector, each with a market capitalisation exceeding US$9 billion. Collectively, these 20 firms represent 62% of the total capital among the 129 largest companies in the industry and generate an overwhelming 97% of the sector's profits, underscoring their disproportionate economic and strategic impact.

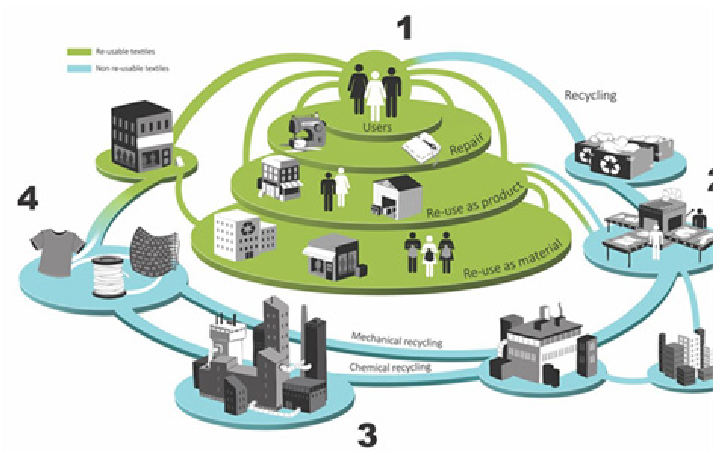

Figure 2: CE business ecosystem model in textile sector
Source: Auranen, 2022

SUDAN

Sudan (Figure 3), the largest country in Africa, spans approximately 2.5 million square kilometres at the crossroads of Sub-Saharan Africa and the Middle East, close to the Red Sea and the Horn of Africa. The nation possesses around 80 million hectares of arable land, although only about 20% of this area is currently under cultivation. In 2023 (Merem *et al.*, 2024), Sudan's population was estimated at 48 million (Table 1), growing at an annual rate of 2.63%, with most inhabitants concentrated in 14 regions along the central and eastern corridor (Merem *et al.*, 2022). Geographically, Sudan is strategically positioned and ecologically diverse, sharing borders with Egypt to the north and several Central and East African nations to the south and east, making it a significant agro-ecological and geopolitical nexus in the region.

Table 1: The Population of Sudan 1960-2023

Market Year	Population	Growth Rates
1960	8,326,462	2.97%
1965	9,712,785	3.25%
1970	11,305,206	3.09%
1975	13,497,543	4.22%
1980	16,673,586	4.39%
1985	19,517,196	1.83%
1990	21,090,886	1.80%
1995	23,290,602	2.59%
2000	44,440,486	2.80%
2005	29,540,577	2.46%
2010	33,739,933	2.40%
2015	38,171,178	3.16%
2020	44,440,486	2.80%
2021	45,657,202	2.74%
2022	46,874,204	2.67%
2023	48,109,006	2.63%

Source: Merem *et al.*, 2024

Figure 3: The area of Sudan

Source: Merem *et al.*, 2024

Sudan's Cotton Land

An examination of Sudan's cotton land-use profile between 1960 and 2022 reveals the persistence and significance of cotton within the nation's agricultural economy. Over this period, the total cultivated area reached approximately 3.7 million hectares, yielding an estimated output volume of 7,616 (1,000 480lb bales) pounds, as shown in Table 2. The data illustrate three distinct phases in Sudan's cotton production history, each reflecting broader economic, environmental, and policy dynamics that shaped the sector's performance.

As shown in Table 2, the first phase (1960-1985) marked a period of high-intensity cultivation and strong export performance, supported by the establishment of large-scale irrigation schemes such as Gezira and Rahad. Cotton was then Sudan's principal cash crop and foreign exchange earner, with extensive land devoted to its production and consistent output growth.

The second phase (1990-2005) witnessed a gradual decline in both cultivated area and productivity due to several factors, economic sanctions, reduced investment in irrigation infrastructure, inconsistent government policies, and competition from food crops. These challenges disrupted the once-thriving export chain and weakened Sudan's position in the global cotton market.

The third and most recent phase (2010-2022) reflects a mixed trend characterised by fluctuating production levels and attempts at revival. Recent efforts towards agricultural reform, coupled with renewed interest in cash crops, have aimed to restore cotton's contribution to GDP and export earnings. Nonetheless, progress remains constrained by climate variability, outdated technologies, and limited value addition.

Overall, the long-term trajectory from 1960 to 2022 underscores both the resilience of Sudan's cotton sector and the pressing need for modernisation, diversification, and integration into emerging frameworks such as the circular and sustainable textile economy.

Table 2: Sudan's Temporal Profile of Cotton Cultivated Area and Production 1960-2022

Market Year	Area (ha) Planted	Production lb 1000 480 lb. Bales
1960	380	525
1965	441	750
1970	510	1130
1975	401	509
1980	388	445
1985	326	652
1990	196	380
1995	220	490
2000	170	340
2005	170	330
2010	42	55
2015	62	210
2020	200	600
2021	200	600
2022	200	600
Total	3706	7616

Source: Merem *et al.*, 2024

Area and Production

An assessment of Sudan's cotton market performance between the 2011/2012 and 2022/2023 seasons reveals marked fluctuations in both cultivated area and production output (Table 3). Across this 12-year period, significant contrasts emerge between the earlier and later years of observation. From 2011/2012 to 2018/2019, the data indicate notable variability in the three principal land-use indicators, total area cultivated, production volume, and yield per hectare. These inconsistencies reflect the unstable nature of the agricultural environment during that time, influenced by recurrent policy shifts, input shortages, and climatic variability affecting irrigation and rainfall patterns.

In contrast, the subsequent period from 2019/2020 to 2022/2023 demonstrates relative stability and consolidation within the sector. During these four years, the extent of land under cotton cultivation, alongside output and productivity levels, remained comparatively steady. This period of consistency suggests improvements in management practices, modest recovery in market confidence, and renewed institutional support for cotton as a strategic export crop. Overall, the analysis underscores a gradual transition from volatility to stabilisation in Sudan's cotton market, laying a potential foundation for future growth and investment if sustained policy and infrastructural commitments are maintained.

Table 3: Cotton Cultivation Area and Production, Other Years 2011-2022

Market Year	Area (1000 Ha)	Production (1000 480-lb Bales)	Yield (Kg/Ha)
2011/2012	127	195	334
2012/2013	45	75	363
2013/2014	127	160	274
2014/2015	46	140	663
2015/2016	62	210	737
2016/2017	96	360	816
2017/2018	180	475	575
2018/2019	180	500	605
2019/2020	200	600	653
2020/2021	200	600	653
2021/2022	200	600	653
2022/2023	200	600	653

Source: Merem *et al.*, 2024

Role of Cotton in the Economy

The agricultural sector has long been the cornerstone of Sudan's economy, sustaining the livelihoods of approximately 80% of the population and contributing around 40% of GDP and 95% of exports. Over the past five decades, economic growth has been largely driven by modern, capital-intensive irrigation schemes along the Nile, primarily aimed at enhancing cotton production. Sudan's natural endowments, including abundant sunshine, favourable temperatures, fertile clay soils, and extensive flat lands suitable for gravity or low-cost Nile irrigation, create ideal conditions for cultivating high-quality long-staple cotton. In 1980/81, just over 840,000 hectares were under cultivation, with approximately 378,000 hectares dedicated to irrigated cotton.

During 1979/80, cotton accounted for approximately 22% of total agricultural output and 56% of all exports, maintaining a steady contribution to foreign exchange earnings since 1972/73. However, the 1970s witnessed a sharp decline in export volumes, dropping from 280,000 tonnes in 1971 to 180,000 tonnes in 1980. Until the mid-1970s, 75-80% of Sudanese cotton production consisted of long-staple varieties, which commanded premium prices on international markets. By 1980, the share of long-staple cotton had significantly decreased, allowing Egypt to expand its market share as Sudanese production contracted. Had production expanded during the 1970s, a shift towards medium-staple cotton would likely have been necessary to meet changing global demand.

Technical Problems

Cotton production in Sudan faces numerous technical challenges, many of which stem from difficulties in its proper application rather than from a lack of available technology. Irrigation supplies are often insufficient and unreliable, distribution canals are poorly maintained, resulting in uneven field water distribution, and drainage systems are generally inadequate. Land preparation is frequently delayed and conducted inadequately, which postpones planting and reduces yields. Fertiliser application is often untimely, and supply inconsistencies further limit productivity.

Although aerial spraying occurs 12 to 13 times per season, it remains largely ineffective, and infestations such as whitefly honeydew continue to pose serious problems. Crop hygiene is frequently poor, including inadequate removal of cotton stalks and substandard weed control. Harvesting is limited, sometimes to only two pickings, and a portion of the crop remains uncollected due to insufficient mobilisation and incentives for pickers.

These technical difficulties are exacerbated by the limited engagement of tenants, who often allocate their time and resources to more profitable activities in agriculture, livestock, or off-farm work. The situation is further compounded by the inability of parastatal organisations to operate effectively, constrained by both financial and managerial limitations.

Environmental Impacts

In the study area and other cotton-growing regions of Sudan, multiple pest and insect infestations pose significant threats to crop productivity, often causing severe economic losses for farmers. To mitigate these attacks, growers frequently rely on approved chemical insecticides, which have historically been the primary means of pest control. Over time, the reliance on these chemicals has escalated production costs, accounting for an estimated 30-40% of total overheads. However, intensive pesticide use has negative consequences, including ecosystem contamination, harm to non-target organisms, and risks to human health.

The primary insect pests affecting cotton include bollworms, jassids, thrips, flea beetles, whiteflies, and aphids. Their prevalence varies according to seasonal shifts, climatic conditions, and the availability of host plants. Early-season pests such as jassids and bollworms, combined with late-season pests such as aphids, exacerbate production risks throughout the growing cycle. For example, during the 2019 market season, Sudanese cotton production suffered catastrophic losses, with infestations of cotton mealy bug and bacterial blight reducing harvests by approximately 80%.

Beyond yield reductions, pest management practices have contributed to increased water use, soil degradation, and environmental pollution. Chemical sprays pose particular risks to aquatic ecosystems, threaten biodiversity, and can have adverse effects on communities, especially those living in low-lying areas of cotton-producing regions. These factors collectively hinder sustainable cultivation and underscore the urgent need for integrated pest management strategies that balance productivity with environmental and community health.

CONCLUSIONS

The transition to a circular cotton economy in Sudan presents a strategic opportunity to align economic growth with social equity and environmental sustainability. By adopting circular principles such as cotton waste recycling, eco-efficient manufacturing, and sustainable farming practices, the sector can generate new employment, empower local communities, and reduce dependence on resource-intensive inputs. However, ensuring a just transition requires targeted support for smallholder farmers, inclusive policy frameworks, and capacity-building initiatives to prevent social marginalisation. Environmentally, circularity can curb chemical pollution, conserve water, and restore soil health, strengthening ecosystem resilience. The success of this transformation will depend on integrated actions among policy-makers, industry, and research actors. With coherent governance, investment, and social dialogue, Sudan's cotton industry can evolve into a regenerative model that delivers enduring economic, social, and ecological value.

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BIOGRAPHY

Dr Ramadan Mohammed is an Associate Professor in the Department of Textile Engineering at the Sudan University of Science and Technology and an affiliated researcher at Istanbul Technical University, Türkiye. He received his PhD in Textile Composites from Donghua University, China, where his work concentrated on the development and characterisation of advanced fibre-reinforced composite materials. His academic and research interests include high-performance textile composites, smart and sustainable materials, circular textile economy, and the integration of novel fabric architectures for structural and functional applications. Dr Mohammed has contributed to numerous peer-reviewed publications and international conferences, and he actively promotes cross-border research collaboration between Africa, Asia, and Europe in the field of textile innovation and sustainability. He also supervises postgraduate research in materials science and textile engineering, focusing on the advancement of environmentally responsible technologies for the textile and composite industries.

Professor Hasabo Abdelbagi Mohamed Ahmed is a materials scientist and full professor with expertise in nanotechnology, textiles, and sustainable materials. He earned his PhD and BSc from Sudan University, a Postgraduate Diploma from the University of Leeds (UK), and a Master's degree from the University of New South Wales (Australia). Currently a visiting professor at Istanbul Technical University, he is a member of the Society of Engineers and the Institute of Materials (UK). His research focuses on advanced fibres, polymer composites, and environmentally friendly textile production. Professor Hasabo has published extensively in international journals and contributed to innovation in sustainable fabric technologies and nanomaterials for the fashion industry.

Dr Azzam Ahmed is an Associate Professor of Textile Engineering at Sudan University of Science and Technology (SUST), and a Visiting Researcher at the James Watt School of Engineering, University of Glasgow, UK. His research focuses on advanced composite materials, especially carbon, glass, and basalt fibre reinforced polymers, hybrid FRP confinement systems, and textile-reinforced concrete used for structural and fire-resistant purposes. He has published extensively on the mechanical and durability performance of FRP materials and sustainable textile technologies. Dr Azzam also leads efforts to modernise textile engineering education and to revitalise the Sudanese cotton industry through research, innovation, and industry collaborations.