Cultivating Sustainability in Fashion Industry Using Agriculture Residue

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Key Messages

- Fashion is the third biggest greenhouse gases (GHG) emitter industry, contributing between 2 - 7% (1.025-3.29Gt, data for apparel only) of global CO2 emissions.
- Unsustainable practices in the production of clothing, a lack of recycling possibilities partially caused by blend mixing (only 12% of material used in clothing and fabrics is downscaled or cascaded), and limited land available for increasing cotton production call for sustainable alternative raw materials for clothing production.
- Agricultural residue-based fibers can increase the fashion industry's sustainability by reducing the number of non-renewable resources that are currently used (98Mt annually).
- Accounting for over 50% of the world's supply of fibers and 63% of global agricultural value, South and South-East Asian countries show huge potential for the implementation of agricultural residue-based fibers.

The fashion industry is of massive importance when considering future global sustainability. For starters, fashion is the third biggest greenhouse gases (GHG) emitter industry, contributing between 2 - 7% (1.025-3.29Gt, data for apparel only) of global CO_2 emissions[1,2,3]. Currently, most fabrics produced are made from fossil fuel-based fibers (63%) and cotton fibers (26%)[1]. This has major environmental impacts. Annually 0.5Mt of microplastics are released from the laundry of synthetic textiles into the oceans[4]. Additionally, the fashion industry is also a major contributor to water stress, consuming 93 billion cubic meters of water per year[1]. Moreover, in the raw material extraction phase cotton has the highest impact on ecosystem quality due to pesticide use and intensive land use[2]. At the same time, clothing is a key sector of the global economy, valued at $1.3 trillion and employing 300 million people along the value chain[1]. Between 2000 and 2015, clothing consumption doubled, and this trend shows no signs of slowing[1].

It is imperative to transition fashion towards a sustainable industry and one pathway is using next generation materials which are carbon renewable sources[5,6]. 24% of the fashion industry's emissions are accounted for by the raw material extraction phase, evidencing the importance of introducing alternative materials[6]. Research has differentiated three options of renewable carbon sources to produce circular textiles: biomass, recycled content and CO_2 (See Annex 6)[5,6]. Biomass offers the most immediate potential as an alternative feedstock in textile fiber production[7]. It can be used as a raw material input to produce biosynthetic fibers, Man Made Cellulose Fibers (MMCF), as well as plant fibers. However, available arable land for more virgin natural fibers production is scarce due to competing uses such as food and feed production[7,8,9]. As such, the extent to which more virgin natural fibers can be produced for the clothing industry is limited. Nonetheless, crop residues represent a viable biomass source for plant fibers, MMCF, and biosynthetic fibers (See Annex 5), offering an alternative feedstock that can be turned into fabrics[10].

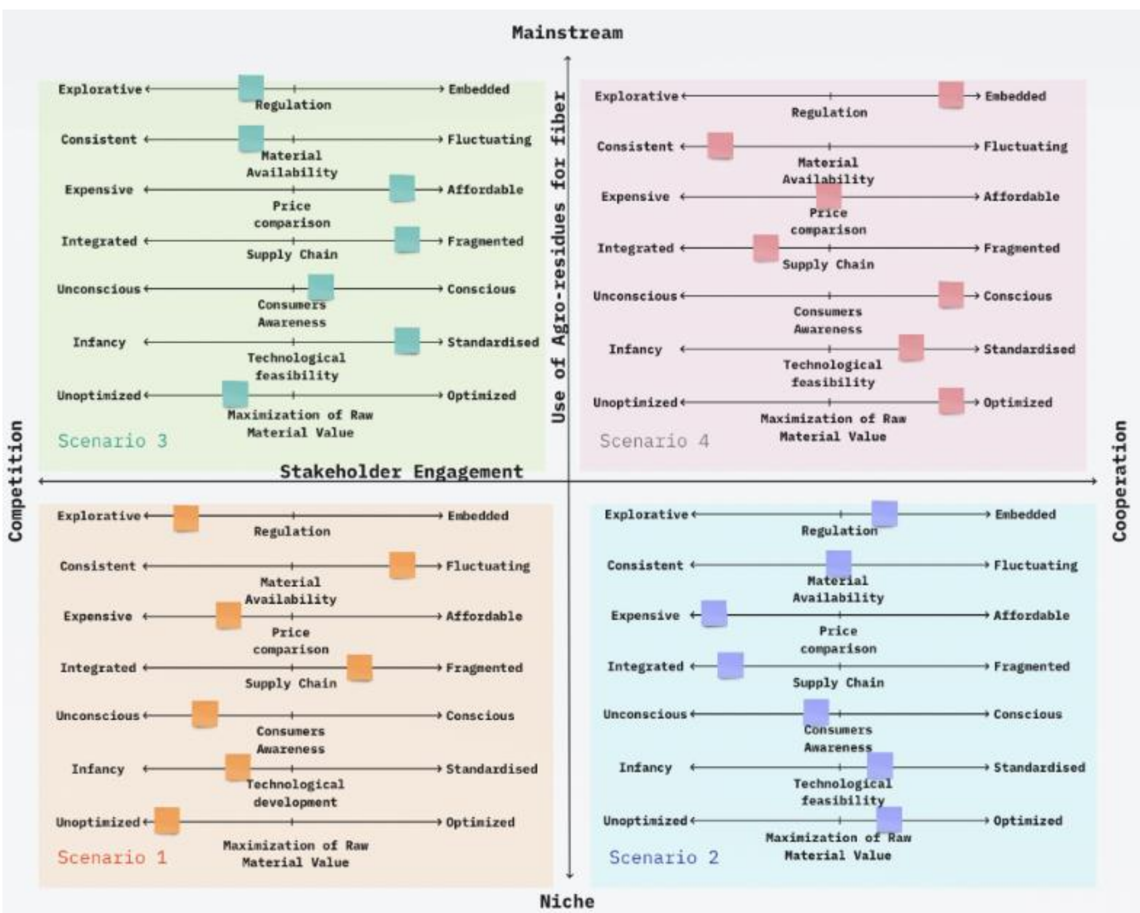
Increased production and consumption in the agricultural sector have led to millions of tons of agricultural residues being generated yearly[11]. The use of agricultural residues as textile fiber feedstock would reduce the dependence on fossil fuels and resource intensive crops and simultaneously provide extra income for farmers[10]. Accounting for over 50% of the world's supply of fibers and 63% of global agricultural value, South and South-East Asian countries show huge potential for the implementation of agricultural residue-based fibers[10]. The share of clothing exports has grown exponentially in countries such as Cambodia, Pakistan, Bangladesh, Vietnam and India[12], representing a strong driver for the region's economic development. The already existing local infrastructure from the fiber manufacturing hubs would also ease the transition towards using agricultural residues[10]. Due to the current cost involved in collection, transportation, and recycling, crop residues are commonly burnt, having negative impacts on air quality, soil and public health[13]. Agricultural residue-based fibers could offer a solution to this harmful low-cost, low-effort waste management practice currently in place[10].

Future Scenario Analysis

The use of agricultural residues to produce fibers is still in its infancy. Literature discussing this technology focusses on the potential it has for implementation and shows evidence that it is not yet commonly implemented[10]. Initiatives like the "Untapped Agricultural Waste Project" by Fashion for Good also shows the industry being in its infancy since this initiative is focused on the technical feasibility of producing natural fibers from agricultural residues[14]. Since the technology is still emerging, there is limited available information on what the implications could be of the use of agricultural residues as textile fiber feedstock. A future scenario analysis was carried out to identify the potential social and environmental impacts of the use of agricultural residues to produce fibers. This analysis also provides useful guidance for stakeholders involved in the industry regarding potential future pathways.

The future scenario analysis outlines the possible pathways of textile fiber production from agricultural residues based on different driving forces. Through research and expert interviews, several driving forces were identified as playing a key role in the future of agricultural residue-based fibers (see Figure 1). The type of interaction between stakeholders and the extent to which production of fiber from this material is upscaled were identified as the two main drivers for the potential social and environmental benefits from the production of agricultural residue-based fibers. Stakeholder engagement is measured on a scale of cooperation to competing against each other. Stakeholder engagement takes multiple forms, from intra-small-holder farmers cooperatives all the way to international alliances steering the industry. The use of agricultural residues for fiber production refers to the degree to which agricultural residues are used in clothing production. Whether this industry remains niche or whether it upscales into becoming mainstream.

Figure 1.



The environmental and societal impacts of the implementation of agricultural residue-based fibers will differ depending on the four different future scenarios (see Annex 2). What follows is an all-compassing view of the different environmental and societal benefits and limitations.

Environmental: The extent to which mainstream sources of raw material (fossil-fuels, cotton) are replaced to varying extents by agricultural residue. As a result, less or more microplastics will pollute the oceans from washing synthetic fibers. Whether there is technological innovation of the processing of agricultural residue into MMCF and natural fibers to ensure low energy consumption, few or no water loss, and no discharge off toxic hazardous waste into water sources. The easiness upon which farmers can collect and store agricultural residue, and a willingness to do so based on sufficient income remuneration to prevent crop burning. Whether agricultural residue use for textile fiber production leads or not to harmful cultivation practices such as mono cultivation and intensive pesticide use.

Societal: Benefits for farmers will be dependent on how many of them gain a new source of income from the sale of agricultural residues. It should also be considered whether the purchase cost of the biomass is fair and whether final payment is received. Another societal consideration is the extent to which clothing made from agricultural residues-based fibers is available for consumers, and the extent to which regulations made to foster this technology limit the availability of clothing. Finally, societal benefits or limitations from the implementation of agricultural residue-based fibers will depend on the working conditions of workers and the types of chemicals used in the raw material processing stage.

Requirements for Agricultural Residue-based Fiber Production

Based on the future scenario analysis, to ensure the potential environmental and societal benefits deriving from the implementation of agricultural residue-based fibers, several requirements were distinguished.

Availability of Agricultural Residue for Textile Fiber Production

To increase environmentally friendly practices in the fashion industry using agricultural residues, it is of importance to ensure a consistent supply of high-quality agricultural residues (see Annex 7). For this, standardization in terms of length, uniformity and durability are needed[10]. Furthermore, the seasonal nature of crops should be accounted for by researching preservation, storage, processing, and densification options[10]. The consistency of crop yields is also dependent on weather conditions, temperature, soil composition, water quality, additive use, pesticides, fertilizers and other chemicals[10]. It is important to consider that future climate variability and extreme weather can impact yields of agriculture in the future, especially in the Global South[10]. Given the economic importance of the agricultural sector, climate variability becomes even more important given the potential societal impacts.

Performance of Agricultural Residue-Based Fibers

Currently, textiles made from agricultural residue do not have the necessary characteristics to act as a replacement for current materials[10]. They lack requirements in terms of softness, stretchability, and flexibility[10]. As such, more innovations are needed, since the production from 100% of a raw material increases potential in biodegradability. However, because requirements are not yet met, blending fabrics remains necessary[10] and since mixed blends can be problematic in the recycling phase, there is a need to identify favorable blends[10,15]. When identified, this can also reduce the possibilities of greenwashing through using agricultural waste in unsustainable blends[15].

Price Comparison of Clothes Made with Agricultural Residue-Based Fibers to Mainstream Materials

To ensure affordable prices for clothes made from agricultural residue-based fibers, financial incentives are needed as well as substantial investments that can favor the reaching of scale economy to ensure lower prices in the long run as production increases[9,10]. Currently, large companies have very strict material budgets[15]. When considering technological profitability, new costs will have to be considered such as additional expenses of raw material collection, storage and transportation, increased quality and durability of clothing. Fair salary for workers and the inclusion of adequate remuneration or partnerships with farmers is also necessary[10,15], since the livelihoods of around 40% – 60% of societies in South and South-East Asia are derived from the agricultural sector[10]. To provide a low-cost transition, agricultural residue-based fibers should fit within existing equipment used in conventional fiber production[10]. However, processing approaches (e.g., viscose) of raw materials into fiber should be improved to reduce the use of hazardous chemicals to improve working conditions.

Maximizing the value of raw material: In most cases, the production of fiber from agricultural residue does not require a 100% use of the raw material[7,10,16]. 10-20% of dry matter from pineapple leaves can be used to produce clothing[17]. To ensure that the production of clothing from agricultural residues has minimal waste, it should be ensured that the remaining residual biomass has an application[17]. When not considering the maximalization of the raw materials, use of agricultural residues can compete with other uses[10]. On the contrary, maximization of the raw materials means that the residual biomass could be turned into a high value organic fertilizer[17]. Which if provided to farmers would ensure the production of agricultural residue-based fibers does not compete with farmers need to ensure good soil health[17].

Policy Recommendations

Based on extensive literature reviews, conversations with experts in the field, and future scenario analysis, the following recommendations can ensure the implementation of agro-residues for the fashion industry.

Create incentives for circular agricultural residue management: Local governments and municipalities should promote a centralized agricultural residue waste management system to avoid crop burning. Farmers should be provided with effective collecting methods and facilities to store agro-residues until collection by textiles manufacturers. The collection and storage of agriculture residue should aim to feed a cellulose dissolving plant with an annual capacity of 500,000 tons.

Agro-textile cooperatives: should be established by the Ministry of Agriculture (or equivalent), which will basically be associations of small-scale farmers in South and South-East Asian countries. These cooperatives can collectively negotiate with agro-textile producers, ensuring fair representation and stronger bargaining power. The Ministry of Agriculture can provide funding, infrastructure, and expertise to initiate and sustain these cooperatives.

Digital platforms created by the national governments: The national governments can create and run a digital platform or apps that can connect small-scale farmers with the agro-textile producers. These platforms can serve as marketplaces, providing information on available technologies, market trends, costs, and facilitating direct communication between stakeholders.

Establish United Nations agency for sustainable textiles: The agency should promote the industry's transition towards the predominant use of carbon renewable sources. International standards developed should encompass various aspects, including the use of sustainable raw materials (like agriculture residue), quality, durability, processing and storage of these materials, energy, and water efficiency, also ensuring safe and fair working conditions. International standards should encourage countries, especially the ones in South and South-East Asia, to adopt them as a part of their national regulations, as this can also help them meet their emissions-reduction pledges.

Promote renewable feedstocks: Policy makers could stimulate demand by incentivizing the use of recycled materials and/or disincentivizing the use of virgin materials. International regulations should address barriers to trade, such as import or export bans. Countries in the global north could implement bans on the import of clothing made of nonrenewable carbon sources as well as unsustainable fiber mixes (EU strategy on circular textiles). Simultaneously countries in the global south could implement bans on the import of textile waste to reduce environmental and social consequences of tons of unrecyclable material.

Increase transparency throughout the value chain: For policymakers, this can be achieved by setting international standards such as eco-labelling, digital product passport, due-diligence regulations or through extending producer responsibility schemes for textiles. The EU strategy for circular textiles can be a leading example in the kind of regulations needed. Other regional international organizations like ASEAN should encourage similar measures to promote sustainable practices in the fashion industry.

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Annex

Annex 1. Interviewed Experts

No.	Institution	Topics	Interview date	Country	Interview date
1.	Anuprerna	Circular economy, social impacts, sustainable materials.	28th November 2023	India	28th November 2023
2.	Wageningen University & Research (1)	Conventional vs next generation textiles fibers.	22nd November 2023	The Netherlands	22nd November 2023
3.	Wageningen University & Research (2)	Sustainable fashion, agro-waste based fibers.	29th November 2023	The Netherlands	29th November 2023
4.	Spinnova	Cellulose extraction technology, environmental impacts.	28th November 2023	Finland	28th November 2023
5.	University of Agriculture Faisalabad: Faculty of Agricultural Engineering & Technology, Department of Fibre Technology	Banana fiber extraction technology, conventional vs next generation materials.	23rd November 2023	Pakistan	23rd November 2023
6.	Green Whisper	Banana fiber textiles, social impacts, sustainable materials.	7th December 2023	France	7th December 2023
7.	Greenport West-Holland	Circular economy, agro-waste potential, investments barriers.	28th November 2023	The Netherlands	28th November 2023

Annex 2. Future Scenario Analysis

Scenario 1 – Startup stagnation: The production of fibre from agricultural residues remains largely unregulated as it is still a competitive niche industry. There is not enough demand nor cooperation between stakeholders to replace crop burning as the most convenient method of disposal. Consequently, large amounts of GHG are still emitted from this practice and air quality remains harmful to local populations. On the other hand, the low demand for agricultural residues for fibre production means it is more readily available for alternate uses like biofuel production. Moreover, cotton and polyester continue to be the biggest sources of feedstock for fibre production which continues to cause environmental havoc from microplastic pollution, and intensive farming. Crop residues are mainly used to produce viscose fibre, which is an environmentally harmful process as well as an unsafe working place for workers due to the toxic chemicals used. The supply of clothes made from agricultural residues is limited and expensive. This means that socially consumers feel unsatisfied about their inability to consume aligned to their values.

Scenario 2 – Socially responsible boutiques: Across the supply chain of agricultural residue-based fibres bottom-up best practices are established as stakeholders actively cooperate. An integrated supply chain means that clothes manufacturers and innovators working with agricultural residue, are closely engaged with smallholder farmers. As such, farmers involved in this industry gain a new source of income which is substantial to their earnings. Nonetheless, only a few of them will enjoy this benefit and as such crop burning is not eradicated. The final materials produced in this scenario will be expensive and likely only affordable in the Global North or to richer communities. The high cooperation between stakeholders catalyses a bigger fightback against greenwashing and increases the demand for better regulations. Nonetheless, the very expensive price of clothes made from agricultural residue-based fibres limits the extent of consumers awareness.

Scenario 3 – Sustainable fast fashion: Agricultural residues are used as a main source for clothing production, but because of a lack of collaboration, sustainability can be affected. The competitive nature in this scenario could result in companies using greenwashing to seem more sustainable than they are but would also cause materials to be more affordable. The demand for farmer-produced agricultural residues would grow resulting in better compensation for the farmers. However, it could also result in unfair agreements because of a lack of collaboration and transparency throughout the supply chain. Due to the competitiveness of the industry technological developmental is very advanced, leading to large productive capacities at low costs. In turn, clothes made from agriculture residues are widely available for consumers. Environmentally, a larger production of fibre from agricultural residue would improve air quality given a reduction in crop burning, lower the GHG emitted during raw materials extraction needed for the fashion industry, and decrease microplastics pollution. Nonetheless, an increase demand for crop residue in an unregulated market may lead to an increase in harmful cultivation practices such as mono cultivation and intensive pesticide use. Additionally, although a larger proportion of clothes are biodegradable given that they are made from agricultural residues, high consumption means that end of life disposal costs impacts is still considerable.

Scenario 4 – Circular agricultural residue-based fiber: The collaboration of stakeholders on both a local and international scale can have the result of embedded regulations that take the environment and social aspects into account. Regulations will limit the use of non-renewable carbon sources in the textile industry which will increase demand for crop residue-based fibers. Additionally, consciousness about the detrimental effects of mixing blends when manufacturing clothes will lead to it being regulated. This, however, will limit the amounts of clothes available for consumption. The lack of competition will create fewer incentives for the fast development of innovations, and this results in the costs of materials reducing at a slow pace. The higher prices of mainstream materials may cause the need for a shift in consumption, becoming less. High levels of collaboration means that agricultural residues value is maximized in the processing stage through a cascading of different valorization options. This means that the parts of the crop residue which are not used for fiber production are turned into a high value organic fertilizer and returned to the farmer for maintaining soil conditions.

Annex 3. Case Study – Maleema – Making the fashion industry of India more sustainable

The initiative began with Srinithya and Jaya, two siblings from the southern state of Tamil Nadu, India who aimed to enhance sustainability in the fashion industry by creating and manufacturing biodegradable clothing. They founded Maleema, a sustainable fashion brand in India that initially started by producing breathable, lightweight, and biodegradable scarfs and unisex T shirts using banana fibers that they locally sourced from their farmers and processed in their production units. Today they have scaled up to being India's most loved fashion brand that uses eco-friendly materials and ethical production practices to create stylish and affordable clothing, accessories, and other home décor products. Apart from using banana fibers in their clothing, they use other agricultural residues like cork, hemp, coconut leather, pineapple leaves, sisal fibers to produce a wide range of affordable products like passport covers, laptop sleeves, crossbody bags wallets belts clutches, dresses, shirts, pants, socks, kitchen towels, laundry baskets, straw cleaners, and bath scrubs to mention a few. These products are available in a wide range of designs, styles and colors and have created job opportunities for over 2000 people in the rural areas in India, along with creating job opportunities for several artisans and small businesses.

Annex 4. Glossary

Agricultural residues (or waste): To the scope of this policy brief, agricultural residue is defined as waste left over after cultivating and processing agricultural products like fruits, vegetables, and grain.

Crop residues: to the scope of this policy brief, "crop residues" is used as a synonymous term to agricultural residues.

Raw extraction material phase: We refer to the sourcing of raw materials from which textiles fibers are made. In the case of synthetic fibers raw material extraction implies drilling and fracking to extract oil (fossil fuel). If the textile fibers are crop based, plants (cotton, hemp, flax, etc.) are cultivated following conventional agricultural practices with the only scope of producing textiles. Man-made regenerated fibers are forestry-based; therefore, they derive from the extraction of cellulose from trees. Animal fibers (leather, wool, silk) are protein-based fibers from mammals, insects, or birds.

Fossil-based fibers: these are synthetic fibers made by polymerization of monomers to polymers in an industrial process. As of now, synthetic fibers make up 63% of global textile fibers production with the most common being polyester (PET), thanks to the combination of low prices, due to its long existence on the market, and desirable properties (stretchy, durable, waterproof).

Crop-based fibers: vegetable fibers, cellulose based on vegetable origin like seed fibers (e.g. cotton), bast fibers (e.g. linen or hemp). Cotton is the most common natural fiber thanks to its structure (length, strength) that ensures an easy spinning process of cotton fibers into yarn. Furthermore, cotton is soft, breathable, and machine washable.

Regenerated Man-made cellulose fibers (MMCF): forestry-based textile fibers (viscose and lyocell). In this case, cellulose is extracted from biomass. This is a long process that requires consistent amounts of chemicals and for these reason companies are in search of non-toxic solvents or mechanical extraction processes.

Fibers blends**:** to enhance fibers properties or achieve nowadays, most textiles are made of different fibers blended in the same fabrics. A single-component textiles often doesn't fulfil the requirements of the consumers, for this reason, fibers are combined to combine the best qualities of different fibers (e.g. mixing elastane with cotton to make stretchy jeans or mixing wool with PET to achieve lower prices).

Greenwashing: as concerns about the environmental impacts of the fashion industry rise, brands have been discussing their unsustainable practices through "greenwashing" their customers. Eco-friendly labels, recycled PET and sustainable cotton have been advertised. However, the ultimate scope of these more sustainable practices isn't true environmental engagement, simply a new marketing strategy to reassure consumers and adapt to their needs. This way brands can keep over-producing, and customers over-consume without guilt.

Annex 5. Agricultural Residue Implementation

It is important to consider to what extend agricultural residue-based fibers can replace current mainstream materials. The high potential of agricultural residue- based fibers lies in the versatility of this alternative feedstock. Different extraction processes can lead to different types of fibers, therefore different applications:

1. MMCF: Regenerated cellulose fibers and cellulose derivatives can be made from all types of biomasses containing cellulose, but up till now mostly wood or cotton. Depending on the initial cellulose content in the biomass, minor or major processing is required to obtain a cellulosic fiber that can be used as a textile fiber.
2. Natural fibers: in this case, a mechanical process is used to extract the fibers from the stem or leaf of the plant. The fibers, after been washed to remove impurities and dried, undergo a process that allows these fibers to be spinned like conventional plant fibers (cotton). In this case, the fibers obtained will resemble the properties of cotton (strength, water absorption, softness...)
3. The issue with the first two fiber production processes is that they alone are not able to provide an alternative to fossil fuel feedstock-based fibers. PET is praised for being durable, waterproof, stretchable, and insulating. Lately innovators have been exploring biobased synthetic fibers to provide valid alternatives to PET. This can happen through the extraction of glucose from biomass (mostly sugarcane or corn).

Annex 6. Renewable Carbon Sources

To produce sustainable textiles, it is needed to a) reduce the use of virgin resources; b) phase out of fossil resources c) prevent the release of harmful microfibers to the environments. It is important that the new resources fit in the existing infrastructure of textile production to ensure a smooth and rapid transition towards more sustainable materials.

Now almost 65% of our textiles come from fossil resources, and only 35% is made from biomass (plant based or animal based). When we look at alternative feedstocks, it is important to make sure that they are sources of renewable carbon, which leaves us to three options: CO2, recycling, and biomass.

- CO2 offers potential as a renewable carbon source, however, technologies in this area are not advanced yet, meaning the scale to which CO2 can be turned into fiber is very limited because CO2 is an inert gas, thus it is difficult to convert to other molecules. After CO2 is captured, high levels of energy are required to isolate molecules are isolated into monomers.
- Recycling: in this case post-consumer textiles are the renewable carbon source. Depending on the recycling technology used (mechanical, chemical or physical) different intermediate structures can be obtained (fibers, monomers or polymers).
- Biomass offers the most opportunities as a renewable carbon source. It is the most conventional way of obtaining textile fibers. However, to produce sustainable textiles we need to broaden our use and scope to less familiar biomasses such as agricultural residues. According to FAO 38% of the global land surface is dedicated to crop cultivation, meaning that there is a vast source of feedstock for this technology. However, land is limited which means that competition over crop use with other sectors (fuel, energy, bio-based materials) might be a barrier to scaling up agricultural-residues based fibers.

Annex 7. Priority Matrix for Agricultural Residues with Optimal Promise for Commercialization

In the report Spinning Future Threads [10], several agricultural residues are researched across various countries in South and South-East Asia. The following priority matrix shows a scoring from 1 to 100 of eight crop sources for agricultural residues. The scoring is based on nine dimensions for suitability and feasibility for the uptake of the specific agricultural residue as fiber feedstocks. Their findings were that rice straw and risk husk show the biggest potential across South Asian and South-East Asian countries.