

Textile Industry in a Changing World: Challenges of Sustainable Development

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Abstract

In the last years, sustainable practices have been developed to minimize the negative effects of production and excessive consumption on the environment. The textile and clothing industry is one of the most polluting industries globally and needs to rethink its strategies. The fast-fashion caused an increase in production, and the environmental weight associated with the textile industry also increased. The problems range from the enormous expenditure of water resources to the carbon and greenhouse gas emissions to reaching the consumer. This review focuses on the eco-friendly approaches taken by the industry towards supportable apparel manufacturing, from the choice of raw materials to the last step in the textile industry.

Author Keywords. Textile Industry, Sustainable Development, Slow Fashion.

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1. Introduction

Globalization radically altered the nature of the textile trade worldwide. The textile and clothing industry (TCI) is an essential asset in human life, generates about 1000 billion dollars each year, contributing with seven percent of the total world exports, and hires about 35000 thousand employees around the world ([Desore and Narula 2018](#)). However, this industry has environmental disadvantages: it is responsible for severe ecological problems throughout its supply chain. The textile supply chain is vast and intricate, and, implementing sustainable practices that cover it entirely is a challenge. This chain starts in the raw material extraction phase - the cradle stage - and goes through several other steps, such as manufacturing, distribution, and use, before the cycle ends at the disposal (grave) stage. After the raw material extraction, the textile chain has a first process that is fibre production. Then this is followed by the production of yarns and fabrics and ends in the clothing manufacturing process. At this stage, the finished product is ready to be shipped to the client by distribution and retailers. The final step is the usage and disposal that is mainly controlled by consumers, whose behaviour has a significant influence on the global environmental impacts ([Muthu 2014](#)).

The eco-friendly practices and the application of the circular economy concept are considered the foundation of sustainability, as they impact the entire supply chain of the textile industry (Gardetti 2019; Manickam and Duraisamy 2019). Based on this assumption, this review offers an overview of the textile industry, some of its impacts on the environment and shows several sustainability strategies that have been applied in this changing world.

2. Textile Industry

2.1. Socio-economic impact of the textile and clothing industry in Portugal

The TCI is one of the oldest and most traditional Portuguese industries and remains one of the largest and most influential national business sectors. It covers various activities, from the transformation of natural, artificial, or synthetic fibres into yarns and fabrics to the production of a wide variety of products. The retail sector is the final part of the value chain of this industry. Some industrial companies have their distribution networks. Based on the latest available data from the Portuguese Institute of Statistics (INE), in 2016, the textile and clothing sector comprises 12,227 companies (of which, 3517 are related to the textile sub-sector and 8710 are related to the clothing sub-sector). These companies represent about 18.3% of the total national manufacturing industry. In Portugal, the industries in this sector are mainly made up of micro-enterprises and small and medium-sized enterprises (SMEs), representing 99.6% of the total business sector (Direção Geral das Atividades Económicas 2018). As for geographical location, about 76.1% of these industries are in the North of the country, 10.6% in the Centre, 9.2% in the Metropolitan Area of Lisbon. The remaining 4% is distributed between Alentejo, Algarve and the Autonomous Regions of the Azores and Madeira. The textile and clothing sector employs 138,000 people, representing about 20% of the total manufacturing industry.

Looking at the numbers presented, it is reasonable to acknowledge that these industries represent one of the most critical sectors of the Portuguese economy, due to job creation and their contribution to the wealth created in the country, with a weight of 4% in the gross domestic product (GDP), in 2016. TCI's exports are growing rapidly, with an increase of around 5% since 2013. 60% of the total exports refer to clothing, while the remaining 40% relates to textile materials (Cardoso and Quelhas 2018).

This growth in TCI in Portugal, and Europe, also reflect the various changes and challenges that the sector has faced and continues to face. This growth is based on the combination of several factors: industrial know-how, technological innovation, design, quality, speed and flexibility, reliability, specialized human resources, services with high added value, and the existence of a structured and dynamic sector, organized in clusters, supported by several competence centres, promoting a sustained growth of the industrial activity. The TCI today, in Portugal and the rest of Europe, follows strict principles of social and environmental sustainability.

2.2. Environmental impact of the textile and clothing industry

The emergence of fast fashion has changed the way society looks at how we are dressed. World clothing production doubled from 2000 to 2014, exceeding one hundred billion pieces per year in 2015 (Cobbing and Vicaire 2016). However, with this increase in production, the environmental weight associated with the textile industry also increased. This industry is the second most polluting, behind only the oil industry. In addition to the enormous expenditure of water resources, there is also the impact

associated with dyes or pigments, which often end up contaminating water resources. It has been shown that between 15 and 20 percent of water contamination is caused by the textile treatments that strongly impact the environment (Kant 2012). On the other hand, the carbon and greenhouse gas emissions are continuously emitted from the production process, transport, and use (Loetscher, Starmanns, and Petrie 2017).

Even after reaching the consumer, the associated environmental impact is still considerable since there are serious problems with recycling. When a piece of clothing is no longer useful, it ends up being ruled out. A part is placed in containers for reuse, but another part will end up in undifferentiated bins, and consequently, its only destination is landfill and incineration (Loetscher, Starmanns, and Petrie 2017). Fast fashion has also increased the compulsory purchase of clothing. Easy access to online stores selling cheap products and adopting a fast-fashion concept helps consumers buy new trends (Morgan and Birtwistle 2009; Vadicherla et al. 2017). Besides, the retailers, who have adopted the idea of fast fashion, sell fashion products with more competitive prices but designed to last ten times less than the textile products produced in a slow fashion concept (Coste-Maniere et al. 2019; Joung 2014). According to Greenpeace, people buy, on average, 60% more textile products than they did in 2000 and only keep them half the time (Cobbing and Vicaire 2016), which consequently leads to an increase in waste.

The promotion of the reduction, reuse, and recycling of industrial waste, based on a solid scientific approach, and with the development of new added-value products, is a priority in the eco-friendly strategies. First of all, in what regards reduction, the TCI should be proactive, increasing the products' quality to promote a longer life-time. More quality is associated with higher prices and margins, contributing to the industry's sustainability in a new scenario with less production and sales. Higher quality will also increase the possibility of reuse, helping decrease waste. And finally, the TCI should be able to incorporate more efficiently recycled textile materials, not only by incorporating recycled fibres in the manufacturing processes but mainly by adopting new strategies to promote recycling. These strategies may involve the recovery of new raw materials from used textiles, one example being the development of new finishing products. Besides the environmental advantages, these newly developed products should give textiles enhanced properties and characteristics, valued by the final consumer, to properly promote the circular economy. It is possible to create new and enhanced products while promoting waste reduction and a lower environmental impact associated with this industry.

3. Overview and Sustainability Challenges of the Textile and Clothing Industry

Many approaches can be used in order to achieve sustainability in this industry, from the selection of raw materials to the end-of-life of a product (Nayak, Panwar, and Nguyen 2020). Emerging technologies, advanced materials (renewable and biodegradable materials), and environmentally friendly production approaches are helping fashion and textile companies to achieve sustainable production (Nayak, Panwar, and Nguyen 2020). On the other hand, the agreement of actions between manufacturers, government, non-governmental organizations, and consumers, can help to obtain a more environment-friendlier industry.

In the case of raw materials, the industry should focus on renewable (natural fibres such as cotton, flax, wool, silk, etc., or man-made cellulosic fibres, like viscose and lyocell) and

decomposable materials (recyclable polyester, nylon, among others). However, even these natural fibres are not integrally sustainable. For example, cotton, which is a natural and biodegradable material, needs an enormous amount of water for its cultivation and processing. The water consumption of the production of synthetic fibres is expressively lower compared with cotton, e.g., on average, 50–100 L water is needed for processing 1 kg of synthetic textile material (Saxena, Raja, and Arputharaj 2017). However, the manufacture of synthetic fibre consumes much more energy.

Regarding the chemical processing of fabrics, this one has the most significant environmental impact. However, this step can become more environmentally friendly with the adoption of more recent technologies, such as enzymatic processing, plasma treatments, the use of natural pigments/dyes, microwave, and ultrasound treatments. Another key challenge faced by the TCI is the adoption of sustainable practices in the manufacture of products, such as a careful selection of raw materials, eco-friendly processes, and assessment of the product's life cycle (LCA and recyclability).

3.1. Fibre types and textile structures

The TCI has diverse activities, from the transformation and treatment of fibres into yarns and fabrics to the finishing and conversion of these fabrics into products; thus, the textile industry is highly complex. Textile fibres can be divided into three major categories (Elmogahzy 2009):

- Natural fibres, including cotton, wool, silk, linen, hemp and jute.
- Artificial or man-made fibres, including those from the transformation of natural polymers (such as viscose, acetate, lyocell, and modal).
- Synthetic fibres, which can be organic based on petrochemical products such as polyester, nylon/polyamide, acrylic, and polypropylene or inorganic materials (for example, glass, metal, carbon or ceramic).

Each of these types of fibres has very specific environmental footprints, and sometimes it is difficult to identify which one is the most favourable. Natural and artificial fibres need higher amounts of water to be produced than synthetic but are produced from renewable sources that are mostly biodegradable. Even between natural and artificial fibres, the water demand is not the same. Cotton production is an agricultural activity, with high water demand and consumption of fertilizers and harmful pesticides, releasing dangerous wastes into the soil and water systems. Artificial fibres are mainly produced from cellulose obtained from different sources, from cotton linters to wood or bamboo. The environmental footprint of wooden cellulose is very dependent on the type of tree used for its production.

Obtaining fibre and yarn (extruded or spun) is just the first operation on the TCI. These materials can go through three different processes for the production of fabrics: weaving, knitting, and nonwoven production (Elmogahzy 2020). The steps involved in the production of fabrics are shown in [Figure 1](#).

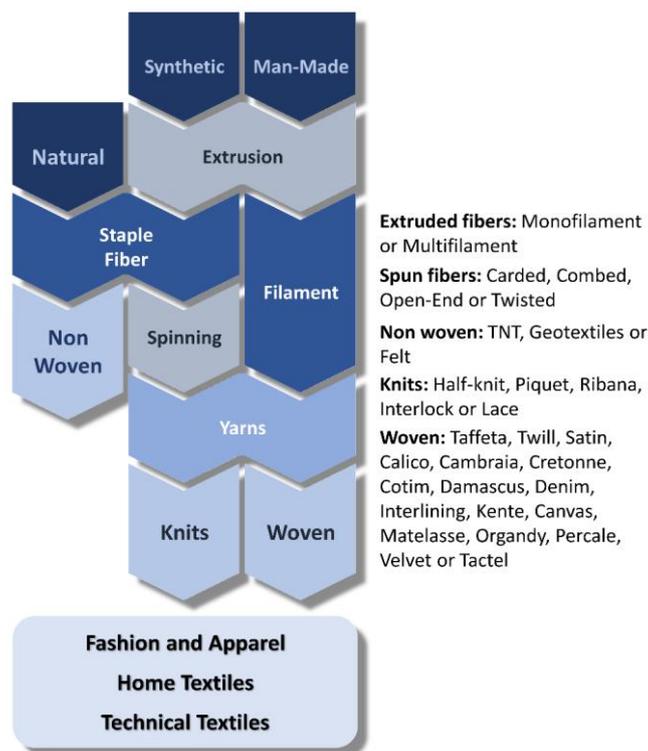


Figure 1: Representative scheme of several types of yarns and textile structures
 Adapted from Gokarneshan (2004) and Hayavadana (2016)

The variety of raw materials, operations, and products is reinforced by the adoption of differentiation strategies in the production companies. In turn, this segments their markets according to the characteristics of the customers, a fact that increases the complexity of the textile sector.

Like yarn, fabric production is also a phase that requires much energy. The total electrical energy consumed per linear meter of fabric is 0.45-0.55 kWh (Fletcher 2014). It is evident that power is an essential factor that has a big impact on the final cost of a textile piece. Energy-efficient technologies are imperative to obtain sustainable production. New weaving technologies, such as projectile, rapier, air and/or water jet, and multiphase looms, not only consume less energy but also provide better efficiency and produce less waste when compared to the conventional machinery.

The use of all-in-one garment (or seamless) manufacturing can also decrease the environmental impact (Arana et al. 2020; Nawaz and Nayak 2015). This technology produces 3-dimensional (3D) textile pieces avoiding the fabric manufacturing steps, like weaving and knitting, cutting, and sewing operations, as it is shown in Figure 2. Therefore, this technology consumes between 30% to 40% less time and saves energy compared to the conventional process. Besides, seamless technology reduces the cost of labour and waste involved in the cutting process (Arana et al. 2020).

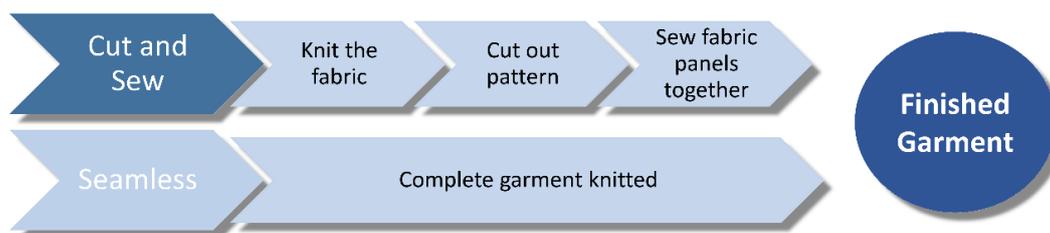


Figure 2: Outline of production strategies

3.2. Importance of textile finishing

Currently, there are substantial scientific and technical challenges for textiles that reach the final consumer to offer not only protection but also other functional properties, such as antibacterial, fire retardancy, water and/or dirt repellency, and wrinkle-resistant properties (Smith 2010). The textile finish confers these properties and can be divided into several processes throughout the industry, each aimed at a specific effect/property. There are five major aims for textile finishing (Kan 2015):

- Enhance the dimensional stability of the textile material (e.g., elongation, compressive shrinkage and heat adjustment).
- Change the feel of the textile material (e.g., softening and hardening).
- Enhance the appearance of the textile material (e.g., calendaring, dyeing, printing, bleaching).
- Change the technical capacity of the textile material (e.g., waterproofing, antibacterial and fire retardancy).
- Enhance the durability of the textile material (e.g., moth and mold-proof, anti-crease, anti-odour).

A property that remains of extreme importance is smoothness. Human skin is very sensitive to touch, soft-touch being a crucial factor in offering comfort in general clothing (Bartels 2011; Teli 2015). The development of softeners based on synthetic surfactants, which are applied to each wash cycle, has been the solution to achieve this crucial effect. However, this process has limitations: the softness offered by this type of softener is temporary; the surfactants used are sometimes aggressive to certain fibres, and; softeners have high pollutant content. Thus, the development of more permanent solutions, with more ecological and sustainable products and processes, is both necessary and urgent (Teli 2015).

All the operations aimed at improving the appearance of the fabrics have a huge potential to harm the environment due to the large consumption of both water and chemicals (Samanta et al. 2019; Tounsadi et al. 2020). Large efforts have been made to minimize these impacts, by reducing the water demand of these operations, using more eco-friendly pigments and dyes, sometimes even using natural dyes applied in soft conditions, and shifting to chlorine-free bleaching agents, but much more work could yet be done (Chen et al. 2019; De Smet et al. 2020; Haji and Naebe 2020; Hussain and Wahab 2018; Vouters et al. 2004).

Super-repellency and its application to “easy-cleaning” textiles (Blossey 2003) is another current challenge of great relevance for the textile industry. The repellent finishes are achieved through compounds that, by adsorbing on the fibres, reduce the associated surface Gibbs energy (Schindler and Hauser 2004). These compounds are generally polysiloxanes, organosilanes, polytetrafluoroethylene, fluorinated polyacrylates or fluorosilicones, with great prevalence for fluorinated compounds (Fan et al. 2017). However, there is accumulated experimental evidence that such compounds cause environmental problems and are harmful to organisms, in particular problems of bioaccumulation and toxicity in the environment (Giesy and Kannan 2001; Johansson, Fredriksson, and Eriksson 2008; Schindler and Hauser 2004).

It is imperative to look for solutions that give textiles more eco-friendly added value properties and, at the same time, promote greater environmental awareness in the consumer.

The textile chemical processing, also called wet processing, is the most damaging step for the environment, as it uses a lot of water, energy, and toxic chemicals (Saxena, Raja, and Arputharaj 2017; Tomaney 2015). The use of harmless substances, or even the reduction of the amount of chemicals, eco-friendly processes, the use of enzymes in processes, and biotechnology can help this industry to be more sustainable. One alternative water-free technique is plasma treatment, which also reduces thermal energy (Kan 2015). This treatment is a dry and eco-friendly technology that can help obtain new functionalities without altering the textiles' intrinsic properties and aesthetics (Lakshmanan and Raghavendran 2017). The treatment is performed by exciting, partially ionized gas with the consumption of a low amount of water and energy.

3.3. Sustainability in fashion and textile uses

Nowadays, the search for sustainability is one of the main objectives in most industries because sustainable practices increase trust between the company and its customers. The term sustainability can be defined as “satisfying the current needs without compromising the future generation’s needs” (Purvis, Mao, and Robinson 2019). Sustainable practices could focus on three perspectives: environmental, economic, and social (Purvis, Mao, and Robinson 2019). The term “green” or “green production” is gaining much importance in many sectors. As a result, producers and retailers in the fashion and clothing sector are increasingly adopting practices that help the environment and comply with ethical guidelines.

Many of the chemicals used in conventional cotton agriculture are contributing to deteriorating soil quality and increasing acute toxicity. The choice of using organic cotton not only reduces soil and water pollution but also has improved properties, such as being hypoallergenic and having a softer touch. Thus, organic cotton is a good option for raw materials in the textile and clothing industry (Avadí et al. 2020).

New technologies and materials (nanomaterials) are emerging in sustainable clothing and textile production regarding eco-friendly processes. In the case of eco-friendly processes, some new methods have advanced in the techniques that are used conventionally: spinning (open-end rotor and air-jet spinning), weaving (rapier, projectile, air-jet, multiphase, and water jet looms), and knitting (high-speed circular knitting, and seamless knitting). These techniques have the advantage of using less energy, being more efficient techniques, and producing less dust and noise. Usually, yarn and fabric manufacturing is a mechanical technique that takes a tremendous amount of energy and generates a large volume of waste, dust, and noise (Karthik and Gopalakrishna 2014). The total energy consumption in the textile industry can be split as 23% in weaving, 34% in spinning, 38% in chemical processing, and 5% in other several processes. The curious detail is that the energy consumed when the cloth reaches the consumer (care and maintenance phase) is almost four times higher (75-80%) compared to their production (20-25%) (Nayak and Padhye 2015).

In addition to the entire production process, other aspects of sustainability must be considered. Several different approaches may be used to reduce energy and water, such as using more water and energy-efficient equipment, training the staff on energy efficiency skills, using sensor systems in lighting, and enhancing rainwater harvesting for non-drinking purposes, can also help to obtain a sustainable textile industry. The remaining waste generated during production (production waste) like plastic, paper,

excess fabrics, and cardboard packaging should be recycled and reused. Textile waste is more broadly classified into three types: postconsumer waste, preconsumer waste and production waste based on their sources. The postconsumer textile waste results when clothing comes to the end of its useful life cycle. With the appearance of fast fashion, the term of pre-consumer waste also emerged. This type of waste is generated in excess of production, which includes remains from store sales and some products resulting from innovative trials developed in the industry and defective returned goods. Around 95% of that textile waste could be recovered by recycling or upcycling (Pandit, Nadathur, and Jose 2019). According to Teli et al. (2014), upcycling is the process of converting waste or useless products into new materials or products of better quality by adding valuable features and remodeling. It is one of the most economical and fashionable forms of sustainability in the textile industry in the case of pre/post-consumer waste (Pandit, Nadathur, and Jose 2019). Another strategy that needs to be implemented is the concept of cradle-to-cradle. This practice is used in a circular economy and uses recycling to close the cycle, enabling the production of a new generation of products from the initial articles. The circular economy is a model whose objective is to keep products/components/materials in circulation in the cycle as long as possible and maintaining its value (Pandit, Nadathur, and Jose 2019).

In recent years, several tools and indices have been developed to assess and compare various systems' impact on the environment. These tools or indices include Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), Cost-Benefit Analysis (CBA), Material Flow Analysis (MFA), and Ecological Footprint (Ness et al. 2007; Resta and Dotti 2015).

LCA is broadly used in the textile and clothing industry. The Life Cycle Assessment is a methodology used to estimate the total environmental impact of a product, process or service, from the cradle to the grave (from raw material, production and use phase, to the waste management stage) (ISO 2006; Kumar and Suganya 2019). In the LCA process, the product's impact on human health, the natural environment, and resources are measured during each stage of product manufacture (ISO 2006).

4. Final Remarks

Industrial companies need to understand that being environmentally friendly is not just about having a conscience about the environment view, but also a question of being profitable. Using products and processes that are energy and water-efficient, costs are reduced, and incomes are increased. Having green practices creates brand loyalty, improves corporate status, and, naturally, this is also lucrative.

Producers and retailers should be the first to encourage consumers to buy responsibly, introducing a concept of slow fashion and engaging in recycling and upcycling practices. The slow fashion helps consumers take into account economic models and the use of sustainable practices in the production, distribution and use. On the other hand, it alerts the consumers to the valuation and knows the product that he/she buys, while helping to mitigate large volumes of waste and environmental pollution.

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