Journal of Textiles, Coloration and Polymer Science
https://jtcps.journals.ekb.eg/
Egyptian Society for Textile Science and Technology
الجمعية المصرية لعلوم وتكنولوجيا النسيج

Environmental Sustainability and Innovations in the Fashion Industry

Roba E. Glal Al-Den [a], Sherine S. Abdel Wahab [a], Hager A. Atallah [a], Yousra D. Mohamed [a] and Ahmed G. Hassabo [b]*

[a] *Clothing and Fashion Technology Department, Faculty of Applied Arts, Benha University, Benha, Egypt.*
[b] *National Research Centre (Scopus affiliation ID 60014618), Textile Research and Technology Institute, Pre-treatment, and Finishing of Cellulose-based Textiles Department, 33 El-Behouth St. (former El-Tahrir str.), Dokki, P.O 12622, Giza, Egypt.*

Abstract

The idea of environmental sustainability holds that human consumption of natural resources from the earth's ecosystem must occur at a pace that permits self-renewal. For manufacturers and brands, cutting back on water use, packaging waste, carbon footprints, and environmental impact is a constant goal. Companies have discovered the financial benefits of these sustainable initiatives. For instance, restricting the amount of materials used in packaging usually lowers the materials' overall cost. The textile industry makes a substantial contribution to foreign exchange earnings, global economic growth, and the creation of goods required to ensure human welfare. There are 300 million workers in the textile industry, many of them are women. In the global ecology, natural resources are scarce, so it's critical to use them carefully. Sustainability plays a major role in this prudent use. To build a better future, brands and consumers must work together. Practically speaking, choosing greener options can reduce carbon footprints. Another important option is the circular economy, which emphasizes recycling and minimizing waste. The textile and apparel industries can no longer be regarded as sustainable simply by using organic ingredients and efficient processes. The fifth least sustainable industry is thought to be the textile and fashion sector, which accounts for 5.4% of global pollution. From raw materials to completed goods, it has a significant negative impact on the environment. Every stage of the manufacturing process generates waste, so sustainability is urgently needed. Even though natural materials (such as cotton, hemp, jute, etc.) are thought to be sustainable, producing them calls for a sizable quantity of water and agricultural land. Most consumers think that using natural textiles helps to preserve the environment. Various sources, however, present the opposite information and demonstrate how highly polluting it is to manufacture natural fibre, such as cotton. Synthetic fibre production is dependent on non-renewable resources, and high-energy machinery is used in the extraction process. Polyester is the most widely used synthetic material in the fashion industry, and its production necessitates high temperatures and a lot of water for cooling. The leather industry not only causes harm to animals but also accounts for 15% of greenhouse gas emissions caused by humans. The tanning process of leather requires a significant amount of water and chemicals. Research is being done to find sustainable alternatives to current materials to mitigate their negative environmental effects. The objective of this chapter is to examine and compile the most recent, environmentally friendly, innovative materials and their technologies for the fashion sector. Additionally, an assessment of those materials' commercial viability in terms of technology and cost will be conducted.

Keywords: Environment, the fashion industry, recycling, textile , Textile waste , sustainability , Sustainable fibers , Organic , fibers , Renewable.

Introduction

Among other things, the coronavirus pandemic has taught us that society needs to be rebuilt, but in a more equitable and ecological manner. In order to accomplish this, we also need to transform the textile and fashion industries, which generate enormous volumes of waste annually. However, what exactly is waste textile? When clothing is no longer worn and becomes waste, it reaches the end of the textile industry's value chain. At this point, the major players in the industry have begun to express

* Corresponding author: Ahmed G. Hassabo, E-mail: aga.hassabo@hotmail.com, Tel. 00201102255513
Received date: 31 December 2023, **Revise Date**: 21 February 2024, **Accept Date**: 25 February 2024
DOI: 10.21608/jtcps.2024.259736.1314

interest in recovering sizable amounts of waste and recycling or reusing it.[1]

Experts rank the oil industry as the primary source of pollution, with textile waste coming in second. Romanians purchase 60% more clothing than they did in the early 2000s, far more than they actually need, and wear and keep their clothing for far too short a time. The objects that present our bodies in public and convey a lot about us—our personal preferences, the image we want to project of ourselves, our compliance with social norms, and perhaps even our social and economic standing—clothes serve as a symbol of the intersection of the public and private spheres. A closer look can "see" how a garment was put together, what kind of fibers it is made of, how much plastic it contains, how far it has traveled to get to us, and the appearance of the factory where it was made. 7,000 liters of water were even used for something as simple as a pair of jeans! That's the water a man has consumed for nearly a decade!

Additionally, 2 billion pairs of jeans are made annually. In the production process, 2,700 liters of water are required for a T-shirt! Water is just one of the materials required to make clothing, though. According to the industry, 400 billion square meters of textiles are dyed each year using 1.7 million tons of chemicals. However, Greenpeace claims that only 340 billion square meters are really utilized. The EU, which estimates that between 10% and 20% of the textiles produced are wasted, only validates the data.[1]

The Clothing Industry's Effect on the Environment

Among the top five industries that pollute the environment the most is the fashion industry. This figure highlights how crucial it is to comprehend the processes involved in the creation, use, and disposal of clothing. Profit margins are the primary concern for many businesses, with little regard for the consequences of producing enormous amounts of waste. Businesses will go with the less expensive option if they can reduce the cost of the clothing without compromising environmental quality. A significant portion of the issue stems from the fact that, despite the issue's identification, no steps have been taken to create regulations that would hold businesses responsible for their pollution rates. Customers are also a part of the issue, not just the businesses. Because new lines and styles are released every week, consumers are led to believe that they are constantly in need of new clothing. We are taught to view consumption in this way, but most consumers are unaware of the ways in which this way of thinking is damaging the environment. Businesses must alter their production processes to address this problem, and consumers must become aware of the effects on the environment and modify their consumption patterns.[2]

According to data from the Technical Textile Markets, the demand for synthetic fibers, particularly polyester, has almost doubled over the past 15 years due to the fashion industry's increased output. The energy-intensive process of making polyester and other synthetic fabrics uses a lot of crude oil and emits pollutants like particulate matter, hydrogen chloride, and volatile organic compounds, all of which can worsen or cause respiratory diseases. Wastewater from polyester manufacturing facilities contains volatile monomers, solvents, and other byproducts of polyester production. According to the Resource Conservation and Recovery Act, the EPA classifies a large number of textile manufacturing facilities as producers of hazardous waste.

Environmental health and safety concerns are not limited to the manufacturing of synthetic textiles. One of the most widely used and adaptable fibers in the production of apparel, cotton, has a big impact on the environment. According to the USDA, this crop makes up 25% of all the pesticides used in the US, which is the world's largest exporter of cotton. Subsidies help the cotton crop in the United States by maintaining high production and low prices. One of the first cogs in the globalization of fashion is the large production of cotton at low, subsidized prices.[3]

The World Method A large portion of the cotton produced in the US is exported to China and other nations with cheap labor, where it is processed into fabrics, cut, assembled, and milled in accordance with fashion industry standards. The UN Commodity Trade Statistics database shows that China is now the world's top exporter of fast fashion, making up 30% of global apparel exports. Pietra Rivoli, a Georgetown University professor of international business and author of The Travels of a T-Shirt in the Global Economy (2005), estimates that Americans buy about 1 billion Chinese-made clothes annually, or four pieces of clothing for every citizen of the country.[3]

The U.S. National Labor Committee reports that some Chinese laborers earn as little as 12–18 cents an hour while working in subpar conditions. Additionally, many emerging economies are vying for a piece of the global apparel market despite the fact that doing so may result in lower wages and unfavorable working conditions for employees due to the intense competition on a worldwide scale that drives down production costs. The United States is importing a growing amount of clothing from diverse nations like Bangladesh and Honduras.[3]

According to a September 2006 report by consultant Oakdene Hollins, Recycling of Low Grade Clothing Waste, an estimated 21% of annual clothing purchases remain in the home after being made,

increasing the stocks of clothing and other textiles held by consumers. According to the report, this stockpiling amounts to a rise in the "national wardrobe," which is thought to indicate a sizable amount of latent waste. September 2007, Volume 9, Number 9. A 450 • Perspectives on Environmental Health Emphasis | Waste Management Mike Donenfeld/Shutterstock and Zed Nelson/Panos Pictures, from left to right There is a chance that every stage of the clothing production process will have an effect on the environment. For instance, conventionally grown cotton, one of the most widely used materials for clothing, is also one of the crops that depends most on water and pesticides (a claim that is refuted by Cotton Incorporated, a U.S. cotton growers' organization). A number of toxics may be present in effluent at the factory stage (see the waste products from a Bangladeshi garment factory spilling into a stagnant pond above). These pollutants will eventually find their way into the solid waste stream. The EPA Office of Solid Waste reports that each American discards over 68 pounds of clothing and other textiles annually, accounting for approximately 4% of municipal solid waste. However, this number is rising quickly.[3]

According to the 2018 Report on Microplastics by the UN Environment Program, marine plastic pollution is pervasive and harmful to marine life. 2010 saw between "4.8 and 12.7 million metric tons of [land-based] plastic" enter the ocean, which had a detrimental impact on creatures and ecosystems.[4]

Plastic is mistaken for food by animals, which can result in poisoning, organ damage, and starvation. When fish consume microplastics, the plastics accumulate higher up the food chain where they are eventually consumed by humans and other apex predators. Furthermore, game fish, dolphins, pinnipeds, seabirds, whales, and turtles are still caught in nets that commercial fishing boats discard. These animals become entangled, strangled, and eventually drowned in these ghost nets that drift around. Nowadays, plastic pollution has been discovered in every ocean basin, along every shoreline, and from the ocean's surface to the lowest seafloor. Put another way, it is destroying every marine ecosystem.[4]

There are five main ocean basins on Earth, and each one has gyres, which are ring-shaped surface currents. Garbage patches are produced when these gyres concentrate floating plastic pollution in their centers. This is an artificial problem brought about by society's inappropriate disposal of plastic waste and insufficient recycling efforts, coupled with the world's ever-increasing production of plastic. Plastic floating in these gyres ranges in size from nanometer-sized microplastic particles to miles-long fishing nets. Many people live their lives surrounded by plastic, but because of poor management practices and inappropriate disposal, plastic can wind up in the ocean and cause extensive harm to marine ecosystems.[4]

Textile waste.

Owing to the large amount of textile waste generated globally, textile recycling and reuse can be a viable way to lessen the amount of solid waste that ends up in landfills, as well as a way to cut down on energy use, the production of virgin materials, and the environmental impact. This essay discusses the significance of recycling textile waste from an environmental, social, and technical standpoint and highlights several strategies for repurposing it. In addition, a few technical uses of waste textiles have been examined to shed more light on the circular economy approaches to sustainability taken by the textile and fashion industries.[5-11]

Due to population growth and economic development, there is a steady increase in the demand for textile products worldwide. This trend is expected to continue. In the meantime, the textile sector is struggling with severe resource and environmental issues. Sixty-three percent of textile fibers come from petrochemicals, the production of which and its eventual disposal result in significant emissions of carbon dioxide (CO2). The majority of the remaining 37% is made up of cotton (24%), a thirsty plant linked to toxic pollution from heavy pesticide use as well as water depletion (the Aral Sea's desiccation is the most famous example). More extensive effects are produced at later stages of the textile production process for the majority of environmental impact categories. The spinning of yarns and the weaving or knitting of fabrics are two common processes that use fossil fuels, which results in emissions of particulates and CO2. Wet treatment processes (dying, finishing, printing, etc.) are also major sources of toxic emissions. According to Allwood et al. (2006), the primary environmental problems facing the textile industry are waste, hazardous chemicals, water use, and greenhouse gas emissions. Sandin and associates. (2015) estimate that in order for the clothing industry to be deemed sustainable in relation to the planetary boundaries outlined by Steffen et al. (2015), the impact per garment use in a western country (in this case, Sweden) must be reduced by 30–100% by 2050 for several environmental impact categories. (2016) demonstrate that such a significant shift necessitates a variety of impact-reduction strategies, most likely involving increased reuse and recycling.[6, 12]

A topology for recycling and reusing textiles.

Reusing textiles includes a variety of techniques for giving them to new owners, either modified or not, in order to extend their useful life. One way to do this is by renting, trading, swapping, borrowing, and inheriting. These methods can be made easier

by places like thrift stores, flea markets, garage sales, internet marketplaces, charitable organizations, and clothing libraries. Different types of reuse have been conceptualized in academic literature using terms like access-based consumption, product-service systems, collaborative consumption, and commercial sharing systems. Conversely, repurposing pre- or post-consumer textile waste for use in new textile or non-textile products is commonly referred to as textile recycling. In this work, we take a more expansive view of textile recycling, encompassing the recycling of non-textile products and materials (like PET bottles) into textile products.[12]

The three main categories of textile recycling routes are mechanical, chemical, and, less frequently, thermal. This is frequently an oversimplification of the situation, since recycling routes frequently involve a combination of thermal, chemical, and mechanical processes. For instance, when we talk about chemical recycling, we usually mean a recycling process where the polymers are either dissolved (for natural or synthetic cellulosic fibers like cotton and viscose) or depolymerized (for synthetic polymer fibers derived from petrochemicals, like polyester). Thus, after being disassembled to the molecular level, polymers are resound into new fibers and monomers or oligomers are repolymerized. However, the recycled material is typically mechanically pretreated before the depolymerization or dissolution. Furthermore, thermal recycling frequently refers to the process of turning PET flakes, pellets, or chips into fibers through melt extrusion; however, because the flakes, pellets, and chips were created mechanically from PET waste, this recycling method is also known as mechanical recycling. Moreover, it is common to mistake the term "thermal recycling" for "thermal recovery," which is the process of burning textile waste to produce heat or electricity. To make matters more complicated, recycling is sometimes used to refer to incineration with energy recovery, even though in this paper we are focusing only on material recycling. Thus, it is unclear and dubious to systematize recycling routes into mechanical, chemical, and thermal ones. The current paper systematizes recycling routes according to the degree of disassembly of the recovered material, rather than the type of process involved. Fabric recycling is the process of recovering and reusing a product's fabric to create new products (sometimes this is referred to as material reuse). Fiber recycling occurs when the fabric is disassembled but the original fibers are kept.[6][12]

Polymer/oligomer recycling occurs when the fibers are broken down but the polymers or oligomers are kept intact. Moreover, monomer recycling occurs when the monomers are retained while the polymers or oligomers are broken down. Next, there are numerous.

It's also important to discuss other recycling route classifications. Downcycling, for instance, occurs when the recycled material is of lesser value (or quality) than the original product. The majority of current textile recycling methods involve downcycling. Textiles from clothing and homes are recycled into things like upholstery, low-quality blankets, industrial rags, and insulation (Schmidt et al., 2016). Upcycling, on the other hand, is the process of creating a product out of recycled materials that is more valuable or high-quality than the original. Fabric and fiber recycling generally results in materials of lower quality (if quality is defined in terms of fiber quality) than materials made from virgin fibers (unless mixed with yarn from virgin fibers), as wear and laundry reduce the length of the fibers and the constituent molecules. [12]

Because of this, recycling fabric and fiber is generally regarded as downcycling (at least in terms of fiber quality; certain end products made from recycled fibers or fabrics may still be regarded as upcycled in terms of other end product qualities, such as aesthetics, fit-for-purpose, or material qualities defined by fabric construction). On the other hand, recycled monomers, oligomers, and polymers usually produce fibers that are just as high-quality as virgin fibers. It is important to note that, despite being examples of downcycling when it comes to fiber quality, recycling of fiber and fabric is not always less desirable than recycling of polymers, oligomers, or monomers from the standpoint of the waste hierarchy. On the other hand, a cascade strategy might be the best option, whereby the waste textile is first recycled as fabric or fiber, and then it is recycled as polymer, oligomer, or monomer once the length of the fiber is lowered to the point where the material is unsuitable for recycling as fabric or fiber.[12]

Recycling routes can also be categorized as closed- or open-loop recycling. Open-loop recycling, also known as cascade recycling, describes procedures in which the material from a product is recycled and used in another product. Closed-loop recycling, on the other hand, refers to the use of recycled materials in a (nearly) identical product. Depending on the context, a particular recycling path may be referred to as either closed- or open-loop recycling. This is because the term "product" can here refer to various degrees of refinement. For instance, a fiber or fabric that is a product in a business-to-business setting might not be in a retail or consumer setting (where clothing is a major category of textile products). According to the latter perspective, closed-loop recycling depends on certain conditions being met, such as a T-shirt being recycled back into another T-shirt or even a T-shirt of a specific size, color, and—possibly most important-

ly—quality (such as fiber length). A more lenient definition of closed-loop recycling, on the other hand, might include recycling a material category—like packaging—into the same material category as opposed to another—like textiles, as in the case of the previously mentioned bottle-to-fiber recycling.[12]

Sustainability

The concepts of sustainability and global warming, internationalism, conservationism, and social justice have all gained traction in recent years. Sustainability necessitates environmental preservation, social responsibility, and a society that strikes a balance between human and natural systems. Globally, societies today struggle with social, economic, and environmental issues. This is the reason why academics and practitioners are becoming interested in the sustainability principles. Generally speaking, sustainability refers to the procedures or actions that make it easier to mitigate the loss of natural resource availability and to preserve ecological balance globally. Every industry is affected by the idea of sustainability, including the textile, agricultural, urbanization, infrastructure, water availability, energy use, and transportation sectors.[9, 10, 13-17]

The urban population has significantly increased globally since the industrial revolution. Many families and both skilled and unskilled workers are drawn to urban areas in search of improved job prospects, a better quality of life, a higher standard of living, better education, better infrastructure, sustainable transportation, and other benefits. Growth in urbanization was observed first in America, Europe, Africa, and Asia's larger megacities .[13]

According to data from the United Nations, the number of people living in cities has been rising steadily over the past century. Due to economic growth, better urban infrastructure, and adequate employment opportunities, people are migrating from rural areas to urban areas. In the upcoming years, about 1.1 billion people in Asian countries will move from rural to urban areas in search of better opportunities (UN Environment Program, n.d.). Approximately 70 million people, or 55% of the world's population, reside in urban areas.

According to UN estimates, by 2050, 70% of the world's population—roughly 6.3 billion people—will live in urban areas, making up two thirds of the global population (United Nations Water and Urbanizations n.d.). Approximately 60% of the world's Gross Domestic Product (GDP) is produced by 600 major cities. Globally, cities account for about 85% of GDP in developed nations and 55% of GDP in developing nations. Urban areas account for 80% of GDP in the Asia Pacific region, which promotes economic expansion and eventually raises living standards. [13]

By 2050, an estimated $20 trillion more will be invested annually in buildings and urban infrastructure. Over 75% of the world's natural resources, including energy, food, water, raw materials, and fossil fuels, are consumed by urban centers worldwide. Eco-cities, or green cities, are other names for sustainable cities that prioritize the triple bottom line—the social, economic, and environmental spheres.[13]

Pillars of sustainability

Environmental Sustainability

Environmental sustainability holds that natural resources from the planet's ecosystem must be used by humans at a rate that permits self-renewal. Most of the time, the environmental aspect is given the most attention. For manufacturing companies and brands, lowering their water consumption, carbon footprints, packaging waste, and environmental impact is a constant goal.

Corporations have discovered the financial benefits of these sustainable initiatives.

For example, reducing the amount of materials used in packaging usually means paying less overall for those goods.[18]

Economic Sustainability

This pillar is responsible for guaranteeing global economic stability and universal access to resources like steady sources of income. People may also maintain their independence and have access to the resources they require to meet their basic needs.[18]

Social Sustainability

Social sustainability recognizes that just officials who respect individual, cultural, and labor rights and treat everyone equally are traits of thriving communities. People are protected from bigotry. Universal human rights and basic needs are available to everyone.[19]

Why Sustainability Is Important?

1. Reduced energy use: The use of renewable energy sources, such as solar and wind energy, is emphasized in sustainable cities and societies. It is possible to lower long-term energy costs by implementing sustainable practices. Monthly utility bills are decreased by using energy-efficient solar and wind energy equipment.
2. Healthy living for everybody: A sustainable city and society promote a healthy lifestyle for people by emphasizing clean water, food purity, waste management recycling, and a decrease in CO2 emissions into the atmosphere.
3. Better living conditions: The mass population now enjoys better living conditions as a result

of the sustainable city and society, the affordable housing market, the use of electricity, the construction of sustainable buildings, planned construction, and the use of sustainable materials. Social equality and a higher quality of life depend on opportunities, institutions, and resources being available and accessible to all.[13]

Sustainable textiles

Sustainable textiles are those that, throughout the whole product life cycle, are safe and healthy for people and the environment, and that source all of their energy, materials, and process inputs from recycled or renewable resources. It might also imply that.

All phases of the product life cycle have the potential to improve social well-being, and materials can be safely recycled back into industrial or natural systems. Sustainable textiles refer to methods for developing more environmentally friendly materials and technologies as well as ways to enhance industry recycling. In the context of textiles, sustainability is the use of resources without depleting them.[20]

In all stages of the product life cycle, all materials and process inputs and outputs are safe for the environment and human health. This is the definition of sustainable textiles.

- All inputs—materials, energy, and processes—come from recycled or renewable resources.
- Every material can safely reintegrate into industrial or natural systems.
- Every phase of the product life cycle actively promotes the highest caliber of repurposing or recycling of these materials.
- Every stage of a product's life cycle improves society's well-being.

Sustainable fabrics and textiles are essentially produced with limited impact to the environment and community and can be categorized in the following ways :

- Organic: A crop grown with the use of biofertilizers and organic manures, among other organic agricultural practices. Hemp, organic cotton, and organic ramie/jute (linen) are some examples of crops that are grown without the use of pesticides, chemicals, or artificial fertilizers. Natural Wool may be included in this category if the sheep were raised on "organic" land and organic pigments were used to produce and color the finished yarn.[20]
- Eco Textiles: According to organizations like OEKOTEX, IFOAM, etc., an eco-friendly textile product is one that is manufactured with care and processed within environmentally friendly parameters. Based on the method of cultivation, natural fibers like organic cotton, hemp, jute, and ramie are regarded as eco textiles.
- Recycled and biodegradable: Textiles that can be broken down into smaller pieces to create new textiles or turn into fibers, as well as natural and synthetic fibers.
- Textile Processing and Sustainability: A few procedures, such as those related to spinning, dying, printing, and finishing, need to be taken into account in order to create sustainable fabrics and textiles. In general, textile processing is better for the environment when it uses less energy, water, chemicals, and effluent disposal.
- Purchase and Produce Locally.[20]

Sustainable fibers

Many people believe that an organic or natural fiber qualifies as a "sustainable fiber." Any artificial fibers that harm the environment on the ground will be rejected by them. However, because they require fewer resources than "natural fibers," some synthetic or man-made fibers may be more sustainable than those found in nature.[20, 21]

The discussion surrounding the sustainability of natural fibers primarily centers on the amount of water and energy used in their production. Hazardous chemicals are frequently used, which not only harm the environment but also cause thousands of deaths annually if the fibers are not organic. If the energy source is non-renewable, the amount of energy required to convert plant cellulose—such as that found in cotton or ramie—into fiber can be enormous and extremely harmful. Growing natural fibers uses a lot of water, which frequently leaves others without access to clean water and can contaminate nearby soil and render it unusable.

The main obstacles to sustainable fiber production differ depending on the material, so it's critical to evaluate each step of the process, the resources used, and the effects. Some of these include the large amounts of energy and non-renewable resources used in the production of synthetic and cellulosic fibers, the emissions released into the air and water during this process, and the negative effects on water quality associated with the production of natural fibers.

The main sustainability issues in the production of fiber vary depending on the type of material, so it's critical to evaluate.

The main sustainability issues in the production of fiber vary depending on the type of material, so it's critical to evaluate individual procedures, resources used, and effects. Some of these include:

- the substantial energy and non-renewable resource consumption for synthetics.
- the emissions to air and water from the production of synthetic and cellulosic fibers.
- the negative effects on water associated with the production of natural fibers.

The Man-Made Fibers (MMF) Industry, in particular, has a long history of pursuing sustainability-promoting initiatives. Since 1992, manufacturers of synthetic fibers have implemented the responsible care program, which has been embraced by numerous nations.[21]

Like any other product, the sustainability of man-made fibers is determined by the amount of energy, raw materials, and other resources consumed as well as by the emissions of solid, liquid, and gaseous waste products. It is important to remember that significant environmental savings can be achieved during both the in-use and disposal/recycling phases. Enhancing the sustainability of synthetic fibers serves as the foundation for enhancing ecological, financial, and societal outcomes.[20]

How can the textile and fashion industry go green.

There are other ways the fashion industry can go "green" and safeguard the planet's natural resources and future than just using organic fabrics. Businesses must also practice fair trade, fair labor, and increased ethics; this is known as "ethical and environmental awareness".

This indicates that businesses are building safe working conditions for the laborers from whom they obtain their materials, paying a fair price, and providing fair employment opportunities. In addition, they are "engaging in environmentally sustainable practices, making sure that product quality is maintained, honoring cultural identity as a stimulus for product development and production practices, offering business and technical expertise and opportunities for worker advancement, contributing to community development, building long-term trade relationships, and being open to public accountability."[22]

In this regard, organic and recycled fashion can both support environmentally friendly, sustainable development:

Recycling

"Recycling is the term used to describe textiles that have been discarded by customers, retailers, or nonprofit organizations and have been carefully sorted, graded, and separated into waste-free products that can be used again." Designers breathe new life into recycled apparel and organic materials to create stylish dresses, skirts, jackets, pants, and other items that appeal to and fit the needs of the customer.

Both the fashion industry and the public had to take some action. It is imperative that the fabrics be recycled and used in a reversible way. This will prolong the fabric's life and relieve farmlands of the burden of producing large quantities of cotton, say, through chemical growth.[20]

Organic

For textiles to be considered organic, they must be manufactured organically or derived from natural sources like plants or animals. Either environmentally friendly dyes or dyes derived from plants or minerals should be used on organic apparel. The dyeing process should not involve the use of heavy metals or any other dangerous chemicals. Every facet of the organic apparel market should be approached with a conscience for the environment and ethics.[20]

Natural fibers

The growing "green" economy, which is predicated on energy efficiency, the use of renewable feedstocks in polymer products, industrial processes that lower carbon emissions, and recyclable materials that reduce waste, will all heavily rely on natural fibers.

Natural fibers are the epitome of a renewable resource, having been replenished for millennia by both human ingenuity and the natural world. Additionally, because they absorb the same amount of carbon dioxide as they produce, they are carbon neutral. They mostly produce organic waste during processing, but they also leave behind residues that can be used to create sustainable housing materials or energy. When their life cycle comes to an end, they are completely biodegradable.

While the processing of some natural fibers can result in high levels of water pollutants, the pollutants are mostly biodegradable, unlike the persistent chemicals—including heavy metals—released in the effluent from the processing of synthetic fibers.

According to more recent research, the production of one tone of polypropylene, which is extensively used in packaging, containers, and cordage, releases more than three tons of carbon dioxide, the primary greenhouse gas that causes global warming, into the atmosphere. Jute, on the other hand, absorbs about 2.4 tons of carbon for every ton of dry fiber.

In terms of life cycle disposal, natural fibers truly shine. Because natural fibers absorb water, fungi and bacteria cause them to decay. Natural fiber products can be burned without releasing any pollutants, or they can be composted to enhance soil structure. Conversely, synthetic materials present a variety of disposal challenges to society. They contaminate soil and groundwater with heavy metals and other substances. Recycling necessitates expen-

sive separation, and burning generates pollutants. For every tone of burned material in the case of high-density polyethylene, three tons of carbon dioxide are released. Synthetic fibers left to the environment, for instance, add to the 640 000 tons of abandoned fishing nets and gear that are thought to be in the world's oceans.[20]

There are many natural fibers which can be considered as eco-friendly, such as:

Organic Cotton

The world's most popular textile product, cotton is the ideal fabric for casual wear. Despite being the most valuable non-food agricultural product, it has been dubbed the "dirtiest" crop in the world because of its history of unethical labor practices, extremely hazardous chemical inputs, and disastrous water misuse.[23]

Because organic cotton doesn't use pesticides, herbicides, or insecticides during the growing season, it is far more environmentally friendly than traditional cotton. More encouraging is the recently developed cotton cultivated in the Aztec way of life. It is naturally grown in shades of brown and green and has colored fibers long enough to be spun into thread. It also has the added benefit of maintaining its color and becoming more vibrant after the first few washings.[23]

Organic linen

Organic linen is defined as linen derived from flax fiber. It might also be a reference to linen made from other plant fibers that are grown organically.

Bamboo fiber

swiftly Not to mention their incredible softness and kind-to-skin qualities, bamboo textiles have enormous potential as a sustainable textile because they grow without the need for water, fertilizers, or pesticides. Clothes made of bamboo can be hypoallergenic, breathable, and naturally antibacterial. Though bamboo is one of the most sustainable resources on the planet, there are differences between the sustainability of bamboo as a crop and the sustainability of the processing methods used to make the fabric.[24-27]

It is well known that bamboo grows naturally and doesn't require pesticides. It is rarely eaten by pests or contaminated by diseases. The antibacterial and bacteriostasis bio-agent known as "bamboo Kun" was discovered by scientists to be exclusive to bamboo. This material is tightly mixed with the molecules of bamboo cellulose throughout the process of producing bamboo fiber. Even after fifty washings, bamboo fiber fabric maintains its excellent anti-bacterial and bacteriostasis properties. According to test results, after bacteria are cultivated on bamboo fiber fabric, there is a death rate of over 70%. The inherent antibacterial properties of bamboo fiber are very different from those of chemical antimicrobials. The main characteristics of bamboo fiber are as follows:[24]

- naturally anti-bacterial.
- green and biodegradable.
- breathable and cool.

Hemp

One of the earliest textile plants in human history, hemp is also one of the most adaptable and ecologically friendly natural textile plants on the planet. Strong as hell, hemp doesn't need herbicides because it grows so quickly that weeds can't keep up. Because it is indigestible to insects and grows with very little water, it doesn't require pesticides. It is antibacterial and UV protective. Sadly, cotton has surpassed it because it is softer. [28, 29]

By far, the crop with the most potential for ecofriendly textile use is hemp. The ecological footprint of hemp is considerably smaller than that of most other plants considered for their fibers. Because hemp plants grow so quickly and densely, weeds find it difficult to hold, doing away with the requirement for synthetic fertilizers and herbicides. There is no need for irrigation because it grows abundantly in the amount of water found in an average rainfall and is extremely pest resistant. Because hemp naturally has long fibers, spinning it requires little processing. These fibers have a long lifespan as well. There are numerous weights and textures available in hemp textiles. It can be used for nearly anything, including plasterboard, rope, bags, clothing, hats, and insulation. Hemp was used to make both the first American flag and the first pair of jeans by Levi Strauss.

Jute

Jute is a vegetable fiber that has been used for thousands of years and has great potential going forward, much like hemp. [29-33]

Ramie

Among the strongest natural fibers are ramie fibers. Ramie is eight times more durable than cotton and becomes even more so when wet.

Alpaca

Alpaca sheep don't need to be treated with antibiotics, don't eat a lot, and don't need insecticides injected into their fleece. Alpaca wool has a long lifespan as well.[20]

<u>Renewable Raw material</u>

The majority of man-made fibers (MMF) are produced using synthetic polymers with oil as the

feedstock. On the other hand, some MMFs also rely on renewable resources. Modal, viscose, and lyocell are three common and significant MMFs that use wood as a renewable resource. Clearly the most significant biopolymer in the world is cellulose. Cellulose is a remarkable and distinct biopolymer that makes up around half of all biomasses on Earth. Pulp is created from wood, and fibers are created from pulp. The natural carbon cycle includes the pulp and fiber industry. In the context of sustainability, a tiny but increasing share of the production of synthetic fibers comes from novel raw material sources like corn or vegetable oil.

PLA fibers and the polymerization of PTT polyester using bio-propanediol (PDO) derived from corn as an alternative to oil-based PDO are two common examples. Tencel Lyocell, also known as Eucalyptus Tencel, is made solely from the wood pulp of Eucalyptus trees that have received certification from the Forestry Stewardship Council (FSC). The fiber is marked with the Pan-European Forest Council (PEFC) quality seal. Because eucalyptus is woody, it requires energy to be transformed into a soft fiber that can be used for clothing.

The eucalyptus is chopped and then reshaped into a fiber that can be spun. This is produced using a method that is comparable to that of other semi-synthetic natural fibers, like viscous bamboo fabric. The method by which Eucalyptus Tencel is the most environmentally friendly man-made cellulosic fiber on the market today, and it is far more eco-friendly than other options.[20]

Non-renewable Raw Material

When it comes to product types and volume, synthetic polymers derived from oil serve as the primary source of man-made fibers (MMF). In comparison to renewable resources, this non-renewable resource is not the most preferred one in terms of sustainability. This needs to be taken into account along with other resources, such as water and land use, that are required for the production of natural fibers.[20]

Conclusion

Recognizing the diversity and heterogeneity of players, interests, and values associated with clothes is essential on both the supply and demand sides. This acknowledgement is necessary because, in every society on the planet, clothes will continue to be infused with a variety of socio-cultural norms and distinctions. The question then becomes how different paths towards sustainability and accountability can interact positively and productively with the fundamental human need to look well-groomed, polished, and tidy. The articles in this special issue emphasize the need for support from all parties involved if they are to assume greater accountability for sustainability in the textile and apparel industries. This is applicable to a wide range of consumers, from private individuals to street-level procurement officials. By increasing their awareness of the interests and players involved in the production of quick, appealing, and reasonably priced fashion and textiles, consumers may be further persuaded to adopt sustainable practices through innovative consumer tools (such as corporate transparency guides, experiential learning in higher education, and procurement policies). The critical role that their capacity to engage in reflective awareness of the limitations of various tools and expertise plays is also important. For example, they can critically evaluate the ways and reasons that different actors try to legitimize their actions by talking about transparency. Finding customer groups that could be encouraged to act as leaders in this regard is a crucial task for influencing others' behavior. If done well, this could help close the gap between raising awareness of issues and altering behavior accordingly. Consequently, there is a vast difference in problem solving, dialog/capacity building, and choice. Responsibilities cannot be allocated equally. In contrast, some collective buyers (public or private) can be much more professional and equipped with expertise knowledge so that they can engage in further stakeholder dialogue and capacity building whose purpose is to promote sustainable and responsible management. Many individual consumers can only be expected to try to be aware and competent buyers who choose available products with a reflective mind. This special issue teaches us that taking responsibility and managing sustainability must be long-term and learning oriented. There will always be disagreements about sustainability and who is responsible for it. Thus, it is imperative that the public discourse on accepting responsibility and the accountability of participating parties never ends. Here, research is crucial in pointing out the advantages and disadvantages of current practice and providing recommendations for future directions.

Conflict of Interest

There is no conflict of interest in the publication of this article.

Acknowledgment

The authors thank to the National Research Centre, Giza, Egypt for the financial support of this work and also gratefully grateful to the Faculty of Applied Arts, Benha University

Funds

There in no funding

References

1. MARIANA-CLAUDIA, M.-P. The fashion industry and its impact on the environment, *Annals of'Constantin Brancusi'University of Targu-Jiu. Economy Series*, (1) (2022).

2. Sordello, C. Pollution by fast fashion, (2021).

3. Claudio, L. Waste couture: Environmental impact of the clothing industry, National Institute of Environmental Health Sciences, (2007).

4. Ruggiero, M., Schamber, A., Schroeder, O. and Analysts, S. Fast fashion and ocean pollution: Exploring problems and potential solutions, (2021).

5. Shirvanimoghaddam, K., Motamed, B., Ramakrishna, S. and Naebe, M. Death by waste: Fashion and textile circular economy case, *Science of The Total Environment*, **718** 137317 (2020).

6. Yalcin-Enis, I., Kucukali-Ozturk, M. and Sezgin, H. Risks and management of textile waste, *Nanoscience biotechnology for environmental applications*, 29-53 (2019).

7. Hassabo, A.G., Salama, M., Mohamed, A.L. and Popescu, C. Ultrafine wool and cotton powder and their characteristics, *J. Nat. Fiber*, **12**(2) 141-153 (2015).

8. Abd El-Aziz, E., Abd El-Rahman, R.H., Mokhtar, A.A., El-Desoky, S.S., El-Bahrawy, G.A., Ezat, H.A. and Hassabo, A.G. Textile effluent as a potential problem for environmental and human health: Causes and overcome techniques, *Egy. J. Chem.*, **66**(12) 445 - 453 (2023).

9. Fahmy, A.E., Mohammed, M.A., Ahmed, E.a. and Hassabo, A.G. Recycling and sustainability innovations in the textile industry, *J. Text. Color. Polym. Sci.*, - (2024).

10. Glal El-Den, R.E., Abdel Wahab, S.S.M., Atallah, H.A.A., Saleh, Y.D.M. and Hassabo, A.G. Environmental sustainability and innovations in the fashion industry, *J. Text. Color. Polym. Sci.*, - (2024).

11. Ragab, A.G., Al-Gizawy, A.S.H., Al-Minyawi, O.M.A., Hassabo, A.G. and Mahmoud, M.N.I. Environmental impact of clothing manufacturing and the fashion industry, *J. Text. Color. Polym. Sci.*, - (2024).

12. Sandin, G. and Peters, G.M. Environmental impact of textile reuse and recycling–a review, *Journal of cleaner production*, **184** 353-365 (2018).

13. De Vries, B.J. Sustainability science, Cambridge University Press, (2023).

14. Alaswad, M.H., Fiad, N.S., Muhammad, R.R., Muhammad, K., Farghaly, S.T. and Hassabo, A.G. Achieving environmental sustainability using the art of patchwork in contemporary clothing design, *J. Text. Color. Polym. Sci.*, **21**(2) 459-466 (2024).

15. Farghaly, S.T., Alaswad, M.H., Fiad, N.S., Muhammad, R.R., Muhammad, K. and Hassabo, A.G. The impact of fast fashion on sustainability and eco-friendly environment in fashion design world, *J. Text. Color. Polym. Sci.*, **21**(2) 449-458 (2024).

16. Othman, H., Mamdouh, F., Yousif, A.a.R., Ebrahim, S.A., Reda, E.M. and Hassabo, A.G. The transformative power of green chemistry: Advancing sustainability and natural fiber utilization, *J. Text. Color. Polym. Sci.*, **21**(Special Issue) 33-50 (2024).

17. Subaih, R.A., Elhefnawy, H.I., Saada, M.A., Abdelkareem, S.T., Elemam, Y.A. and Hassabo, A.G. Achieving sustainability within industrial design, *J. Text. Color. Polym. Sci.*, - (2024).

18. Rathinamoorthy, R., Suvitha, L. and Raja Balasaraswathi, S. Sustainable technologies and materials for future fashion, Novel sustainable process alternatives for the textiles and fashion industry, Springerpp. 107-138, (2023).

19. Guifang, W., Han, K. and Salmon, S. Applying enzyme technology for sustainable growth, *Asian Textile Journal*, **78**(12) 95-98 (2009).

20. Curteza, A. Sustainable textiles, Radar, pp. 19-21 (2011).

21. Thyavihalli Girijappa, Y.G., Mavinkere Rangappa, S., Parameswaranpillai, J. and Siengchin, S. Natural fibers as sustainable and renewable resource for development of eco-friendly composites: A comprehensive review, *Frontiers in Materials*, **6** 226 (2019).

22. Ikram, M. Transition toward green economy: Technological innovation's role in the fashion industry, *Current Opinion in Green Sustainable Chemistry*, 100657 (2022).

23. Hulm, P. and Domeisen, N. Organic cotton, International Trade Forum, International Trade Centre, p. 30 (2008).

24. Muhammad, A., Rahman, M.R., Hamdan, S. and Sanaullah, K. Recent developments in bamboo fiber-based composites: A review, *Polymer bulletin*, **76** 2655-2682 (2019).

25. Kamal, M.S., Mahmoud, E., Hassabo, A.G. and Eid, M.M. Effect of some construction factors of bi-layer knitted fabrics produced for sports wear on resisting ultraviolet radiation, *Egy. J. Chem.*, **63**(11) 4369 - 4378 (2020).

26. Hassabo, A.G., Eid, M.M., Mahmoud, E.R. and Asser, N.A.H., A. Innovation of smart knitted

fabrics for functional performance of sportswear upon treatment using phase change material, *Egy. J. Chem.*, **66**(3) -133-156 (2023).

27. Othman, H., Ebrahim, S.A., Reda, E.M., Mamdouh, F., Yousif, A.a.R. and Hassabo, A.G. Focus on bamboo and its physical, chemical properties, and dyeing methods, *J. Text. Color. Polym. Sci.*, **21**(2) 293-312 (2024).

28. Khattab, T.A., Mohamed, A.L. and Hassabo, A.G. Development of durable superhydrophobic cotton fabrics coated with silicone/stearic acid using different cross-linkers, *Mater. Chem. Phys.*, **249**(122981) (2020).

29. Hassabo, A.G., Shaker, S., Khaleed, N. and Ghazal, H. An observation on dyeing techniques of polyester/cotton blended fabrics using various dyes, *J. Text. Color. Polym. Sci.*, **21**(1) 205-220 (2024).

30. Nada, A.A., Hassabo, A.G., Mohamed, A.L., Mounier, M.M. and Abou Zeid, N.Y. Liposomal microencapsulation of rodent-repelling agents onto jute burlaps: Assessment of cytotoxicity and rat behavioral test, *JAPS*, **6**(8) 142-150 (2016).

31. Mohamed, A.L., Hassabo, A.G., Nada, A.A. and Abou-Zeid, N.Y. Properties of cellulosic fabrics treated by water-repellent emulsions, *Indian J. Fibre Text. Res.*, **42**(June) 223-229 (2017).

32. El-Sayed, G.A., Othman, H. and Hassabo, A.G. An overview on the eco-friendly printing of jute fabrics using natural dyes, *J. Text. Color. Polym. Sci.*, **18**(2) 239-245 (2021).

33. Othman, H., Reda, E.M., Mamdouh, F., Yousif, A.a.R., Ebrahim, S.A. and Hassabo, A.G. An eco-friendly trend of jute fabric in wet processes of textile manufacturing, *J. Text. Color. Polym. Sci.*, **21**(2) 435-442 (2024).