Sustainable Manufacturing and Environmental Pollution Programme

FROM WASTE TO VALUE

Upcycling agricultural residues for sustainable textiles

CASE STUDIES FROM KENYA AND UGANDA

May **2025**

UK International Development
Partnership | Progress | Prosperity

This brief was produced under the Sustainable Manufacturing and Environmental Pollution (SMEP) programme, funded by the United Kingdom's Foreign, Commonwealth and Development Office (FCDO) and implemented in partnership with UN Trade and Development (UNCTAD). The brief was prepared in the context of field visits and interviews organised in early 2025 with relevant SMEP projects in Uganda and Kenya. The mission engaged in fact finding and data collection from project grantees and their supply chain actors, such as farmers and fibre manufacturers. The work was coordinated by Dr. Henrique Pacini, under the supervision of Dr. Chantal Line Carpentier. The research team was composed of Lorenzo Formenti and Prof. Anil Hira (Simon Fraser University). This paper has benefitted from comments by Glen Wilson and Elzette Henshilwood (SouthSouthNorth), Rodrigo Carcamo and Kris Terauds (UNCTAD). The research team is also grateful for the inputs from Kimani Muturi (TEXFAD), Edwin Kamalha (Busitema University), James Boyd-Moss (Mananasi Fibre Ltd.), Joseph Bahati (Banana Industrial Research and Development Centre, BIRDC) and students from Busitema University, Mackenzie Tuhirirwe, Amosi Mangeni, Amati Allen, Mwesigye Barnabas and Timanyire Tegras.

Desktop formatting, layout and graphics were designed by Lia Tostes. Henrique Pacini took the cover photo.

Disclaimer

Contents

1.

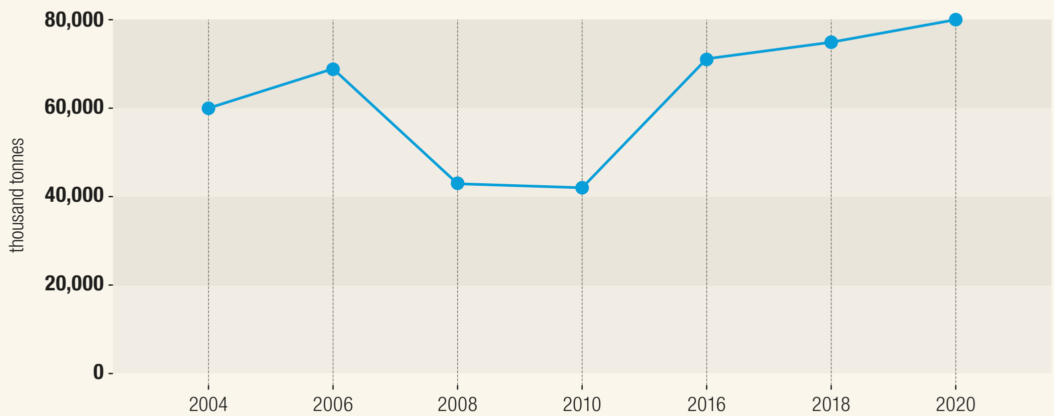
Textiles

An industry in need of a sustainability transformation

The global textile industry is massive, valued at $594.1 billion in production in 2022 alone (Euromonitor, 2023). It represents one of the most important "ladder" industries for developing countries seeking to promote industrialisation and create jobs. Textiles and garment manufacturing has historically been one of the most accessible sectors for initiating productive capacities because of its labour intensity and relatively low barriers of entry (Kim et al., 2010). Demand for textiles has increased from an estimated 8.3 kg/person in 1975 to 15.5 kg/person in 2023 (Textile Exchange, 2024). At the same time, the number of times clothing is worn has decreased by 36% in the past 15 years (EMF, 2017).

Yet, the industry is unsustainable, creating massive unmanaged waste as seen in Figure 1 , as well as creating an estimated 10% of global greenhouse gas (GhG) emissions (Brocker, 2024). The use of recycled materials is being embraced by brands and (especially Western) consumers to improve the sustainability of textile markets. This has also gained regulatory traction, with the EU introducing Product Environmental Footprint (PEF) guidelines and working on an Ecodesign for Sustainable Products Regulation and a Strategy for Sustainable and Circular Textiles, both of which include provisions on recycled content. However, as of 2024, only an estimated 11% of clothing contained recycled materials in global markets (Brocker, 2024). Despite efforts towards a circular economy in the EU, post-consumer textile waste has increased over the last decade (Figure 1).

In addition to the growing volume of waste, sustainability concerns include microplastic pollution, water use, labour standards, dyes discharge, the use of synthetic (fossil-based) polymers and the limited use of renewable energy in the production process. Unlike natural fibres, synthetic fibres degrade into micro and nano-plastics but do not decompose into harmless substances. Plastics have been linked to maritime ecosystem and human health hazards, including respiratory, cardiovascular, digestive as well as fetal health issues and cancer (Landrigan et al., 2023).



← Figure 1. Textile waste generated by households in the EU (2004–2020)

Source: Authors on data Eurostat, accessed Feb. 17, 2025.

Note: Data from 2012 and 2014 are not available. Data are for EU-27 countries, including Croatia and excluding the United Kingdom.

Adding to the challenge is the fact that instilling circular production is a complex and challenging process, given the highly fragmented nature of apparel supply chains and the myriad of subcontractors involved in the global textiles and apparel markets. While almost all textile waste is recyclable, an estimated 75% ends up in landfills globally (Wagaw and Babu, 2023). Textile production, globally, consumes approximately 93 billion cubic meters of water, a growing concern as climate change alters rainfall patterns. Water use is largely concentrated in production methods such as irrigation, with cotton accounting for 26% of clothing fibres, and being water-intensive to produce (Wagaw and Babu, 2023).

Adding to this challenge is the linkage with fossil fuels use and climate change impact. Derived from petrochemicals, polyester surpassed cotton as the most used fibre in the world in the early 2000s. It fuelled the high growth of global fibre production, which more than doubled between 2000 and 2024, from 58 million tonnes to 124 million tonnes (Textile Exchange, 2024). Between 2005 and 2010 it replaced cotton as the most widely used fibre in the world and is the largest contributor to the double-digit growth of global fibre production between 2000 and 2024. An estimated 63% of textile fibres are produced from petrochemicals (Wagaw and Babu. 2023). Thus, there is a pressing need to develop more sustainable fibres to meet increasing demand.

Several strategies are being explored to reduce the environmental footprint of textile materials, including consumer awareness, better regulation of and incentives for highly polluting industries such as fast fashion, and use of recycled materials. One avenue is the development of new sources of low-impact fibres to at least partly move away from materials that have a large carbon, water or plastic footprint (UN Environment Programme, 2023). In this context, fibres that are derived from by-products sourced from or linked to established supply chains, such as those based on agricultural waste, are an important tool to reduce the environmental impact of textiles.

This brief explores the potential of alternative natural fibres in textiles, focusing on banana and pineapple fibres as compelling case studies. The study investigates these promising materials from a trade perspective, employing a mixed-methods approach. It combines a comprehensive literature review with insights gathered from field visits and interviews with SMEP projects in Uganda and Kenya. The research includes basic modelling to assess the potential impact of scaling local projects to the national level, specifically on commodity demand and trade. Modelling is based on parameters defined in collaboration with researchers at Busitema University in Uganda, with data gathered from local entrepreneurs and farmers.

↓ Image 2. Carpets produced from banana fibre

© TEXFAD, Uganda, 2025

2.

The need for alternative textile fibres

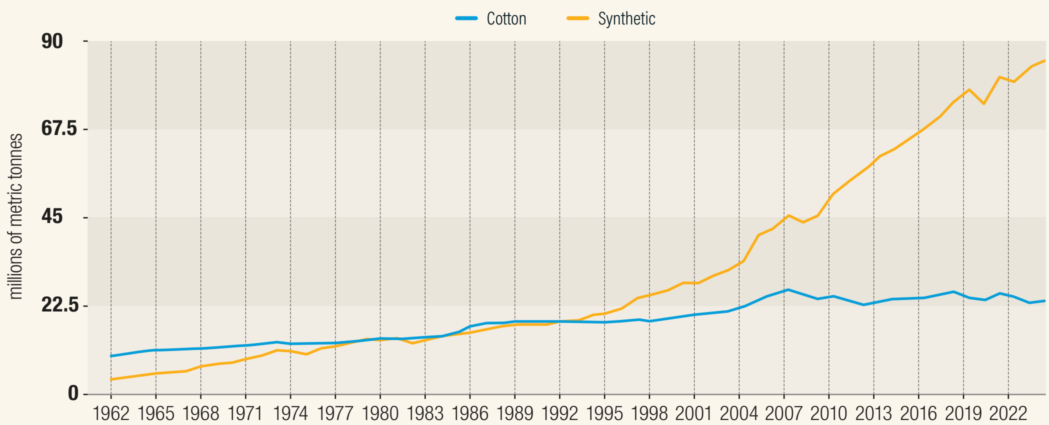
2.1. Conventional fibres and their environmental problems

Traditional textile fibres, both natural and synthetic, can have significant environmental externalities, largely influenced by cropping methods and practices. It is thus crucial to acknowledge the diverse contexts of fibre production. Industrial cotton production methods can be resource-intensive, requiring large amounts of water and land to grow. Beyond the environmental stresses of industrial cotton cultivation, industrial production also relies on chemical inputs, such as pesticides, which can degrade the soil and pollute waterways. Cotton cultivation requires an estimated 200,000 tonnes of pesticides and 8 million tonnes of fertilizer annually, representing 16% and 4% of global consumption respectively (UN Environment Programme, 2023, 2020). Conversely, cotton cultivation in regions like Africa is often rainfed and conducted by smallholders who lack access to chemical inputs, resulting in a vastly different environmental footprint compared to large-scale industrial operations.

While cotton has sought after qualities, the greatest growth over the last 6 decades, and particularly from 2000, has been in synthetic or synthetic fibres, that are mostly based in petrochemicals (Figure 2).

Synthetic fibres such as polyester may be durable, but their production is energy intensive, relies heavily on fossil fuels and hazardous chemicals such as antimony. At the same time, washing polyester clothing releases an estimated half a million tonnes of plastic microfibres into the ocean each year, the equivalent of more than 50 billion plastic bottles (Ellen MacArthur Foundation, 2017).

Efforts to recycle textile fibres, including synthetics, by breaking them down and then recreating fibres, are far more costly than mechanical recycling. Recycled materials, such as PET from plastic bottles, are often used to make recycled polyester. Such efforts, however, face considerable challenges including the inconsistency in quality, type, and scale of feedstock, the significant skills and technology needed, and the lack of understanding of the durability of such fibres (UN Environmental Programme, 2023). Even more costly and technologically challenging is chemical recycling, whereby synthetic polymers are broken down into monomers for reformulation as synthetic fibres. In fact, in 2024, less than 1% of the global fibre market came from pre- and post-consumer recycled textiles (Textile Exchange, 2024). There is therefore a growing interest in exploring alternative sources of textile fibres, particularly those with a lower environmental impact.



← **Figure 2.** Cotton versus Synthetic Textile Fibre Production (1962–2024)

Source: OECD and FAO (2024), p.215.

2.2. Established and emerging alternative natural fibres

The issues around industrial cotton raises the importance of low-impact production and recovery methods for conventional natural fibres, as well as a consideration of agriculture residues as a source of fibres that have a lower lifecycle footprint (Esteve-Turrillas et al., 2017; Khan et al., 2022). There are already established options in natural fibres, ranging from bamboo to jute, abaca, coir, kenaf and sisal (JACKS), and other commodity-grade fibres like hemp (UN Trade and Development, 2022a). These fibres offer a compelling alternative to conventional textile fibres. They are derived from renewable plant sources, with no need for fossil fuels as source materials (though fossil fuels are still generally used to manufacture and transport them). Moreover, they generally require fewer chemical inputs and less water to grow than cotton, minimizing environmental impact.[1] Under certain conditions, their biodegradability can reduce waste to landfill and eliminate the microplastic pollution associated with synthetic fabrics. As such, they are also being explored as ways to reduce plastic waste, such as promoting the use of reusable cloth bags as an alternative to plastic bags (UN Trade and Development, 2022b).

However, the JACKS sector is often limited to home textiles or decorations because its base fibres are harder and sometimes not suitable for use in clothing. New and emerging fibres include hemp fibre, pineapple leaf fibre and banana pseudostems fibre, where stems account for about 60% of the plant's fresh weight (Fiallos-Cárdenas, Pérez-Martínez and Ramirez, 2022). Pineapple and banana leaf residues would otherwise often be left to rot in the field or be burnt. Bamboo fibre is also being used for textile applications, especially as a feedstock for viscose (rayon) production (Tausif et al., 2015).

While constituting just 5.7% of global fibre production in 2018 (Bao et al., 2022), these established alternative natural fibres have wide applications, ranging from packaging (including cloth bags) to technical applications. For example, kenaf is a crop native to Africa now grown around the world. It is resistant to insects and resilient to climate change. The woody core can be used for structural materials while fibres can be derived from the stem core or bark. Kenaf has been used as an adsorbent material, insulation, and paper, as well as being mixed with synthetic polymers, for auto interior linings, ceilings, and furniture. It could also be used for packaging, bags, and fabrics (Ramesh, 2016). Sisal, a plant that naturally grows in North Africa, is drought resistant, and provides a fibre that has similar properties to cotton in terms of water absorption, ability to be bleached, inflammable nature, and tensile strength (Korodowou et al., 2024). Bamboo shows the potential to replace synthetic fibres in reinforcing structure composites (UN Trade and Development, 2022b; Li et al., 2021).

The use of blends of alternative fibres with traditional materials, particularly cotton, is an important pathway towards adoption.[2] In addition to being used in pure form, alternative fibres can be used as a blend replacing up to 30% of traditional fibres such as cotton (Khan et al., 2024). Blending can reduce some of the disadvantages of these alternative fibres, such as poorer spinnability, elasticity, and less smoothness when compared to conventional fibres. For example, bamboo fabrics can be processed to be softer than cotton, achieving a silk-like texture, with high levels of moisture absorption. They require less dye and dry as fast as cotton. While 100% bamboo fabrics are known for their exceptional softness, they often lack durability and versatility in certain applications. Therefore, they are frequently blended with cotton, silk, or polyester (Babu and Chandrasekhara, 2023). In some cases, special treatments such as cottonisation are used to soften the fibres and increase their blending potential and use (De Quiroz et al., 2020; Khan et al., 2022; Sauvageon et al., 2018).

1 This comparison looks at the production stage of alternative fibres. It is important to acknowledge that their primary processing into usable fibres, which may involve blending with other fibres and chemical treatment such as viscose production for bamboo and hemp, also has environmental implications. A comprehensive life cycle analysis would be required to fully compare these processing stages with those of conventional fibres like cotton.

2 Blending strategies follow a similar strategy used in other economic sectors, such as biofuels-gasoline blends and renewable electricity-conventional electricity shares on the grid. The key factor behind successful blending strategies is technical suitability and performance.

Table 1. Global fibre production by feedstock (2022)

Fibre source	Global production MILLION TONNES	%	Fibre source	Global production MILLION TONNES	%
ramie	9.5	0	hemp	304.8	0.3
other animal fibres DEHAIRED	24	0	wool CLEAN	1,058	0.9
abaca	76.9	0.1	coir	1,106	1
kapok	78.2	0.1	jute, kenaf, and allied fibres	3,349	3
silk RAW	91.3	0.1	cellulosic	7,195	6.4
flax	175	0.2	cotton	25,321	22.6
sisal, henequen, and similar	276	0.2	synthetic	72,444	64.6

↑ *Source:* Discover Natural Fibres Initiative (2025). **DNFI World Natural Fibre Update – January 2025**. https://dnfi.org/dnfi-world-natural-fibre-update-january-2025 *Accessed 21 January 2025*

2.3. The geography of fibre production

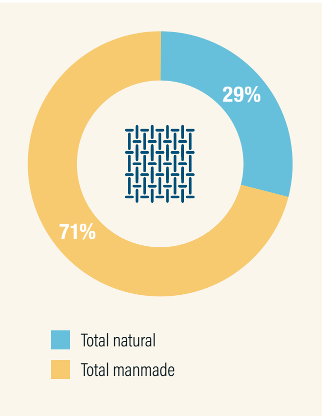
World production of natural fibres was estimated at 32.5 million tonnes in 2022, an increase of 1.5% from the previous year. At 25.3 million tonnes, cotton accounts for about 60% of natural fibre production and 23% of all fibre production (Table 1). While markets signal increased interest in alternative natural fibres such as jute and hemp, the market shares of these fibres remain negligible. Conversely, manmade fibres such as polyester and polyamide dominate global markets, accounting for over 70% of fibre production in 2022 (Figures 2 & 3) after fuelling textile consumption growth over the past 30 years (see Section 1).[3] These figures suggest that, despite their potential, no material is currently on track to compete with cotton or synthetics on a large scale. Synthetic fibres such as polyester are cheaper; have more consistent qualities; are water and stain proof/resistant; and easier to manufacture (not being subject to weather and soil conditions), handle and adapt to different fabric needs (made-to-order) (Jaffe et al., 2020).

However, most of the natural fibre production occurs in the developing world, reflecting potential for growth. For example, Ecuador and the Philippines produce almost all of the world's abaca, while India and Bangladesh produce almost all of the world's jute. Coir fibre is mainly produced in Sri Lanka, the Philippines and Indonesia, while 2/3 of kapok fibre is produced in Thailand and Indonesia. Tanzania, China, Brazil and Kenya produce most of the world's sisal, henequen and fique fibre (DNFI, 2025).

A new UN Trade and Development database measuring world trade in non-plastic substitutes, including natural plant and animal fibres, confirms this trend and reveals new insights. Overall, developing countries account for about 45 per cent of world exports of natural fibres, measured in current USD value. However, there are notable differences at the fibre level, where the weight of developing countries varies widely, from 88 per cent for jute to 29 per cent for hemp (Figure 4). Overall, developing countries tend to dominate exports of alternative fibres such as coir, abaca and sisal, all of which have developing country shares of exports above 50%. Conversely, developed countries export more traditional fibres, as they account for 61% of cotton exports and 59% of wool. These facts underscore the need to develop fibres that are appropriate to each geography, making the most of each country's comparative advantages.

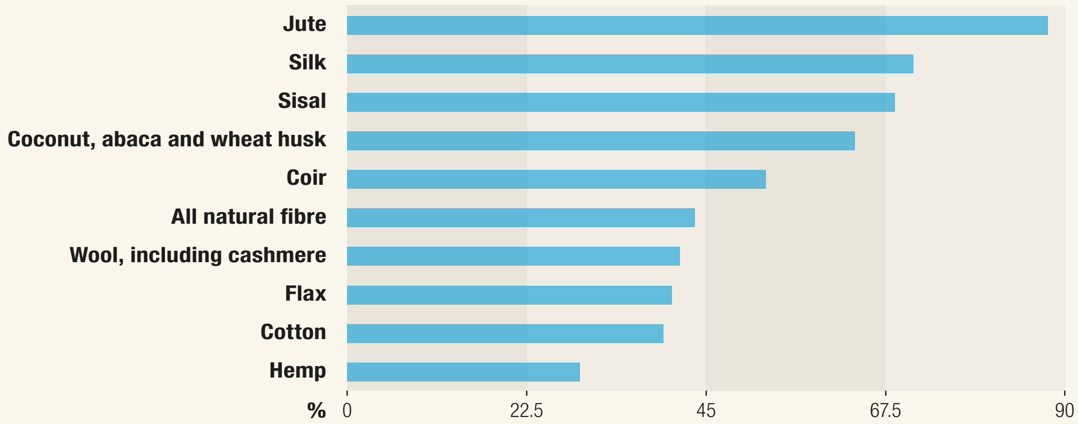
↓ **Figure 3.** Cotton versus Synthetic Textile Fibre Production (1962–2024)

Source: Discover Natural Fibres Initiative (2025). **DNFI World Natural Fibre Update – January 2025**. https://dnfi.org/dnfi-world-natural-fibre-update-january-2025 *Accessed 21 January 2025*



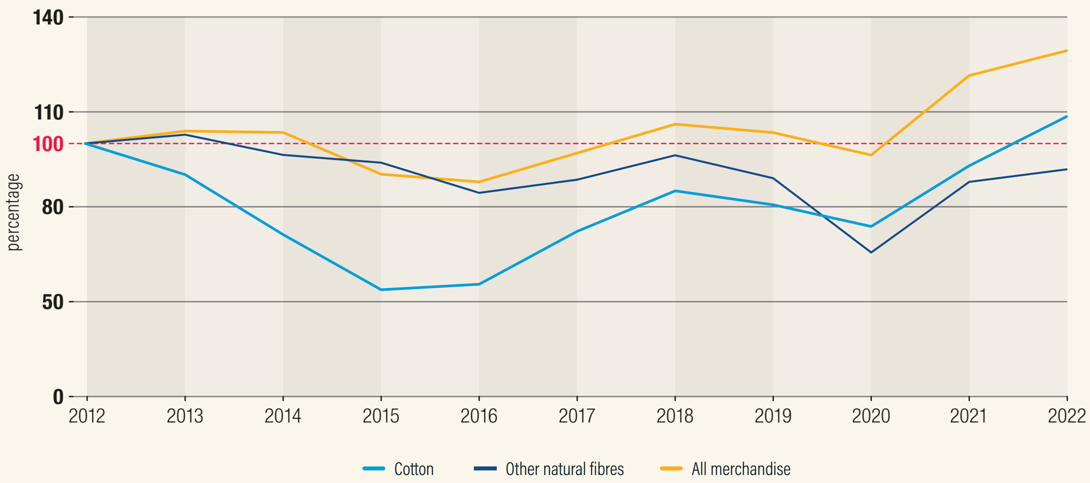
3 The high growth and market dominance of synthetic fibres can be explained by different factors, including significantly lower production costs, made-to-order manufacturing parameters that natural fibres cannot replicate, and year-round availability, unconstrained by the seasonal limitations of natural fibre harvests.

Natural fibres are traded across borders in patterns that mirror those of production, indicating opportunities for producing countries. Global exports of natural fibres were worth USD 37 billion in 2022, with cotton accounting for around 60%. Wool including cashmere takes the lion's share of the rest at 24%, followed by flax (7%) and silk (5%). Yet, exports of natural fibres have underperformed all merchandise exports, except for cotton, which rebounded after the pandemic, in line with general merchandise exports (Figure 5). Between 2012 and 2022, merchandise exports grew at an annual rate of 3%, while cotton grew by 1% and other natural fibres, by contrast, recorded a 1% average annual decline. Despite the short-term rise, as seen in Figure 2, cotton consumption has remained relatively flat for the last 3 decades.



← Figure 4. Cotton versus Synthetic Textile Fibre Production (1962–2024)

Source: UN Trade and Development data (2024). https://unctadstat.unctad.org/datacentre *Accessed 30 January 2025*



← Figure 5. Global exports of cotton and other natural fibres, index (2012=100)

Source: UN Trade and Development data (2024). https://unctadstat.unctad.org/datacentre *Accessed 30 January 2025*

Note: Other natural fibres include abaca, coconut, coir, flax, hemp, jute, silk, sisal, wheat husk and wool including cashmere. Volatility may be partly explained by price movements and stockpiles by major consumers.

← Image 3. Banana pseudostems, source of fibre for banana production. Less than 1% of plant mass are fibre

3.

Opportunities for agri-waste valorisation

While fibres such as JACKS are gaining traction as sustainable alternatives, these fibres are often derived from dedicated crops that are specifically grown for their fibre. Embedded emissions can still be high, as this requires the establishment of land-based production systems that can be resource intensive and release organic and chemical pollutants. In contrast, there are waste-based options that involve converting agricultural residues such as husks, stems and leaves, which have no immediate secondary use, into high-value textile fibres. This allows value addition to otherwise discarded organic matter, expanding the frontier of economic opportunities within crops while reducing the environmental footprint of virgin fibre production.

The production of textile-grade fibres from crop residues, such as pineapple leaves and banana stems, can follow two main approaches: mechanical cottonisation and chemical processing into viscose. Each method offers distinct advantages depending on the intended textile application.

In the cottonisation process, fibres are extracted directly from the leaves of pineapple plants or the pseudo-stems of banana plants. In most circumstances, the first step is retting, a microbial or enzymatic treatment that breaks down non-fibrous plant components, helping to separate the fibres. Some producers skip this stage. The second step in decortication, a mechanical process that strips the fibres from the plant material.[4] Once extracted, the fibres undergo further cleaning, carding to remove residual plant matter, and drying processes to align them for spinning. To make the fibres more suitable for textile production, they can be cottonised—a refining step that softens, shortens, and treats the fibres to behave more like cotton or flax. This method produces a natural, slightly coarse textile material, often used in linen-like fabrics or blended with cotton for sustainable fashion applications.

Alternatively, banana and pineapple fibres can be processed into viscose, a regenerated cellulose fibre that offers a finer and more uniform texture. This process begins with pulping, where the extracted fibres are chemically treated to isolate pure cellulose. The cellulose is then dissolved in a chemical solution, such as sodium hydroxide and carbon disulfide, to create a viscous liquid, which is extruded through fine nozzles into an acid bath, where it solidifies into regenerated fibres. The resulting material has a silkier texture, making it more versatile for high-performance textiles.

4 Note that the production process of SMEP-supported Mananasi Fibre Ltd., which is presented as a case study in Section 3.1, does not include retting and decortication is the first step.

Viscose – also known as rayon – is chemically intensive during production, often involving alkaline treatments (NaOH), Xanthalation with carbon disulfide (CS_2), and extrusion processes coupled with acid regeneration (involving sulfuric acid H_2SO_4). The production of viscose requires careful stewardship of process chemicals, as those can be harmful if released into the environment. While the production of viscose is highly scalable, usage of banana and pineapple cellulosic fibre as a feedstock is not well documented for this purpose, suggesting the main pathway for conversion is mechanical decortication of fibres.

Cottonised fibres maintain a natural, textured feel suitable for eco-friendly fabrics, viscose-derived fibres on the other hand offer a smoother, softer alternative that requires more intensive chemical processing. While both methods contribute to the growing demand for plant-based sustainable textile alternatives, decortication and cottonisation processes generally require less process chemicals and water and are often the preferred choice by smaller producers. Both processes, however, require energy which, depending on the source can increase or decrease the overall pollution footprint of the process chosen.

Waste-based fibres have multiple applications and can enhance the functionality of materials, especially when used as a blend. Banana fibres are a traditional source of material used for clothing, paper, and textiles such as ropes and curtains in India, Japan and the Philippines. They are currently being used along with jute, bamboo and cotton to produce sanitary pads in India. The peels can also be ground into flour to be used as a food additive. (Balda et al., 2021). Banana fibre-based composites show favourable characteristics compared to 100% cotton, including tensile and tear strength, air flow and friction resistance (Khan et al., 2022). Preliminary studies show that a 30% banana fibre/70% cotton blend has similar characteristics to 100% cotton textiles, while saving 25% of energy costs, and using far less water, land and fertilizer (Khan et al., 2024). Pineapple leaf fibre has demonstrated comparable strength to cow leather, with better resistance to colour fading from light exposure in experiments (Sureshkumar et al., 2012). Other benefits include employment opportunities.

Perhaps the most attractive aspect of using alternative plant sources for fibres is their ability to biodegrade and enhance soil quality. More research is needed to better understand which crops have the most promising biodegradation characteristics for such use (Provin et al. 2024). A significant byproduct of processing these plants is the extraction of large volumes of water containing valuable nutrients. This nutrient-rich water presents an opportunity for resource recovery and reuse. However, it requires careful management, as direct discharge can cause water pollution and eutrophication (Sethupathi et al., 2024). Potential applications for using these byproducts include the production of organic fertilizers, such as for controlled algae farming, but further research is needed to optimize this process and minimize environmental risks. In addition, pineapple wastewater has been shown to reduce the toxicity of textile wastewater, a major contaminant, by providing electron donors that fuel microbial processes capable of breaking down harmful pollutants (Nuid et al., 2023).

Pineapple peels have also been used as an effective textile dye (Umesh et al., 2023). Geotextiles, which are textiles used in landscaping applications, have also been made from natural fibres and used for soil stabilisation (to prevent erosion), to help drainage and reinforce roads (Leão et. al, 2012).

In sum, the use of waste-based fibre feedstocks offers developing countries a dual pathway to structural transformation and decarbonisation. By utilizing domestic organic waste streams, these countries can foster new industries aligned with their comparative advantages, offering entrepreneurship opportunities, while reducing the environmental impact of textiles. While still focused on niche applications, novel approaches are gaining traction in developing regions such as East Africa, with promising results at the local level. This is the case in Uganda and Kenya, where SMEP-funded interventions are extracting textile-grade fibres from by-products of banana and pineapple crops, and building connections with partners established in international textile value chains. Through an ecosystem approach and South-South cooperation, these projects are creating market linkages between food systems and manufacturing industries and establishing a circular production and trade cycle.

← **Image 4.** Pineapple fibre-based leather

© Pinatex

3.1. Kenya: Textile grade fibre from pineapple leaf

Pineapple is an important cash crop in Kenya, contributing substantially to job creation and generating foreign currency earnings through exports. Small-scale production, primarily undertaken by rural households, occurs in the Coast, Central, and Western regions. Households cultivate pineapples for both home consumption and commercial purposes. Large-scale operations, concentrated in the Central region, dominate the sector, with a few major farms accounting for most of the production (Hossain, 2016).

Del Monte Kenya Ltd, one of the country's largest producers of pineapple fruit, faces significant environmental and economic challenges due to the predominant practice of burning post-harvest residues, mainly leaves. This process generates significant greenhouse gas emissions and air particulate pollution, posing health risks to nearby communities and wasting biomass. The heat from burning residues also leads to nutrient loss and soil depletion, inviting the use of chemical fertilizers that further increase carbon emissions and long-term input costs to farmers. Recognising the need for a sustainable alternative and to explore economic opportunities in pineapple residues, a partnership between The Chequered Flag and Mananasi Fibre Ltd. launched a pilot project to upcycle this agricultural waste, illustrated in the photo below.

The project introduced a novel decortication technology that transforms pineapple biomass into valuable textile-grade fibres and nutrient-rich compost. By intercepting about 10% of Del Monte's pineapple waste, the project aims to produce 400kg of textile-grade fibre daily. Furthermore, the project explores repurposing the remaining plant material for animal feed and compost. This biochar is being tested in a trial for wastewater filtration and as a compost enhancer, creating a closed-loop system and a promising model for a complete pineapple waste management solution.

Early results demonstrate the project's significant impact. To date, over 1,500 tonnes of pineapple waste have been diverted from Del Monte's fields, yielding 22 tonnes of textile-grade fibre and 158 tonnes of compost. The project has also generated employment for 85 individuals, with gender-balanced workforce and technical skills development. While reducing environmental impact, lowering production costs and promoting a circular economy, the project is also creating cross-sector linkages between large corporations and local start-ups, with a positive multiplier effect on the local economy.

3.2. Uganda: Spinnable textile fibre from banana pseudostems

↑ Image 5. Matooke is a green cooking banana and a dietary staple across Uganda

© Friends Cargo, 2021

Bananas are a staple food crop in Uganda, with approximately three-quarters of farmers engaged in its cultivation and the nation recording the world's highest per capita banana consumption at 220-400kg per annum. With an estimated 70% of the over 6 million tons of annual "matooke" (an abundant banana variety) production absorbed by household consumption, the remaining 30% enters a fragmented supply chain involving multiple intermediaries. As a result, exports remain relatively low, accounting for only 5% of total output (UNDP, 2024).

In 2005, Uganda launched the Presidential Initiative on Banana Industrial Development (PIBID), a government-led facility aimed at transforming the banana industry by developing and commercializing value-added banana products.[5] More recently, in 2017, the government adopted the Uganda Green Growth Development Strategy, which calls for a low-emissions growth path and efficient use of resources. Both are examining ways to create new and useful byproducts from banana production.

There are several startups seeking to develop new products from agricultural materials. These include Hya Bioplastics, which seeks to make plastic substitutes from water hyacinths combined with other waste materials, such as sawdust and cassava starch; Amelia Agro Africa Ltd., which takes agricultural, food and animal waste and creates compost; and TEXFAD, that creates carpets, and handicrafts such as scarves using textile (cotton) waste and fibres derived from banana stems (Buda and Ricz, 2023).

The Banatex-EA project, led by a consortium of stakeholders including private companies, government agencies and universities, is responding to the growing demand for sustainable textile fibres by upcycling agricultural waste from banana farms in Kampala's Wakiso and Mukono districts. Currently, banana pseudostems only fruit once and after the banana harvest, the stems are discarded as waste. Banatex-EA intervenes by extracting raw fibres from these stems, which undergo treatment to become spinnable, promoting resource efficiency and a circular bio-economy.

5 For more information on the PIBID, see: https://www.pibid.org/

← Image 6. Banana pseudostems, source of fibre for banana production

© H. Pacini / Banatex-EA, 2025

← Image 7. Cross sectional view of banana fibres from pseudostems

Within the project, TEXFAD extracts raw fibre from the banana stems using a decortication technology developed in-house and a specialised fibre preparation equipment developed by the National Textile University of Pakistan. It does this by involving local smallholder farmers, providing them with additional income through the sale of banana stems and training them in proper harvesting and banana stem handling practices to ensure quality fibre production. The project is also exploring the use of other banana waste products, such as the sap, which can be fermented into fertiliser, and the remaining biomass, which can be converted into briquettes for fuel, biochar for soil improvement, or used for mushroom growing.

Early results and data collected from field visits show considerable potential. The project has identified and engaged 80 banana farms, established partnerships with key stakeholders and initiated the procurement of necessary equipment for fibre refining and cottonisation (softening). Preliminary assessments indicate a significant potential for supply of textile fibre, with 7 banana stems weighing 20-30 kg each yielding an average of 1 kg of raw fibre. Assuming that 10% of the stalks harvested are used for other purposes, such as mulching, or cannot be used due to poor quality, this can amount to up to 41 tonnes of textile fibre per year, with an estimated value of USD 229,000 and farmers receiving payment for each stem delivered.

The project is also exploring the development of local processing capacity, including the possibility of providing farmers with decorticating machines to extract fibre themselves. This would further enhance productivity by creating efficient logistics, while reducing fuel costs and transport emissions.

4.

Market potential

The Kenya and Uganda cases show that promoting business models that embrace circular economy and resource efficiency principles offers promising solutions to tackle manufacturing pollution while contributing to socio-economic development. This is especially true in countries with large agricultural sectors where value addition is limited to basic food processing that typically results in weak linkages with manufacturing. Taking these innovative approaches to scale would allow sustainable materials such as agri-residues-based textile fibre to enter export markets. This would not only reduce emissions embedded in products but also strengthen urban-rural linkages, benefiting the local economy. Basic sensitivity analysis shows that approaches such as those introduced by the Mananasi Fibre Ltd. and Banatex-EA projects, if adopted nationwide, can drive sector competitiveness and contribute to the achievement of national economic goals.[6]

Despite potential and strong domestic demand, Kenya's textile industry faces significant challenges. These include issues in the upstream part of the supply chain, such as low-quality local cotton lint production due to limited cotton seed availability and quality, underutilisation of existing ginneries caused by low seed cotton supply and the high costs of farming (KIPRA, 2020). This translates in a high dependence on imports. In fact, in 2022, Kenya was a net importer of raw cotton, with imports of 1,155 tonnes worth USD 3.11 million and exports of 199 tonnes worth just USD 7.5 thousand.

If Mananasi's model were scaled up nationally, and assuming no supply chain, technological or financial barriers, it could produce 2,021 tonnes of pineapple-based textile grade fibre annually. This would be worth approximately USD 14.8 million at current market prices. In kg terms, this is twice the amount of cotton that Kenya had to import in 2022 and about 30% of domestic demand, estimated at 6,170 tonnes in the same year.[7] Pineapple fibre is not a perfect substitute for cotton as it can only be blended with standard textiles at a ratio of 30% without major technical challenges. However, scaling up production could still significantly reduce Kenya's reliance on cotton imports. This would help meet the growing textiles demand while adding value to local agricultural waste.

Once one of Africa's largest cotton producers, Uganda has long struggled with sluggish productivity due to the high cost of credit, a lack of cooperative movement and, more recently, climatic hazards (World Bank, 2009; UN Trade and Development 2018; Republic of Uganda, 2022). As a result, value addition in the sector is limited and most foreign earnings come from exports of raw cotton, which in 2022 amounted to 7,617 tonnes worth USD 19.8 million. Despite importing only 110 tonnes of cotton worth USD 325.000, likely for niche applications, the country remains a net exporter. The challenge is to revitalize the sector and add value to locally sourced materials before export.

Applying the Banatex-EA model to all 6 million hectares of bananas grown nationally can work towards this goal, while helping to manage the vast amounts of organic waste generated by one of the world's largest banana sectors. Given the large area harvested, the model could yield over one million tonnes of banana-based textile fibre, with an estimated value of USD 5 billion. This is about 6 times the estimated domestic demand for cotton. Beyond its scale, the premium nature of banana fibre and its suitability for blending with cotton could drive local value addition in handicrafts and home textiles. As part of the Banatex-EA project, local textile manufacturer TEXFAD demonstrates the strong compatibility of these fibres and the possibility for existing cotton businesses to incorporate banana fibre.

6 The figures presented in the following paragraphs are UN Trade and Development estimates based on data from SMEP projects (2025), FAOStat (2022) and UN Comtrade (2022), all collected in February 2025. The model assumptions have been defined and results validated with external sources, including academic literature and key informant interviews.

7 Despite potential, it should be noted that regulatory barriers may limit market access for residue-based fibre, as this type of fibre may be classified as waste by regulations in importing countries, resulting in bans or restrictions on entry.

← Image 8. Banana fibres in sun-drying process

© TEXFAD, Uganda, 2025

5.

Challenges

In sum, despite demonstrated potential, replacing conventional textile materials with sustainable alternatives presents a complex array of challenges, which we summarise here.

First and foremost, it is crucial to avoid assuming that alternative fibres are universally superior to conventional textiles in all market contexts. As noted above, there are certain properties and economic considerations that need to be considered before comparing the market viability of different materials. For example, the energy use of the production process for natural fibres may be higher than that of synthetics (Meng et al., 2024). The loss of material traditionally used for compost fertilizer must also be considered. Simply put, comprehensive life cycle analyses (LCAs) are essential to inform consumers about the true sustainability of alternative products (Tewari et al., 2024).[8] This applies to all products derived from edible plants, from banana-based packaging and fertilizers to textile bio composites (Castillo, De Guzman and Aberilla, 2023; Rodríguez et. al, 2018). Furthermore, replicating key use properties such as flexibility, water resistance, and lightweight nature may be challenging in the short term, like the difficulties encountered in replacing plastic bags (Hira et al., 2022b). As noted above, experiments with using blends may prove a worthwhile solution.

There are several obstacles that have been identified to reach the full potential of activating new circular economy sectors and supply chains. These include the issue of properly valorising externalities, including the energy, emissions, and pollution costs of current industries and the benefits of circular industries; the need for proper harmonisation of standards at the domestic and international levels; developing systems for collection, cleaning and sorting of natural feedstocks as part of a broader effort to remake supply chains, which requires serious financial investment; and increasing consumer awareness of the differences between sustainable and linear consumption (Hira et al., 2022a). While the EU is at the forefront of circular economy efforts, recent studies demonstrate that considerable regulatory barriers along these lines persist within the bloc (Pender et al., 2024).

8 For a discussion of the life-cycle trade-offs of replacing plastics with non-plastic substitutes, see UN Trade and Development (2023).

Such efforts are only multiplied in complexity at the global scale. Large multinational enterprises (MNEs) are understandably cautious about altering their supply chains abruptly. They have concerns about ensuring an adequate volume and consistent quality of natural fibres. More research is needed to develop greater knowledge of the properties and optimal uses of different fibres and composites in different products. It also important for them to show visible differences in natural-fibre vs. artificially created products, to gain consumer premiums, particularly considering the immature state of regulation and policy (Midani, 2023). Thus, while developing country producers feel pressure from global brands towards circular shifts, there is a lack of a clear playbook for doing so outside of clear short-term initiatives such as energy efficiency, given the gaps among the brands and policymakers, and the financial investments required to reach scale (Farrukh and Sajjad, 2024; Jayasinghe et al., 2020).

In many regions, traditional knowledge of local plant fibres has been lost due to the dominance of imported cotton and plastics. In fact, in many cases, fibres from local plants were traditionally used for a variety of purposes, including rope, sanitary pads, medicinal purposes, and bags, but knowledge and support dissipated with the introduction of imported cotton and plastic products, displacing local industry. For example, in Ghana, plantain is primarily seen as a fruit source, overlooking the multiple potential uses of the rest of the plant (Loos et al., 2018). Fibre uses may also change geographically. For example, the contrast between pineapple leaf fibre use in the Philippines (clothing) and its disposal as waste in India (Hazarika et al., 2017) highlights the potential for knowledge sharing and market development, potentially facilitated by large companies.

There are also firm-level challenges that hinder the development of sustainable business models for novel fibres. These include ensuring a steady and adequate supply of feedstocks; constraints facing smallholder farmers, such as a lack of capital and access to equipment and markets; small scale and high production costs, limited technological solutions and agro-industrial clusters; and local support and community acceptance (Institute for Sustainable Communities et al., 2021). Despite positive market signals, addressing these challenges cannot be left to market forces alone and policy support is needed to address market failures. These include financing cooperatives to provide agricultural extension services and vocational training to farmers, knowledge dissemination and technology transfer, including South-south, and support for startup costs.

While less tangible, demand-side and regulatory challenges may be substantial. Textile manufacturers may be reluctant to adopt new materials due to factors such as the higher prices, capital costs for acquiring or adapting machinery, and a general hesitancy to deviate from familiar materials like cotton and synthetics. Furthermore, policy barriers, including Non-Tariff Measures (NTMs) and high tariffs, can hinder market access and discourage innovation. In fact, novel fibres may be subject to particularly stringent regulations because they are derived from edible plants. It is likely that material standards for these fibres are not yet available, and despite being non-food products they end up being subjected to existing standards for food products, which are more stringent and can hamper their trade, or left in a regulatory "limbo".

Sustainable and economically viable fibre production from waste depends furthermore on spatial considerations. Upcycling must occur near farms to minimize transportation costs and emissions, and to ensure rapid processing of perishable materials. For instance, interviews with farmers and business owners in the Banatex-EA project suggest that banana stems must be processed no later than 4 days after harvesting to avoid losing their material properties. In this view, the typical disconnect between agricultural production areas and urban manufacturing hubs presents a challenge but also an opportunity for policymakers to incentivize local supply chains. This includes supporting local textile industries and farmers, particularly in areas with abundant agricultural waste, thus creating new market opportunities and bridging the urban-rural divide.

6.

Recommendations

Challenges can be addressed with forthright efforts by policy and market stakeholders, but clearly more research is needed to help map out such pathways.

FOSTERING INNOVATION AND CAPACITY BUILDING

Developing circular economy markets, beyond proof of concept, requires orchestrated efforts to incentivize stakeholders to shift to new supply chains. To ensure change, we need to start with developing a playbook by which such transformation can be achieved and thus reduce uncertainties. The knowledge required ranges from improving our technical capacity to develop natural fibre feedstocks into case studies of sustainable business models such as the incipient ones developed here.

- **Incentivize** cross-disciplinary research and development (R&D) in sustainable fibre production and processing technologies (e.g. softening).
- **Explore** the potential of blending different fibres to improve functionality and environmental performance; and develop related standards and specifications.
- **Investigate** the use of byproducts from fibre processing for other applications (e.g. organic fertilizers, natural dyes, composting, biochar).
- **Undertake** comprehensive life cycle analyses (LCAs) to assess the context-specific sustainability of alternative fibre products and avoid "greenwashing".
- **Cross-fertilize** fibre-relevant research from different fields, e.g. materials science, environmental science, business and sustainable agriculture to inform product development.
- **Facilitate** knowledge sharing and technology transfer between universities and supply chain actors, including in South-South relationships.
- **Raise** awareness about the business opportunities of waste valorisation and facilitate stakeholder dialogue on solutions that work.

STRENGTHENING SUPPLY CHAINS

Ultimately, circular economies can only be constructed within a clear market framework where incentives push producers and consumers into more sustainable exchanges. Experience from efforts to control hazardous waste and child labour show that when properly accounted for, pollution externalities can be curtailed or properly valorised so that the fundamental features of competition and innovation of markets can continue to improve efficiency.

- **Work** to organise and coordinate a consistent and reliable feedstock supply.
- **Promote** sustainable agricultural practices for biomass preparation and feedstock cultivation, minimizing chemical inputs and water use where possible.
- **Provide** targeted support for smallholder farmers and cooperatives to participate in sustainable fibre production, from extension services to access to finance and technology.

- **Implement** robust traceability systems throughout the fibre supply chain, enabling verification of sustainable agricultural practices, ethical labor conditions, and product origin.
- **Support** the development of local processing capacity, including access to decortication and transport equipment, and funding for innovative startups.
- **Fostering** strong buyer-supplier linkages, both between large companies and innovative start-ups, and between textile manufacturers and agricultural producers.
- **Support** the development of agro-industrial clusters that link agricultural production with textile manufacturing, including innovative start-ups and designers.
- **Strengthen** urban-rural linkages by addressing logistical and infrastructure constraints in feedstock production areas, considering life-cycle considerations.
- **Procurement** policies that favor these alternatives.

DESIGNING AN ENABLING POLICY AND REGULATORY ENVIRONMENT

Ultimately, governments, aided by international support, need to lead the process of transforming the regulatory environment at the global and domestic levels, for the circular economy to emerge. Beyond consideration of externalities, research should show that circular initiatives will have a long-term payoff for future generations through, for example, creating a healthy eco-services system, and improving the health and productivity of workers. International organisations and aid agencies can provide focused support for developing country governments and producers to help finance and otherwise promote the transition.

- **Develop** integrated policy frameworks that support the entire sustainable fibre value chain, from feedstock cultivation to market access, aligning agricultural, industrial, trade, and environmental policies.
- **Address** the regulatory "limbo" by developing specific standards and testing protocols for novel fibres that are distinct from food standards (e.g. sanitary and phytosanitary).
- **Accompany** technical standards with clear definitions and guidance on the use of environmentally and socially responsible materials, such as Textile Exchange's “Preferred Fibres and Materials” (Textile Exchange, 2023).
- **Avoid** applying food safety and health standards to textile fibres derived from edible plants, such as bananas and pineapples, unless there is a substantiated risk.
- **Harmonize** standards and regulations across regions and internationally, using multilateral processes, such as the INC negotiations for a Global Plastics Treaty.
- **Design** targeted tariff lines that specifically recognize and support sustainable fibres; where possible, create separate HS codes for these materials to allow for reduced tariffs.

PROMOTING SUSTAINABLE CONSUMPTION

In the absence of a push from consumers, producers, government and MNEs are naturally reluctant to upend existing profitable business models. If they perceive that circular economy initiatives raise their costs, even if only in the short run, they may find themselves at a competitive disadvantage, reflecting the collective action problems inherent in valorising the commons. Western consumers through their market power can help to push through such resistance, by voting with their money and purchase these alternatives. International organisations can help to focus such responses and twin them with efforts around harmonisation and regulation of trade and investment.

- **Launch** public awareness campaigns to educate consumers about the benefits and sustainability of alternative fibres, highlighting their environmental benefits and potential to support local economies.
- **Enable** the adoption of sustainable alternatives, which are more expensive than cotton and synthetic fibres, through market support mechanisms and fiscal incentives, such as tax breaks for producers.
- **Promote** labelling initiatives that clearly identify and differentiate sustainable fibre products from standard commodities, including through traceability.
- **Minimize** transportation costs and emissions by locating processing facilities close to feedstock sources (e.g. drying and fibre extraction at or near the farm).
- **Explore** the potential for agricultural waste fibres to generate carbon credits and contribute to national climate targets. This includes research into the eligibility of these fibres for existing carbon offset programs.
- **Developing** appropriate methodologies for quantifying and verifying emission reductions associated with the use of agri-waste fibres.
- **Integrate** alternative fibres into green public procurement schemes, such as by defining fibre content requirements for certain goods (e.g. school uniforms) and providing fiscal incentives to suppliers meeting criteria

References

Babu, K. Murugesh and S.M. Chandrasekhara (2023). Chapter six - Production and properties of bamboo yarns and fabrics, in Eds. K. Murugesh Babu, S.M. Chandrasekhara Bamboo Fibres, Woodhead Publishing, Pages 137-168, ISBN 9780323857826, https://doi.org/10.1016/B978-0-323-85782-6.00005-2.

Balda, Sanjeev, Aarjoo Sharma, Neena Capalash, and Prince Sharma (2021). Banana fibre: a natural and sustainable bioresource for eco-friendly applications. Clean Technologies and Environmental Policy. 23:1389–1401, https://doi.org/10.1007/s10098-021-02041-y.

Bao, H., Hong, Y., Yan, T., Xie, X., & Zeng, X. (2023). A systematic review of biodegradable materials in the textile and apparel industry. The Journal of The Textile Institute, 115(7), 1173–1192. https://doi.org/10.1080/00405000.2023.2212848.

Brocker, Marley (2024). Global Apparel Manufacturing. IBIS World. Dec. 2024. Available at: https://my.ibisworld.com/gl/en/industry/C1311-GL/at-a-glance. Accessed: Jan. 20, 2024.

Buda, G., and J. Ricz (2023). Industrial symbiosis and industrial policy for sustainable development in Uganda. Rev Evol Polit Econ 4: 165–189. https://doi.org/10.1007/s43253-023-00097-8

Castillo M., de Guzman M.J.K, and Aberilla J.M. (2023). Environmental sustainability assessment of banana waste utilisation into food packaging and liquid fertilizer. Sustainable Production and Consumption, Vol. 37 (2023), pp. 356-368, https://doi.org/10.1016/j.spc.2023.03.012.

De Queiroz R.S., Da Silva A.P.V., Broega A.C.L. et al. (2020). New Brazilian pineapple leaf fibres for textile application: cottonisation and dyeing performance. SN Applied Sciences. Vol. 2, Art. 72 (2020). https://doi.org/10.1007/s42452-019-1855-8.

Discover Natural Fibres Initiative (DNFI) (2025). World Natural Fibre Update. Jan. 14. Available at: https://dnfi.org/dnfi-world-natural-fibre-update-january-2025, Accessed Jan. 21, 2024.

Ellen MacArthur Foundation (2017), A new textiles economy: Redesigning fashion's future. Available at: https://www.ellenmacarthurfoundation.org/a-new-textiles-economy.

Euromonitor (2023). Global Overview of the Textile and Leather Products Industry. Dec. 2023. Available at: https://www-portal-euromonitor-com.proxy.lib.sfu.ca/analysis/tab, Accessed: Jan. 20, 2024.

Esteve-Turrilas, F.A., De la Guardia, M. (2017) Environmental impact of recover cotton in textile industry. Resources, Conservation and Recycling 116, pp 107-115. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0921344916302828.

Farrukh, A., and A. Sajjad (2024). Drivers for and barriers to circular economy transition in the textile industry: A developing economy perspective, Sustainable Development, 32(6), 7309–7329. https://doi.org/10.1002/sd.3088.

Fiallos-Cárdenas M., Pérez-Martínez s. and Ramirez A.D. (2022). Prospectives for the development of a circular bioeconomy around the banana value chain. Sustainable Production and Consumption, Vol, 30 (2022), Pp. 541-555. https://doi.org/10.1016/j.spc.2021.12.014.

Hazarika, Dipshika, Nabaneeta Gogoi, Seiko Jose, Robin Das, and Gautam Basu (2017). Exploration of future prospects of Indian pineapple leaf, an agro waste for textile application. Journal of Cleaner Production, 141: 580-586, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2016.09.092.

Hira, A., H. Pacini, K. Attafuah-Wadee, and J. Hassall (2022a). Sustainable Manufacturing and Environmental Pollution Programme (SMEP): A Circular Economy Experiment in the Global South. Journal of Developing Societies, 38(3): 287-309. https://doi.org/10.1177/0169796X221106013.

Hira, A., H. Pacini, K. Attafuah-Wadee, D. Vivas-Eugui, M. Saltzberg, and T.N. Yeoh (2022b). Plastic Waste Mitigation Strategies: A Review of Lessons from Developing Countries. Journal of Developing Societies, 38(3): 336-359. https://doi.org/10.1177/0169796X221104855.

Institute for Sustainable Communities, the World Resources Institute India and Wageningen University and Research (2021). Spinning Future Threads: The Potential of Agricultural Residues as Textile Feedstock. Available at: https://laudes.h5mag.com/laudes/agri-waste_report_highlights/home/9656/agri_waste_report_2021_07_01.pdf. Accessed: Jan. 21, 2024.

Jaffe, Michel, Anthony J. Easts, and Xianhong Feng (2020). Chapter 8 - Polyester fibres, in Michael Jaffe and Joseph D. Menczel, eds., Thermal Analysis of Textiles and Fibres, The Textile Institute Book Series, Woodhead Publishing, 2020, Pages 133-149, ISBN 9780081005729, https://doi.org/10.1016/B978-0-08-100572-9.00008-2.

Jayasinghe, R., N. Liyanage, and C. Baillie (2021). Sustainable waste management through eco-entrepreneurship: an empirical study of waste upcycling eco-enterprises in Sri Lanka. J Mater Cycles Waste Manag, 23: 557–565, https://doi.org/10.1007/s10163-020-01140-0.

Khan, Aamer, Muhammad Awais, Muhammad Mohsin, Ayesha Khan, and Kaleem Cheema (2024). Sustainable yarns and fabrics from tri-blends of banana, cotton and tencel fibres for textile applications. Journal of Cleaner Production. 436, 140545, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2023.140545.

Khan, Aamer, Komal Iftikhar, Muhammad Mohsin, Muhammad Ubaidullah, Muhammad Ali, and Ahmed Mueen (2022). Banana agro-waste as an alternative to cotton fibre in textile applications. Yarn to fabric: An ecofriendly approach. Industrial Crops and Products.189, 115687, ISSN 0926-6690, https://doi.org/10.1016/j.indcrop.2022.115687.

Kenya Institute for Public Policy Research and Analysis (KIPRA) (2020). Assessing the Cotton, Textile and Apparel Sector Employment Potential in Kenya. Discussion Paper n. DP/229/2020. Available at: https://kippra.or.ke/wp-content/uploads/2021/02/Assessing-the-Cotton-Textile-and-Apparel-Sector-Employment-Potential-in-Kenya.pdf.

Kim, J-O, Traore, ML., Warfield, C. (2010) The textile and apparel industry in developing countries. Textile Progress 38. Available at: https://www.tandfonline.com/doi/abs/10.1533/tepr.2006.0003.

Korodowou, Ilyace, Latifa EL Farissi, Mohammed Ammari, and Laïla Ben Allal (2024). Evaluating sisal fibres as an eco-friendly and cost-efficient alternative to cotton for the Moroccan absorbent hygiene and textile industries. Industrial Crops and Products. 222 (Part 3):119779, ISSN 0926-6690, https://doi.org/10.1016/j.indcrop.2024.119779.

Landrigan, P. J., H. Raps, M. Cropper, C. Bald, M. Brunner, E.M. Canonizado, D. Charles, T.C. Chiles, M.J. Donohue, J. Enck, P. Fenichel, L.E. Fleming, C. Ferrier-Pages, R. Fordham, A. Gozt, C. Griffin, M.E. Hahn, B. Haryanto, R. Hixson, H. Ianelli, … S. Dunlop, S. (2023). The Minderoo-Monaco Commission on Plastics and Human Health. Annals of global health. 89(1): 23. https://doi.org/10.5334/aogh.4056.

Leão, A. L., B.M. Cherian, S.F. de Souza, R.M. Kozlowski, S. Thomas, and M. Kottaisamy (2012). Natural fibres for geotextiles, c. 9, 280-311 in Kozlowshi, R.M., ed. Handbook of Natural Fibres: Volume 2: Processing and Applications, Elsevier Science & Technology.

Li, Z., Chen, C., Xie, H. et al. Sustainable high-strength macrofibres extracted from natural bamboo. Nat Sustain 5, 235–244 (2022). https://doi.org/10.1038/s41893-021-00831-2.

Loos, T. K., Hoppe, M., Dzomeku, B. M., & Scheiterle, L. (2018). The Potential of Plantain Residues for the Ghanaian Bioeconomy—Assessing the Current Fibre Value Web. Sustainability, 10(12), 4825. https://doi.org/10.3390/su10124825.

Meng, Fanran, Miguel Brandão and Jonathan M. Cullen (2024). Replacing Plastics with Alternatives Is Worse for Greenhouse Gas Emissions in Most Cases. Environmental Science & Technology 2024 58 (6), 2716-2727, https://doi.org/10.1021/acs.est.3c05191.

Midani, Mohamed (2023). Natural fibre composites: What's holding them back? Composites World. Mar. 23. Available at: https://www.compositesworld.com/articles/natural-fibre-composites-whats-holding-them-back. Accessed: Feb. 17, 2025.

Nuid, Maria, Azmi Aris, Ranjeni Krishnen, Shreeshivadasan Chelliapan, and Khalida Muda (2023). Pineapple wastewater as co-substrate in treating real alkaline, non-biodegradable textile wastewater using biogranulation technology. Journal of Environmental Management. 344, 118501, ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2023.118501.

OECD and FAO (2024). OECD-FAO Agricultural Outlook 2024-2033. Available at: https://openknowledge.fao.org/server/api/core/bitstreams/8f255c15-3119-4a3a-9671-b398ccb9dd4b/content. Accessed: Mar. 7, 2025.

Pender, Anne, Luke Kelleher, and Eoin O'Neill (2024). Regulation of the bioeconomy: Barriers, drivers and potential for innovation in the case of Ireland. Cleaner and Circular Bioeconomy, 7, 100070, ISSN 2772-8013, https://doi.org/10.1016/j.clcb.2023.100070.

Provin, Ana Paula, Alexa Medeiros d'Alva, Ana Regina de Aguiar Dutra, José Baltazar Salgueirinho Osório de Andrade Guerra, and Anelise Leal Vieira Cubas (2024). Closing the cycle: Circular economy strategies for the textile industry using banana farming waste. Journal of Cleaner Production. 470, 143352, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2024.143352.

Ramesh, M. (2016). Kenaf (Hibiscus cannabinus L.) fibre-based bio-materials: A review on processing and properties. Progress in Materials Science. 78–79: 1-92, ISSN 0079-6425, https://doi.org/10.1016/j.pmatsci.2015.11.001.

Republic of Uganda (2022). Country Statement on the Cotton Sub-sector 2022. Available at: https://icac.org/Content/EventDocuments/PdfFiles522ccdb1_6e0b_4761_8819_8a1b996ee0ae/Uganda%20Country%20Report%202021-22.pdf.

Rodríguez L.J., Orregob C.E., Ribeiroc I. and Peçasc P. (2018). Life-Cycle Assessment and Life-Cycle Cost study of Banana (Musasapientum) fibre Biocomposite materials. Procedia CIRP, Vol. 69 (2018), pp. 585-590, https://doi.org/10.1016/j.procir.2017.11.145.

Sethupathi, M., Khumalo, M.V., Skosana, S.J. and Muniyasamy, S. (2024). Recent developments of pineapple leaf fibre (PALF) utilisation in the polymer composites—A review. Separations, 11(8), p.245. https://doi.org/10.3390/separations11080245.

Sureshkumar, P. S., Thanikaivelan, P., Phebe, K., Krishnaraj, K., Jagadeeswaran, R., & Chandrasekaran, B. (2012). Investigations on Structural, Mechanical, and Thermal Properties of Pineapple Leaf Fibre-Based Fabrics and Cow Softy Leathers: An Approach Toward Making Amalgamated Leather Products. Journal of Natural Fibres, 9(1), 37–50. https://doi.org/10.1080/15440478.2012.652834.

Sauvageon T., Lavoie J.M., Segovia C., Brosse N. (2018). Toward the cottonisation of hemp fibres by steam explosion – Part 1: defibration and morphological characterisation. Textile Research Journal. Vol. 88, Issue 9 (2018), pp. 1047-1055. https://doi.org/10.1177/0040517517697644.

Tausif, M., Ahmad, F., Hussain, U., Basit, A., & Hussain, T. (2015). A comparative study of mechanical and comfort properties of bamboo viscose as an eco-friendly alternative to conventional cotton fibre in polyester blended knitted fabrics. Journal of Cleaner Production, 89, 110–115. https://doi.org/10.1016/j.jclepro.2014.11.011.

Tewari, S., Reshamwala, S.M.S., Bhatt, L. et al. (2024). Vegan leather: a sustainable reality or a marketing gimmick? Environ Sci Pollut Res 31, 3361–3375, https://doi.org/10.1007/s11356-023-31491-8.

Textile Exchange (2023). Preferred Fibres and Materials: Definitions. Initial Guidance. https://textileexchange.org/app/uploads/2023/02/Preferred-Fibres-and-Materials-Definitions-Guidance-Jan-2023.pdf.

Textile Exchange (2024). Materials Market Report. Sept. Available at: https://textileexchange.org/app/uploads/2024/09/Materials-Market-Report-2024.pdf. Accessed: Jan. 20, 2025.

Umesh, Mridul, Sreehari Suresh, Adhithya Sankar Santosh, Samyuktha Prasad, Arunachalam Chinnathambi, Sami Al Obaid, G.K. Jhanani, and Sabarathinam Shanmugam (2023). Valorisation of pineapple peel waste for fungal pigment production using Talaromyces albobiverticillius: Insights into antibacterial, antioxidant and textile dyeing properties. Environmental Research. 229, 115973, ISSN 0013-9351, https://doi.org/10.1016/j.envres.2023.115973.

UN Development Programme (2024). Banana Fibre: An Alternative Textile for People and Planet. Blog article, April 23, 2024. Available at: https://www.undp.org/uganda/blog/banana-fibre-alternative-textile-people-and-planet.

UN Environment Programme (2020). Sustainability and Circularity in the Textile Value Chain - Global Stocktaking. Nairobi, Kenya. Available at: https://wedocs.unep.org/handle/20.500.11822/34184.

UN Environment Programme (2023). Sustainability and Circularity in the Textile Value Chain: A Global Roadmap. Available at: https://www.unep.org/resources/publication/sustainability-and-circularity-textile-value-chain-global-roadmap. Accessed: Jan. 20, 2024.

UN Trade and Development (2018) Cotton and its by-products sector in Uganda. Available at: https://unctad.org/system/files/official-document/sucmisc2017d4_en.pdf.

UN Trade and Development (2022a) Commodities at a glance: Special issue on industrial hemp. Available at: https://unctad.org/publication/commodities-glance-special-issue-industrial-hemp.

UN Trade and Development (2022b). Substitutes for single-use plastics in sub-Saharan Africa and south Asia. United Nations: New York/Geneva. https://unctad.org/publication/substitutes-single-use-plastics-sub-saharan-africa-and-south-asia.

UN Trade and Development (2023). Beyond plastics: A review of trade-related policy measures on non-plastic substitutes. United Nations: New York/Geneva. https://unctad.org/publication/beyond-plastics-review-trade-related-policy-measures-non-plastic-substitutes.

Wagaw T., Babu K.M. (2023). Textile Waste Recycling: A Need for a Stringent Paradigm Shift. AATCC Journal of Research. 2023;10(6):376-385. https://doi.org/10.1177/24723444231188342.

World Bank (2009). The Cotton Sector of Uganda. Africa Region Working Paper Series No. 123, March, 2009. Available at: https://documents1.worldbank.org/curated/fr/983031468108872111/pdf/517120NWP0WPS110Box342044B01PUBLIC1.pdf.