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Thermoplastic Textile Fibers: Perspectives on Environmental Impacts and Innovations in Production and Recycling

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Revised Version

Dissertation presented at School of Arts, Sciences and Humanities of University of Sao Paulo to obtain the title of Master of Science in Textile and Fashion at the Textile and Fashion Program.

Concentration area:
Textile Processes and Materials

Advisor:
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“You could start at a path leading nowhere more fantastic than from your own front steps to the sidewalk, and from there you could go… well, anywhere at all.”

— Stephen King, It.

RESUMO

RUSCHEL-SOARES, Raysa. **Thermoplastic Textile Fibers: Perspectives on Environmental Impacts and Innovations in Production and Recycling**. 2023. 133 p. Dissertação (Mestrado em Têxtil e Moda) - Escola de Artes, Ciências e Humanidades, Universidade de São Paulo, São Paulo, 2021. Versão corrigida.

Fibras sintéticas são comumente utilizadas na indústria têxtil, com destaque para o poliéster. Ele é utilizado isoladamente ou em mistura com fibras de algodão para a produção de tecidos com mistura PES-CO, amplamente utilizados em roupas e decoração. As fibras mistas, por serem uma junção entre naturais e as sintéticas, carregam os impactos de ambas as produções. Esta pesquisa teve como objetivo estudar os impactos ambientais de fibras sintéticas termoplásticas e mistas, abordando a produção e reciclagem de tais fibras. Para isso, foi realizada uma pesquisa e análise sobre o ciclo de vida das fibras puras e mistas de origem virgem, comparando com fibras puras e mistas de origem recicladas. Foi possível notar dentre os resultados, que a reciclagem de fibras de algodão e poliéster apresentam o menor impacto ambiental quando comparado com a produção a partir de matéria prima virgem e podem ser facilmente transformadas em tecidos para produção de artigos na indústria da moda. As fibras mistas de poliéster-algodão têm maior dificuldade de reciclagem, mas trabalham com reciclagem mecânica e já há avanços na reciclagem química, mesmo que ainda não seja aplicada em larga escala. Após o entendimento de como funciona o processo produtivo e de reciclagem, foi realizada uma pesquisa sobre os indicadores de sustentabilidade que são utilizados como guia para a indústria têxtil. Como não foi encontrado uma grande base de dados sobre os indicadores focados na indústria brasileira, optou-se por uma busca online por empresas que trabalhem com a reciclagem têxtil ou coleta de resíduos têxteis para realizar entrevistas. Dentre as empresas encontradas, foram realizadas seis entrevistas estruturadas, sendo cinco recicladoras e uma empresa de gestão de resíduos e logística reversa. Analisando as entrevistas, foram notados indiciadores de sustentabilidade que possuem um peso maior nos impactos causados pelo processo de reciclagem, como por exemplo, o uso de energia de fontes limpas. O uso de indicadores de sustentabilidade e a aplicação de normas voltadas para a sustentabilidade se mostram essenciais para garantir uma produção mais limpa e com menor impacto ambiental, entretanto ainda há dificuldade do setor em se adequar às normas propostas.

Palavras-Chave: Fibras Têxteis Sintéticas, Termoplásticos, Poliéster, Fibras Mistas, Impactos Ambientais.

ABSTRACT

RUSCHEL-SOARES, Raysa. **Thermoplastic Textile Fibers: Perspectives on Environmental Impacts and Innovations in Production and Recycling**. 133p. Dissertation (Master of Science) – School of Arts, Sciences and Humanities, University of São Paulo, São Paulo, 2021. Revised version.

Synthetic fibers are commonly used in the textile industry, especially polyester. It is used alone or blended with cotton fibers to produce fabrics with a PES-CO blend, widely used in clothing and decoration. Blended fibers, as they are a junction between natural and synthetic, carry the impacts of both productions. This research aimed to study the environmental impacts of thermoplastic and blended synthetic fibers, addressing the production and recycling of such fibers. For this, a research and analysis were carried out on the life cycle of pure and blended fibers of virgin origin, comparing with pure and blended fibers of recycled origin. It was possible to notice among the results, that the recycling of cotton and polyester fibers have the lowest environmental impact when compared with the production from virgin raw material and can be easily transformed into fabrics for the production of articles in the fashion industry. Blended polyester-cotton fibers are more difficult to recycle, but work with mechanical recycling and there are advances in chemical recycling, even if it is not yet applied on a large scale. After understanding how the production and recycling process works, a survey was carried out on the sustainability indicators that are used as a guide for the textile industry. As a large database was not found on the indicators focused on the Brazilian industry, an online search for companies that work with textile recycling or collection of textile waste was chosen to conduct interviews. Among the companies found, six structured interviews were carried out, five recyclers and one waste management and reverse logistics company. Analyzing the interviews, sustainability indicators were noted that have a greater weight in the impacts caused by the recycling process, such as the use of energy from clean sources. The use of sustainability indicators and the application of sustainability-oriented standards are essential to ensure cleaner production with less environmental impact, however, there is still difficulty for the sector to adapt to the proposed standards.

Keywords: Synthetic Textile Fibers, Thermoplastics, Polyester, Blended Fibers, Environmental Impacts.

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LISTA OF ABBREVIATIONS AND ACRONYMS

ABIPET	Brazilian Association of The PET Industry
ABIT	Brazilian Textile and Apparel Industry Association
ABR	Responsible Brazilian Cotton
ABRAFAS	Brazilian Association of Artificial And Synthetic Fiber Producers
ABRAPA	Brazilian Association of Cotton Producers
ABRELPE	Brazilian Association of Public Cleaning and Special Waste Companies
BCI	Better Cotton Initiative
BFFP	Break Free From Plastic
CE	Circular Economy
CO	Cotton
EMS	Environmental Management System
GDP	Gross Domestic Product
IEMI	Institute Of Economic and Applied Research
IPEA	Instituto De Pesquisa Econômica E Aplicada
LCA	Life Cycle Assessment
MIT	Massachusetts Institute Of Technology
MSI	Material Sustainability Index
PE	Polyethylene
PES	Polyester
PES-CO	Polyester-Cotton Blend
PET	Polyethylene Terephthalate
PLA	Polylactic Acid
PNMA	National Environmental Policy
PNRS	National Solid Waste Policy
PP	Polypropylene
PPCS	Action Plan for Sustainable Production and Consumption
PTT	Polytrimethylene Terephthalate
PU	Polyurethane
SAC	Sustainable Apparel Coalition
SRL	Systematic Review of Literature
UNEP	United Nations Environmental Program

SUMMARY

1 INTRODUCTION

When the actual ways in which textile products are manufactured are subjected to scrutiny, many examples of environmental concern can be found. Brazil is one of the major textile producers in the world ranked 4th with nearly 9 billion pieces of manufactured articles and the 4th largest producer and consumer of denim and knitted fabrics in 2019 (ABIT, 2020). It has the largest textile chain in the Western countries: from fiber production, such as cotton plantations, to fashion shows, including spinning, weaving, processing, clothing confection, and retail (ABIT, 2020). However, this production generates 175 thousand tons of textile scraps annually only from the cuts in the clothing industry, from which over 90% are destined to landfills or environmentally incorrect disposal (SINDITÊXTIL - SP, 2012). In some cases, the waste from blended fiber fabrics is incinerated to generate energy, though usually incorrectly disposed of in landfills causing environmental damage. E.g., the timeline for polyester degradation is slow (approximately 400 years) and a valuable non-renewable petroleum-based resource is lost (AMARAL et al., 2018; PERIYASAMY; MILITKY, 2020). Currently, the textile industry is the second largest pollutant, leaving first place for the oil industry. According to a study by BBC NEWS (2017), around 70 million barrels of oil are used every year in the manufacturing area, which means that PES fibers are already present in more than 50% of the total fiber market, and the consumption of clothes with this composition increases about 5% every year. As it is derived from petroleum, it has a production process with intensive use of chemicals and energy, in addition to not decomposing in nature. Between 65% and 70% of the world production of PES is destined for the textile industry and the remaining 30% is destined, for the most part, for the manufacture of PET bottles, and like the bottles, polyester fiber is also eligible for go through the recycling process (CRUZ SANCHEZ et al., 2020). Due to the considerable damage caused to nature by the extraction of raw materials, in addition to processes that increasingly degrade the environment, the concerns about sustainability have become pertinent. Sustainable development is defined as the possibility to supply all present needs without compromising the ability to provide for future generations, as described in the Brundtland Report (KEEBLE, 1988). According to Veiga (2006), it is necessary to find a path that is not satisfied with just using enough to avoid environmental collapse, but also preserving natural resources, stimulating savings based on renewable energies, encouraging the reduction of pollution, and greater social awareness. Reusing can reduce the unnecessary waste of non-renewable materials and energies along with the finite sources of raw materials that are necessary to produce virgin products from oil (SANDIN; PETERS, 2018).

According to Panashe and Danyuo (2020), recycling is a process that transforms preliminary separated materials in order to recover waste through a series of operations, allowing the use of elements as a source of raw material for new procedures. Some of the recycling steps consist of collecting the material, separating them according to their composition, sterilizing them, and transforming them into continuous filaments through extrusion so that they can be sold.

This process is considered one of the alternatives within the concept of sustainable development defined by the UN and should be used when the recovery of waste is economically viable and hygienically favorable, in addition to ensuring that the characteristics of each material are respected (THIOUNN; SMITH, 2020).

Thus, to cover the themes to be developed for this study, six chapters were structured: (i) introduction; (ii) objectives; (iii) bibliographic review, in which contexts of sustainability and circular economy, PNMA and PNRS, textile and plastics chain in the textile industry, and recycling; (iv) methodology; (v) results and discussions, which address the impacts of the textile and plastics industry on the environment, efforts to reduce environmental impacts, the lifecycle of textiles, sustainability indicators and certifications for the textile industry, and the scenario of textile disposal and recycling in Brazil and the recycled fiber market; (vi) conclusions obtained in this work.

2 OBJETIVE

2.1 MAIN OBJECTIVE

Study the environmental impacts of thermoplastic and blended synthetic fibers, addressing the production and recycling of such fibers, and comparing them with the environmental impacts of natural fibers.

2.2 SPECIFIC OBJECTIVES

- Carry out a systematic literature review and analysis of sectoral reports and other documents, regarding production processes for pure thermoplastic and blended fibers, emphasizing on recycling, considering the impacts of this process on the environment;
- Carry out a survey of companies that work with the recycling of synthetic and blended fibers in Brazil;
- Analyze environmental impacts, identifying parameters, on the production and recycling of pure thermoplastic and blended fibers;
- Compare, according to the life cycle analysis, the impacts of pure thermoplastic fibers in their conventional version, recycled fibers and blended fibers;
- Identify applications and market for post-recycling products;

2.3 JUSTIFICATIVE

Studying the environmental impacts of textile recycling is essential for the sustainability of the textile industry. Firstly, textile production is one of the most polluting industries in the world, behind only the petrochemical industry (CHAE; HINESTROZA, 2020; PETERS et al., 2015a), being responsible for a large amount of greenhouse gas emissions, water and energy consumption, and waste generation (SANDIN; PETERS, 2018; SUBRAMANIAN et al., 2020; ZIMON; DOMINGUES, 2018). The analysis of environmental impacts allows identifying critical points in the textile production chain and developing strategies to minimize these impacts.

Furthermore, textile recycling is one of the most effective ways to reduce the environmental impact of textile production (AMARAL et al., 2018; HAHLADAKIS; IACOVIDOU, 2019; SUBRAMANIAN et al., 2020). Reusing fabrics and fibers reduces the demand for virgin raw materials, which can lead to reduced extraction of natural resources and generation of waste. Recycling can also contribute to the reduction of greenhouse gas emissions, since the production of recycled fibers consumes less energy and generates less emissions than the production of virgin fibers (LIU et al., 2020a; PERIYASAMY; MILITKY, 2020).

In addition, textile recycling can generate economic and social benefits, creating new business opportunities and jobs throughout the production chain (CAMILLERI, 2020; ELLEN MACARTHUR FOUNDATION, 2013). Recycling can also contribute to the reduction of production costs, since the reuse of materials can have a lower cost than the purchase of virgin raw materials.

3 LITERATURE REVIEW

3.1 SUSTAINABILITY

3.1.1 Sustainable Development

The Brundtland Report established the most valid definition of sustainable development, which, although it is a concept that captures the concerns of human survival in relation to its needs, is still a very simplistic notion.

> Humanity has the capacity to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development implies limits - not absolute limits, but limitations imposed by the current state of technology and social organization on environmental resources and the ability of the biosphere to absorb the effects of human activities. (...) Sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are made according to needs future and present (KEEBLE, 1988).

The most significant effort in the evaluation of sustainable development began in 1992 after the United Nations Conference on Environment and Development (RIO-92) when the need to organize parameters for the evaluation of sustainable development became clear.

Despite being an assertive definition when it comes to sustainability, it focuses on the idea of development as just the 'satisfaction of needs', disregarding human desires and desires (BÓSIO et al, 2019; ULBRA, 2009). That is, it must meet everyone's basic needs, especially the neediest populations, considering the limitations that the state of social and technological organization imposes on nature.

According to Goodland and Bank (1995), sustainable development must integrate economic, environmental and social forms. Since the economic dimension in charge of analyzing the effectiveness of the productive processes, the environmental dimension that defines the limit of use of natural resources, and the social dimension that refers to respect for the worker, working and payment conditions, as well as encouraging employability, professional qualification and insertion in the market. Dobrovolski (2001) agrees with the divisions made by to Goodland and Bank (1995), and states that the use of these three pillars initiates a sustainable development. The three dimensions are dedicated to combining the three Rs of sustainability in their actions: Reduce, reuse and recycle.

3.1.2 Social, Environmental and Economic Development

A point to be considered when discussing sustainable development is the discussion about the importance of including the economic sphere. There are several extremely polarized views on the subject.

Almeida and Navarro (1997) reports on two antagonistic conceptions, where the first considers the need to think about sustainable development within the economic environment and manage the social area and nature according to the repercussions of the economy, having the interest of several economists interested in the monetization of the environment. As a counterpoint, there is the point of view that considers limiting to understand development and sustainability as something belonging to the sphere of economic sciences. Seen in this way, sustainable development should include aspects such as environmental respect, social justice, cultural acceptance and economic viability. As technology is being developed and improved, the potential to reduce the impacts caused to the environment is acquired, but the way in which the world economy produces and consumes still generates serious damage (VEIGA, 2006)

There is a belief in an 'intermediate path' between the two views reported, in which it is admitted that there will be environmental impacts caused by economic development, but that this will be less and less (SACHS, 2008). This is the scenario where countries invest in economies based on renewable energy, reducing air and water pollution, in addition to maintaining biodiversity. Sachs (2008) believes that in order to achieve an ideal sustainable development, it is necessary that environmental and social sustainability are seen with the same importance as economic sustainability. According to the author, there are five pillars that outline sustainable development (**Table 01**).

Table 01 – Five Fundamental Pillars of Sustainable Development

Pillars	Motives
Social	Social development focused on the prospect of social disruption, untangling from the notion of overconsumption and encompassing the range of material and non-material needs of people.
Environmental	With its two dimensions - life support systems as 'providers' of resources and as 'recipients' for waste disposal. Among its topics are the reduction of waste and pollution, use of natural resources without damage to the environment, self-limitation of material consumption by rich countries and privileged social layers.
Territorial	Akin to the spatial distribution of resources, populations and activities. Relating to modern projects of regenerative agriculture and agroforestry, especially ones operated by small producers, access to adequate credit and market.
Economic	Economic viability through the efficient allocation and management of resources and regular flow of public and private investment.
Political / Cultural	Democratic governance is a value and a necessary instrument. Accrediting changes within cultural continuity and translating the normative concept of eco-development into a plurality of solutions, respecting the particularities of each ecosystem, culture, and location.

Source: Adapted from (SACHS, 2008)

When viewed from a business perspective, Young (2004) states that companies have co-responsibility for solving social and environmental problems, given their political power and ability to mobilize financial and technological resources to develop actions that can be replicated.

Aspects such as the environment, equity for workers and minorities, job security and stability, fair trade within the production chain gained strength, going beyond the limits of the company, which at the beginning was only concerned with issues related to the organization's internal aspects. However, there is still no consensus on the meaning of socio-environmental responsibility (VEIGA, 2006).

3.2 CIRCULAR ECONOMY

3.2.1 The Evolution of Economic Thought

A circular economy is a restorative or regenerative industrial system by intent and design. It replaces the concept of 'end of life' with restoration, uses renewable energy, eliminates the use of toxic chemicals, and aims to eliminate waste through superior design of materials, products, systems and, within that, business models (ELLEN MACARTHUR FOUNDATION, 2013).

CE (circular economy) provokes debates that go beyond issues of materials, waste and recycling. It proposes productivity models and new financial indicators that imply new commercial relationships and the development of circular businesses (BAUWENS; HEKKERT; KIRCHHERR, 2020).

Its concept has strong origins but cannot be linked to a single date or author and has been perfected and developed by different currents of thought since the 1970s (**Table 02**) (CAMILLERI, 2020).

Table 02 – Schools of Thought: Origin of the Circular Economy

Stream of Thought	Concept
Economy of Performance	Term created by Walter Stahel, architect and economist, in 1976, gave rise to the "Cradle to Cradle" model. Vision of an economy in cycles and its impact on job creation through the dematerialization of products, economic competitiveness, resource reduction and waste prevention.
Regenerative Design	Concept developed by John T. Lyle in the United States in 1994. A model which intentionally seeks to reincorporate materials into production or biological cycles, aiming at their renewability.
Biomimetics	Term created by scientist Janine Benyus in 2002 to express a technicist approach inspired by nature. It involves the analysis of natural systems and the reproduction of their functioning for technological development.
Blue Economy	It bases its knowledge of the potential for wealth contained in the oceans, based on the intelligent use and full use of natural resources, without harming ecosystems, and which, when well-managed, can generate employment and business opportunities, being the effective path for development from the country. A sustainable blue economy arises when economic activity is in balance with the long-term capacity of the oceans to support such activities.
Cradle to Cradle	Michael Braungart, together with Bill McDonough developed the concept considered a design philosophy that analyzes all materials involved in industrial and commercial processes, with a focus on pre-production design. This concept gave rise to the certificate "Cradle to Cradle Certified"

Source: Adapted from (BAUWENS; HEKKERT; KIRCHHERR, 2020; CAMILLERI, 2020; ELLEN MACARTHUR FOUNDATION, 2013)

Until the mid-twentieth century, economic thought did not consider any connections between the ecological system and the activities of producing and consuming, the economy was seen as an isolated system (CAMILLERI, 2020).

In the 1970s, environmental issues came to the fore with the perception of the effects caused by the emission of polluting gases, the discharge of untreated domestic and industrial effluents into nature, and incorrect disposal of solid waste (GIANNETTI; ALMEIDA, 2006). The beginning of the environmentalist movement is marked by the release of the book “Silent Spring” by Rachel Carson in 1962 and intensified with the completion of the study “The Limits to Growth” prepared by a team from MIT (Massachusetts Institute of Technology) and commissioned by by the Club of Rome that modeled the consequences of rapid world population growth from the perspective of sustainability (JAEGER, 2018).

The concept of environmental impacts emerged in the 1980s, when the surrounding environment and the plurality of environmental issues began to be considered. However, industries were still focused on treating and compensating for the impacts caused by production, rather than seeking solutions to eliminate them, something that would only be questioned during the 1990s. straight to its source sounds like a simple yet revolutionary idea. The main focus of environmental control becomes the use of products and raw materials with a smaller environmental footprint and productions with little or no environmental damage, and not just the remediation of impacts caused after the production process (CECHIN, 2008; GIANNETTI; ALMEIDA, 2006)

3.2.1.1 Ecological Economy

Nicholas Georgescu-Roegen is one of the main inspirers of ecological economics, and his aspiration was to frame it within the parameters of mechanics. Mechanics understands only locomotion, which, in addition to being reversible, does not contemplate changes in its quality. In economics, the main concern is monetary exchange, without the loss of its attributes (value) (CECHIN, 2008).

Georgescu is credited with applying the second law of thermodynamics (entropy law) as an explanation of how the economy works. According to the law of entropy, energy cannot be used entirely in a useful way, since a part is dissipated in the form of heat and cannot be reused (SCHMIDT, 2019). The linear economy is seen as heat, moving in only one direction; Produce, consume, discard (ROMEIRO, 2001).

The interdependence of economics and natural ecosystems across space and time gave rise to what was called "ecological economics" in the early 1970s with the release of Georgescu's book entitled "The Entropy and the Economic Process" in 1971.

The economic process begins to be seen as a physical process, and there is an integration of the disciplines of economic and ecological studies in order to have an integrated analysis between these systems, since the current model of economy was being strongly criticized, pointing to an incompatibility between economic growth and environmental preservation (CECHIN, 2008; SCHMIDT, 2019).

3.2.1.2 Low Carbon Economy

The low-carbon economy emerged between the end of the 1980s and the beginning of the 1990s as a succession of the ecological economy, and reinforced the need to combat climate change arising from atmospheric emissions through the implementation of practices that reduce and/or eliminate the use of fossil energy. Such energies, the main causes of the greenhouse effect through the large amount of carbon dioxide generated, are replaced by energy from a clean and renewable source (BÓSIO CAMPELLO; DE SOUZA-LIMA; MOSER, 2019; MANO; PACHECO; BONELLI, 2010)

During this period, the Kyoto Protocol was developed, a worldwide agreement that created policies, targets and market mechanisms to allow the global reduction of emissions through investment in more efficient and sustainable technologies matrices (MANO; PACHECO; BONELLI, 2010). This economy has become a market rich in opportunities for technological development and focused on clean production with efficient use of resources. More broadly, the low-carbon economy encourages the rational use of natural resources, in the renewal of energy and in the circularity of production. Therefore, process innovation and technological development are important allies to reduce harmful impacts on the planet matrices (CECHIN, 2008; MANO; PACHECO; BONELLI, 2010).

3.2.1.3 Green Economy

The green economy, which replaces the term “eco-development”, is an economic model that results in improvements in human well-being and social equity, while significantly reducing environmental risks and ecological scarcities (UNEP, 2011).

According to UNEP (UNITED NATIONS ENVIRONMENTAL PROGRAM, 2011), this model is based on three main points:

- Use of renewables: Use of renewable sources on a large scale, replacing energy sources derived from the exploitation of fossil resources.
- Local Biodiversity: Making use of products and services offered by biodiversity, with the creation of value chains linked to ecosystem services.
- Technological development: Advances in the field of technologies for goods and services that rely on techniques capable of reducing pollutant emissions into the atmosphere, reusing waste, and reducing the use of non-renewable materials and energy.

3.2.2 Approaches to the Circular Economy

Concerns about environmental issues have forced the textile industry to gradually respond by introducing textiles to environmentally safe manufacturing processes, as well as modifying its production system. According to Salcedo (2014), the current economic system becomes unsustainable for two main reasons, a behavioral issue and a conceptual one. The concept problem is related to the fact that the human species understands itself to be superior to the other species on the planet and sees nature as an external system and independent of the consequences resulting from its actions. However, the human species damages the environment it needs to live, while the environment does not depend on humans to exist. When it comes to the behavioral issue, the human species consumes natural resources faster than nature is able to replace them, in addition to producing waste and pollution. If all of humanity consumed like a standard inhabitant of the United States, it would take four planets Earth to meet humanity's annual need from nature (SALCEDO, 2014)

Manufacturing industries often follow a linear economic approach. They acquire their resources in the wild, through extraction and mining, to manufacturing products and components. Eventually, consumers buy their products and discard them when they reach the end of their useful life. Waste from these industries and from consumers is landfilled or incinerated. Unsustainable practices like this cause significant changes in the environment and in the biosphere, with catastrophic consequences for human life. Therefore, companies and industry are encouraged to adopt circular economy strategies designed to use, reuse and reduce their dependence on systems that deplete resources, usually characterized by high externalities, including emissions and waste generation (CAMILLERI, 2020)

The circular economy is described as an economic system 'in which the value of products, materials and resources is maintained in the economy for as long as possible and the generation of waste is minimized' (ROBAINA et al., 2020). CE models maintain the added value of products for as long as possible and decrease waste by keeping resources within the economy when products no longer fulfill their functions, so that materials can be used again and generate additional value (CHAE; HINESTROZA, 2020; PEARCE; TURNER, 1990). According to Hahladakis and Iacovidou (2019), local and national governments should receive their own plans and structures for the adoption of CE, considering regional specificities, governance and organizational structures. In some cases, a complete system overhaul may be required.

According to Georgescu-Roegen (CECHIN, 2008), the current economic system does not feed itself in a circular fashion, on the contrary, it transforms natural resources into waste that can no longer be used. The production system designed with the aspects of the circular economy is less polluting, and recycling is already foreseen as one of the pillars of this economic model, for this reason it is easier to reorganize the structure of the production chain so that it adapts to a network of industrial symbiosis, so that there is support between companies, this connection makes the waste of one industry the raw material of another (ROBAINA et al., 2020)

3.2.3 Circular Economy: World and Brazil

Most of the global movements that provoke the rethinking of the economy aim to contain and/or eliminate linear economic thinking in the production process, generating new value for society (BAUWENS; HEKKERT; KIRCHHERR, 2020)

Europe has been a pioneer in promoting debates in the face of a scenario of high industrial competitiveness. Stating how crucial is the implementation of public policies that support and guide such development. In 2015, the Circular Economy Package was approved, its first step towards the circular economy. Since then, the Commission of the European Union (EU) has communicated its commitment to implement the 2030 Agenda for Sustainable Development, aiming to protect the natural environment, reduce soil degradation and prevent the loss of biodiversity, reducing its dependence on the use of natural resources, also providing a comprehensive account of the current situation and discussing opportunities and challenges for various actors around the world (CAMILLERI, 2020; ELLEN MACARTHUR FOUNDATION, 2013).

In Japan, the issue of waste has driven the application of the circular economy through the Law for the Effective Use of Recyclables since 1995, being able to produce PET bottles with 100% recycled material, which reduced the use of new plastics by 90% and by 60 % carbon dioxide emissions (IPEA - INTITUTO DE PESQUISA ECONÔMICA E APLICADA, 2020). In addition, it also has the Japanese Circular Economy Initiative. In 2018, the Japanese Ministry of Environment published a report showing that the environmental industry reached a record value in 2018 (105.3 billion yen) and represents 10.1 percent of the country's entire industry (AICEP - PORTUGAL GLOBAL, 2021; IPEA, 2020).

In the Brazilian scenario, the first signs of the circular economy begin in 2015, following the European model, with industry in the lead (AICEP - PORTUGAL GLOBAL, 2021). However, it is only in 2017, when there is a union between industry and academia that greater efforts can be noticed, such as the production of a first report with a general approach on the subject, considering the connection with Industry 4.0. In 2018, a more detailed report is published, highlighting opportunities and challenges for the Brazilian industry (IPEA, 2020).

There is a wide association between the term 'circular economy' and 'recycling', which is one of the problems in implementing this economic model in Brazil, in addition to the challenge for companies to create new business models that add value to the product/service (CNI - PORTAL DA INDÚSTRIA, 2020).

One of the great challenges is to have a more efficient and lower cost process, reaching a final value more expensive than a new product. However, it can be easily circumvented through the growing demand for products from production processes that are classified as sustainable. In addition, the lack of public policies, tax incentives, and low investment in research, development and innovation are also obstacles (CNI, 2020; IPEA, 2020).

3.2.4 Closed Cycle Systems and Industrial Symbiosis

Braat and de Groot (2012) explain that there are two approaches commonly addressed by economists, called strong and weak sustainability. Weak sustainability assumes the substitutability between natural capital and manufactured capital, and in contrast, strong sustainability “sustains that natural capital and manufactured capital are in a relationship of complementarity and not substitutability” (DAILY; MATSON, 2008). Although many economists believe that natural resources do not represent a prominent place in economic production, the essentiality of such resources for the survival of all land animals, including humans, is remarkable (DALY; FARLEY, 2004).

As an example, it is noted that the union of companies that use PET plastic as a raw material with cooperatives that supply recycled plastic helps to close the cycle and causes a smaller number of bottles to end up unduly in the environment (BBC NEWS, 2017). Providing the consumer with information about the correct disposal can be considered an action to contribute to companies' reverse logistics plans. The use of recycled PET by companies brings profitable advantages, since the cost is around 30% lower than that of virgin PET, in addition to adding value by showing concern for the environment (HAHLADAKIS; IACOVIDOU, 2019).

The product life cycle is the roadmap described by a product in the creation, manufacturing, commercialization and final destination phases. However, there is a difference between destination and final disposal of waste (BERLIM, 2012; BRAUNGART; MCDONOUGH, 2002). In the final disposal, there is an orderly distribution of waste in landfills, observing specific operational standards to avoid damage to human health and minimize environmental impacts, while in the final disposal of waste, it includes reuse, recycling, composting, recovery and energy use or other destinations admitted by Organs competent bodies. In the open cycle, the final destination is the same as the final disposal (BERLIM, 2012; BRAUNGART; MCDONOUGH, 2002; CAMPOS; GOULART, 2017).

In the closed cycle, the final disposal of waste aims at maximizing the use of waste. Thus, transforming them into secondary raw material for other processes. It is described as the process of constantly reusing a material without allowing it to enter the waste stream. Synthetic fibers are the most present in final closed cycle systems (BERLIM, 2012; BRAUNGART; MCDONOUGH, 2002; CAMPOS; GOULART, 2017).

The Cradle to Cradle® design concept recognizes two cycles for materials: technical and biological. The "waste" materials in an old product become the "food" for a new product. In the technical cycle, materials are not depleted during use, but must be seen as service products. Materials in products designed for the technical cycle can be reprocessed to allow them to be used in a new product. As is the case with recyclable products, such as polyester. In the biological cycle, products are consumed during or after use. Materials are returned to the biosphere in the form of compost or other nutrients, from which new materials can be created. Some biological cycle products can be reprocessed through technical cycles several times before finally returning to the biosphere, as is the case with paper recycling. Ultimately, the paper is returned to the biosphere and must be designed accordingly (BRAUNGART; MCDONOUGH, 2002; GIANNETTI; ALMEIDA, 2006).

Idyllically, industrial ecology proposes a connection between industrial systems, making them function as ecosystems in which energy and material consumption is optimized, making waste from one process the raw material for another. This branch of industrial ecology is called industrial symbiosis (GIANNETTI; ALMEIDA, 2006).

Eco-Industrial Parks represent a practical way of applying this concept, cultivating symbiotic relationships through waste and by-product networks between companies in a mutual and systematic way (GIANNETTI; ALMEIDA, 2006). There are several successful cases when it comes to industrial symbiosis, such as the park in Kallundborg, a small port city in Denmark. The exchange of waste in this park added up to 2.9 million tons of materials per year for some companies, collectively reducing water consumption by 25% and supplying 5000 homes with urban heating, in addition to reducing CO2 emissions by 275 thousand tons, saving about 95 million dollars a year (EURONEWS, 2015).

3.2.5 Direct Logistics and Reverse Logistics

The term 'reverse logistics' is linked to product and material reuse operations. It encompasses all logistical activities of collection, disassembly, and processing of products, materials and used parts, in addition to their recycling and environmental aspects, in pursuit of sustainability and compliance with legislation (BALLOU, 2011; CAMPOS; GOULART, 2017).

As part of reverse logistics, there is material flow planning; Management of the flow of information throughout the process; Movement of products in the production chain - from the producer to the final consumer and vice versa; Optimization of resources used in the production and recycling process; Correct destination of items after use (CAMPOS; GOULART, 2017; FRAGA, 2014).

Reverse logistics is closely linked to the PNRS (National Policy on Solid Waste) and is considered one of the fundamental instruments for applying shared responsibility for the life cycle of products. It is a collection of actions that seek to enable the collection and restitution of solid waste aimed at economic and social development (CAMPOS; GOULART, 2017; FRAGA, 2014). In Brazil, compared to developed countries, reuse, recycling, composting, recovery and energy use still do not play a prominent economic role as a profitable activity, and although the PNRS determines that the reverse logistics systems of products are the responsibility of the business sector, so far, these systems have not been implemented on a considerable scale (IPEA, 2012).

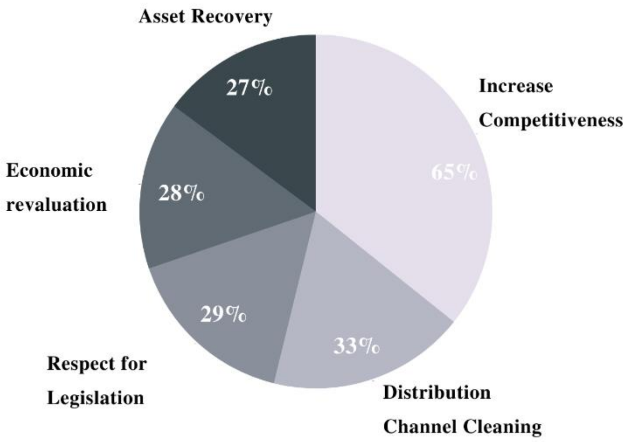
When it comes to reverse logistics, it is common to think of a company and the delivery of its product to the customer and then the return of that product. Some problems are common to occur during this path (BALLOU, 2011; CAMPOS; GOULART, 2017), such as:

- Products and goods that do not reach the final recipient: These cases are related to the lack of integration between the company's systems, generating errors regarding recipient addresses or even lack of communication regarding delivery times and customer availability to receive the products or goods. Whether to deliver the product to the customer, or when it reaches the end of its useful life, there may be great difficulty in finding collection points for the part and/or communication fails when the company picks up this product from the customer.

- Defective products and goods: In most cases, the product or packaging is faulty, or the product delivered has the wrong specifications. Probably, the causes refer to poor storage conditions, problems in registering items, or lack of integration between the company/distributor systems.

According to Leite (2003, the reasons that lead companies to act strongly in reverse logistics vary, but are usually linked to compliance with environmental legislation, so that the necessary treatments are carried out for the product, in addition to being used as a competitive advantage (**Figure 01**).

Figure 01 – Motivations for the Use of Reverse Logistics



Source: Adapted from (LEITE, 2003)

The main benefits are seen in the financial sector, with the reuse of materials stimulating new initiatives and efforts in the development and improvement of processes; Adding value to the product, acting as an after-sales support tool or offering a service for environmental preservation in the marketing and sales area; Contributing to the reduction of product costs, preservation of the environment and also acting as a differential before the competition in the operational part; Inducing investment in research and development of new technologies to comply with legislation in the technology and innovation sector (BALLOU, 2011; CAMPOS; GOULART, 2017; LEITE, 2003).

3.3 PNMA e PNRS

Much of the waste generated is due to the enormous competitiveness of the textile sector, that is, related to the greater supply of products, lower prices and the incentive to excessive consumption by the population. Making this the perfect scenario for rampant and unsustainable consumption, generating an immense amount of post-consumer waste and the use of natural resources beyond their regeneration capacity (BARBOSA; IBRAHIN, 2014). When dealing with the problem of incorrect disposal, there is a lack of specific legislation in Brazil. Aimed at fashion and design, there are some laws of support such as the Copyright Law, guaranteeing the authorship of the creation to the author of the intellectual work. However, when relating the connection between fashion and sustainability, it is necessary to use very comprehensive laws that need to be adapted to the clothing production scenario (BARBOSA; IBRAHIN, 2014; IPEA - INTITUTO DE PESQUISA ECONÔMICA E APLICADA, 2020).

For this reason, the PPCS (Action Plan for Sustainable Production and Consumption) was instituted by the National Management Committee for Sustainable Production and Consumption, launched on November 23, 2011, it is the guiding document for the actions of the government, the productive sector, and the society that leads Brazil towards more sustainable production and consumption patterns. It deals with guidelines for the sustainable conciliation between production and consumption aiming at a better management of renewable and non-renewable resources, aiming at environmental education for conscious consumption, increased recycling of waste, application of an environmental agenda in public management, among others. The global debate on the Green Economy is reflected in the Action Plan for Sustainable Production and Consumption, which becomes an instrument of transition to this new model (ABRAMOVAY; SPERANZA; PETITGAND, 2013; BARBOSA; IBRAHIN, 2014).

Despite the growing demand and desire, there is a lack of government incentives and legislation to guide textile companies towards more sustainable practices. Existing legislation is very subjective and vague, can be applied to a broad industrial spectrum and is therefore easily circumvented.

3.3.1 National Environmental Policy (PNMA) and National Solid Waste Policy (PNRS)

As a basic guide, the National Environmental Policy (PNMA) (Law 6.938/81) of 1981 aims to regulate the various activities involving the environment so that there is preservation, improvement and recovery of the environmental quality conducive to life, in a way to guarantee conditions for socioeconomic development, the interests of national security and the protection of the dignity of human life. It takes into account the maintenance of the ecological balance; Rationalization, planning and supervision of the use of environmental resources; Protection of ecosystems; control of potentially polluting activities, among other aspects (BRASIL, 1981). One of its main aspects is related to waste management, which is called the National Solid Waste Policy (PNRS). The PNRS (Law nº 12.305/10) organizes the way in which the country deals with waste, aims to create a sectoral agreement between the government and industries for the delegation of shared responsibility for the life cycle of a product, demanding from the public and private sectors transparency in the management of their waste (BRASIL, 2010). In addition, the selective collection system was implemented, the prohibition of open landfills, economic incentives for initiatives with environmental responsibility and the adoption of a reverse logistics program (ABRELPE - ASSOCIAÇÃO BRASILEIRA DE EMPRESAS DE LIMPEZA PÚBLICA E RESÍDUOS ESPECIAIS, 2020; BARBOSA; IBRAHIN, 2014). The constant increase in consumption in cities provides a large generation of urban solid waste. This is the law used when talking about textile waste, since there is no regulatory legislation only for pre- and post-consumer disposal of clothing.

The PNRS indicates advances in solid waste management in the country and aims to outline strategic actions that enable processes capable of adding value to waste, increasing the competitive capacity of the productive sector. In the parameters defined by such legislation, emphasis is placed on technologies that enhance the proper use of new alternatives for industry and the recognition of solid waste (IPEA, 2020; MMA - MINISTÉRIO DO MEIO AMBIENTE, 2012). This policy also establishes the shared responsibility of solid waste generators: manufacturers, importers, distributors, traders, citizens and holders of urban solid waste management services in the reverse logistics of waste and post-consumer packaging, creating important goals that will contribute to the elimination of dumps, in addition to establishing planning instruments at the national, state, micro-regional, inter-municipal and metropolitan and municipal levels, forcing individuals to prepare their solid waste management plans (FREIRE; BARREIRA, 2015; MMA - MINISTÉRIO DO MEIO AMBIENTE, 2012). However, it is designed to deal with waste as a whole, not just textile waste. It is noticed that many post-consumer items are disposed of inappropriately, as there is no indication of how to dispose of them or even the method of selective collection of clothing.

3.3.2 Other regulations related to the environment

In the legal sphere, Brazilian initiatives have considered and recognized the importance of environmental responsibility, and although the textile industry is more included in the PNRS, there are other laws that also regulate the clothing production process (**Table 03**).

Table 03 – Brazilian Normative for Environmental Support

Brazilian Legislations	Concept
Environmental Crimes Law (Lei 9.605/98)	It is a very broad law, serving any environmental crime, considering any and all damage caused to the elements that make up the environment: flora, fauna, natural resources and cultural heritage (BRASIL, 1998).
Industrial Zoning Law in Critical Pollution Areas (Lei 6.803/80)	It sets the general guidelines that must be observed for the adoption of industrial zoning in critical pollution areas, that is, in the most industrialized regions of the country. However, it does not establish the physical delimitation of the industrial zones, only general conditions to be observed by the states that will have to elaborate their own specific legislation (BRASIL, 1980).
Public Civil Action Law (Lei 7.347/85)	Responsible for damages caused to the environment, to the consumer, to goods and rights of artistic, aesthetic, historical, touristic and landscape value (BRASIL, 1985).
Agricultural Policy Law (Lei 8.171/91)	It aims to protect the environment. Establishes the obligation to recover natural resources for companies that economically exploit dammed waters and for electricity concessionaires. It makes the Public Power responsible in its spheres for supervising the rational use of soil, water, fauna and flora (BRASIL, 1991).

Source: Author

These laws and regulations are important to ensure that the textile industry operates in a sustainable and responsible manner, minimizing environmental impacts and protecting public health and the environment. In addition, there are other specific standards that regulate the use of dyes, inks and chemicals in textile production, aiming to minimize air, water and soil pollution (FREIRE; BARREIRA, 2015; ZONATTI, 2016).

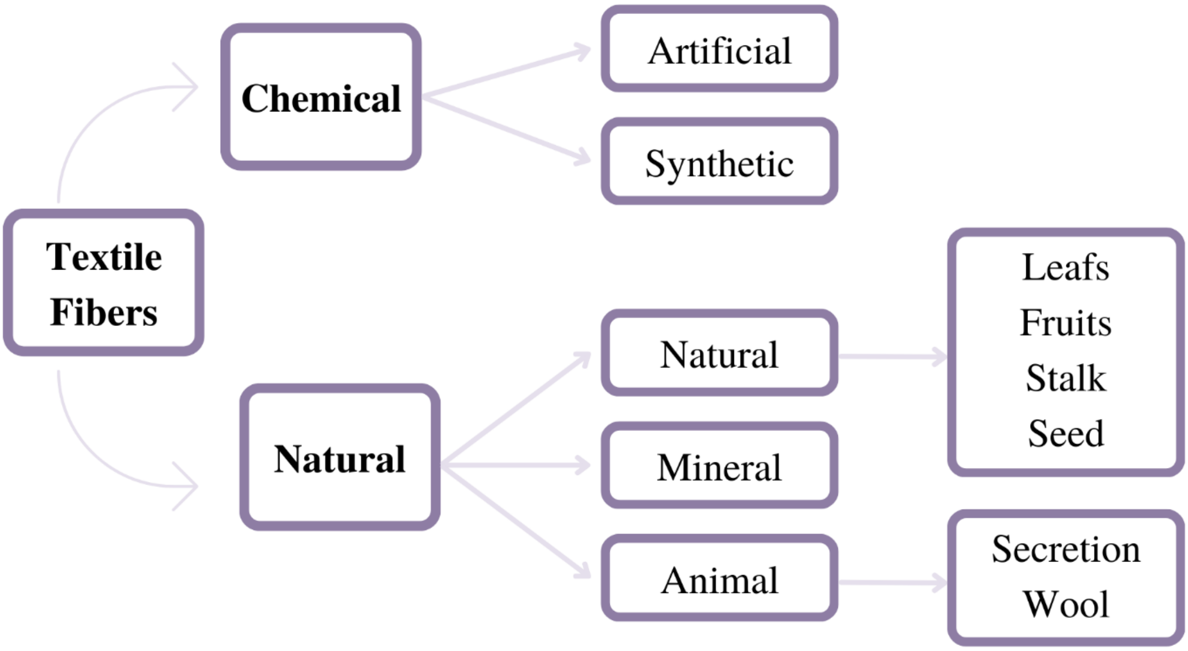
3.4 TEXTILE CHAIN

3.4.1 Fibers

Textile fiber is a general term for materials, natural, artificial or chemical, consisting of filiform elements, forming basic elements for textile purposes. They are characterized by being at least one hundred times longer than their width or diameter (SINCLAIR, 2015; THE TEXTILE INSTITUTE, 2002).

All fabrics are made up of textile fibers, defined by The Textile Institute, (2002) as units of matter characterized by flexibility, fineness and a high length/thickness ratio, and which, when passing through the manufacturing process, are transformed into yarn to be used in textile products or in industrial uses. They can be classified as natural (those found in nature); synthetic (obtained by industrial processes that use polymers synthesized from first generation petrochemical products such as ethylene, propylene, benzene and para-xylene); artificial (obtained through processes that use natural polymer cellulose) (MORTON; HEARLE, 2008; SINCLAIR, 2015). **Figure 02** offers an exemplary view of the fiber set.

Figure 02 – Fiber Classification

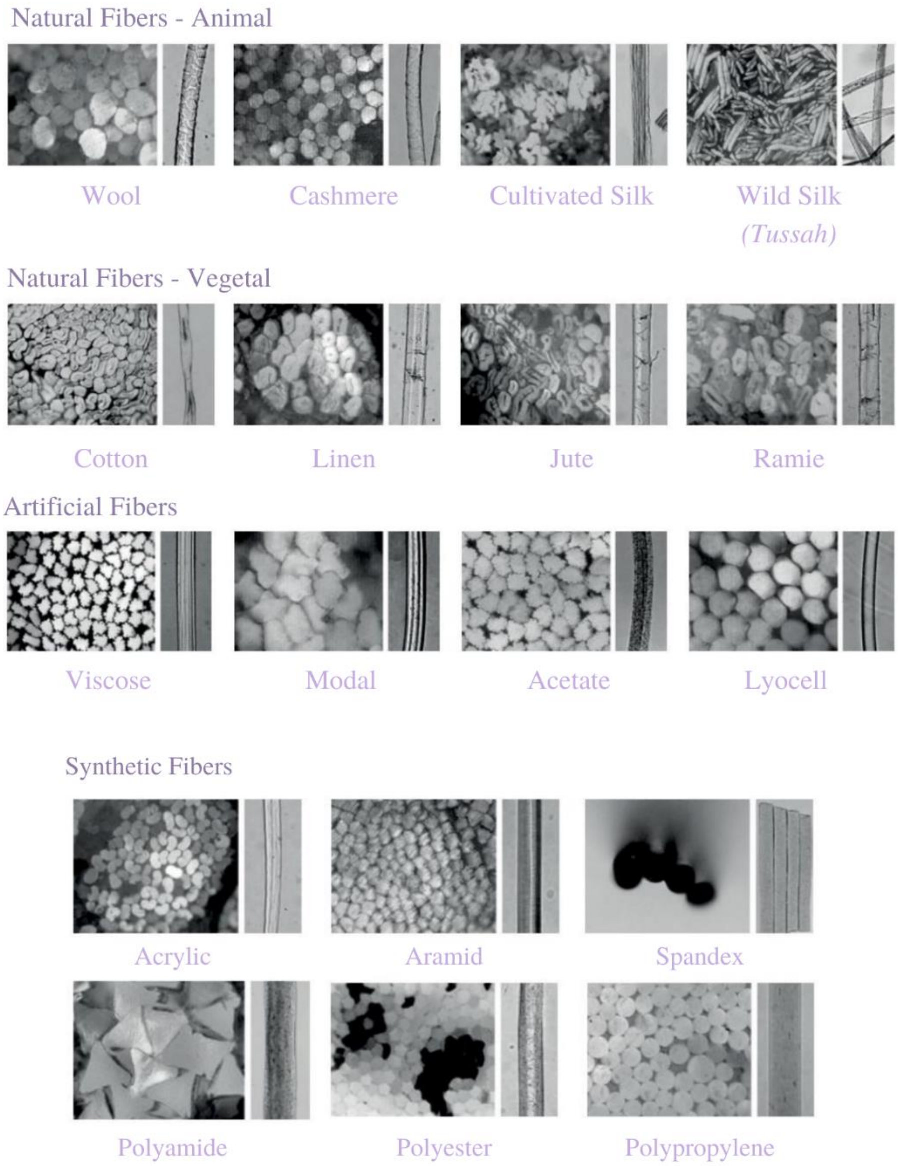


Source: Adapted from (SINCLAIR, 2015; THE TEXTILE INSTITUTE, 2002)

Both the aesthetics of the fibers and the brightness and the feeling of touch depend on their shape and surface (**Figure 03**). Fibers with an almost circular section, such as wool, have a more pleasant feel, providing a better sense of comfort than a fiber such as cotton, which has a flat section like a ribbon. The shape of the fiber and its natural softness also influence the gloss, as it modifies the way in which light is reflected by the surface of the fiber, in the case of synthetic ones, titanium oxide is also added to the polymeric masses, cross section (MORTON; HEARLE, 2008; SINCLAIR, 2015).

Textile fibers can be used alone in the manufacture of nonwovens, interlinings, etc. However, its greatest use occurs in the spinning area (SINCLAIR, 2015).

Figure 03 – Structure of fibers



Source: Adapted from (SENAI, 2014)

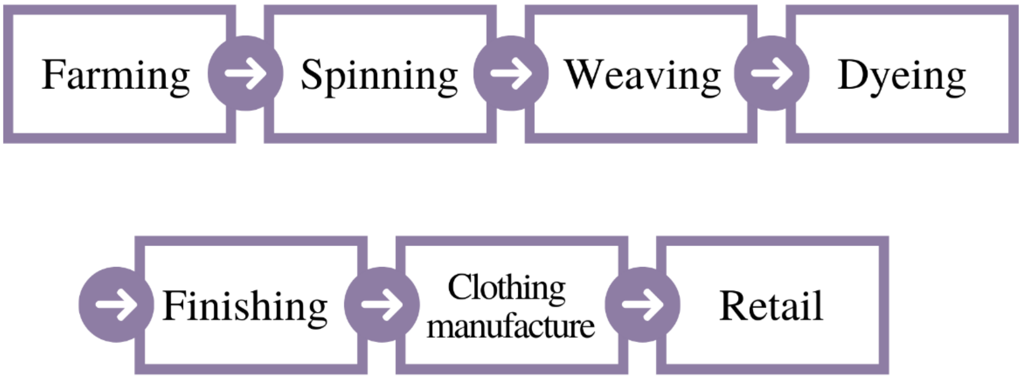
3.4.1.1 Natural Fibers

Natural fibers are all those that are ready-made in nature, requiring only physical processes to transform them into threads (LOBO; LIMEIRA; MARQUES, 2014). They are from raw materials of protein (animal), cellulosic (vegetable), and mineral origin. Natural fibers are processed through rotor (open-end) or ring spinning, the first generally develops carded yarn and the second combed yarn (MORTON; HEARLE, 2008).

These fibers have been fundamental to human life since the dawn of civilization. Cotton fragments dating back to 5000 BC have been excavated in Mexico and Pakistan. The oldest wool fiber was found in Denmark around 1500 BC, and the oldest wool carpet in Siberia dates to 500 BC. Fibers such as jute, coconut and flax have been cultivated since antiquity (LOBO; LIMEIRA; MARQUES, 2014; PEZZOLO, 2017).

Cotton fibers are the purest form of cellulose, which is the most abundant polymer in nature (HSIEH, 2007) since all plants consist of cellulose and lignin in varying degrees (SINCLAIR, 2015). Cellulose in cotton fibers also presents the highest molecular weight among all plant fibers and the highest structural order, which is highly crystalline, oriented and fibrillar (HSIEH, 2007; THE TEXTILE EXCHANGE, 2018). The steps to cotton production are shown as an example in **Figure 04.**

Figure 04 – Flowchart of the Cotton Production

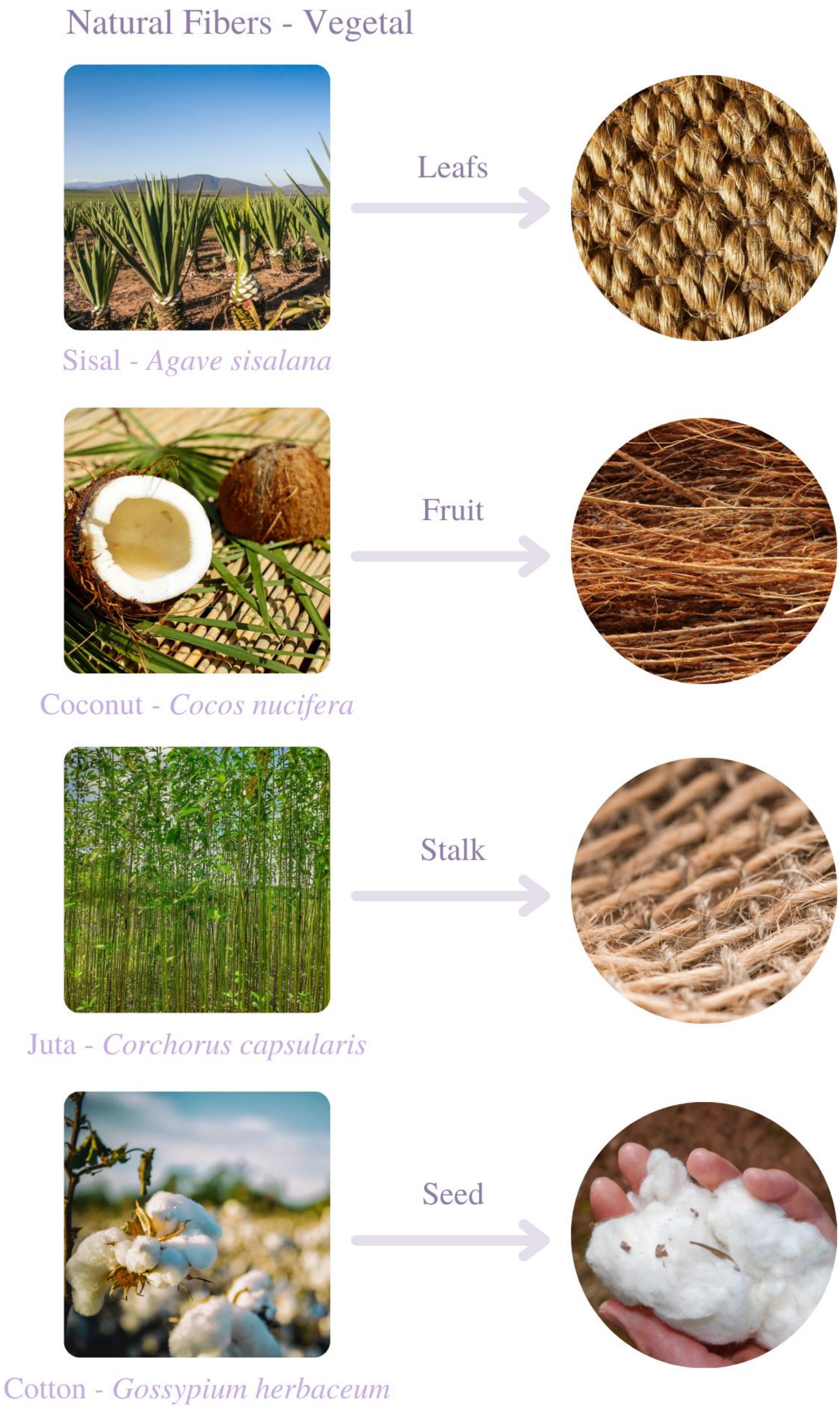


Source: Adapted from (MORTON; HEARLE, 2008; SINCLAIR, 2015)

Despite the continuous evolution in fabric manufacturing methods, the use of fibers has changed little since antiquity. The most commonly used natural fibers in the clothing industry are the ones originated from vegetable and animal source.

Natural plant fibers include seed hair, such as cotton; trunk or stem, such as flax, jute and hemp; leaf fibers such as sisal; and fruit fibers, as is the coconut (**Figure 05**).

Figure 05 – Natural Fibers- Vegetal



Source: Author

All these fibers have very similar chemical composition, however, their physical, mechanical and appearance properties differ greatly from each other. The greatest similarities of these fibers are in their hydrophilicity, good thermal conductivity, low resistance to creasing and low dimensional stability that they provide to the fabrics (LOBO; LIMEIRA; MARQUES, 2014; SINCLAIR, 2015). Cotton still is considerate the most important of the vegetal fibers because of the comfort when the clothing is in contact with skin.

Animal fibers are known as protein fibers because their basic chemical structure is composed of amino acids. All protein fibers contain the elements carbon, hydrogen, oxygen and nitrogen in their composition. In each fiber, they are combined in different molecular ways and in various amounts. As a result, the properties of each fiber tend to be very particular, giving fabrics distinctive properties, colors and textures (LOBO; LIMEIRA; MARQUES, 2014; PEZZOLO, 2017; SINCLAIR, 2015). They include wool, hairs and secretions, such as silk (**Figure 06**).

Figure 06 – Natural Fibers – Animal

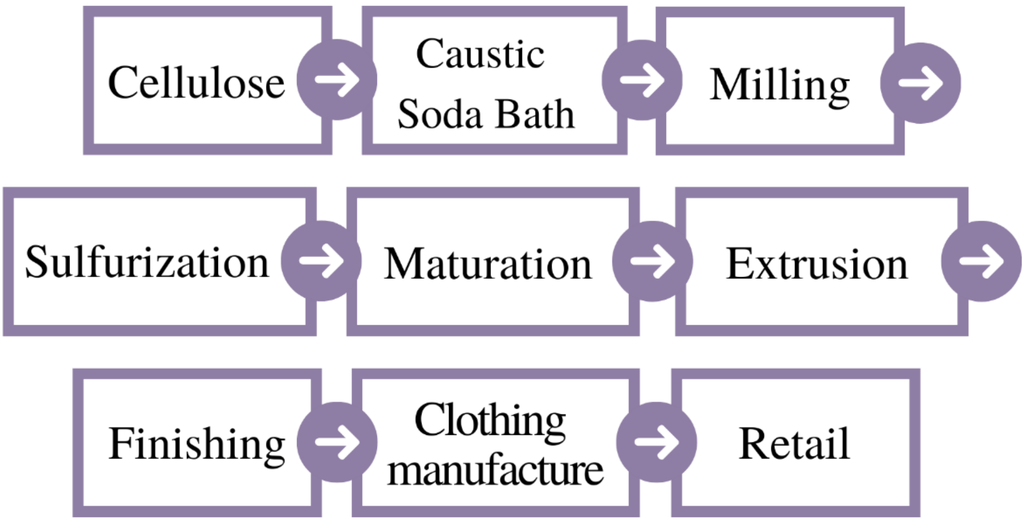
Source: Author

3.4.1.2 Artificial Fibers

Artificial fibers are produced by man, but using natural polymers such as cellulose, such as wood pulp, as raw material. These polymers are regenerated, giving rise to new fibers, these are produced from extrusion and can be transformed into full fibers, filamented and multifilament. The most used are Viscose, Acetate, Lyocell, and Modal (LOBO; LIMEIRA; MARQUES, 2014; MORTON; HEARLE, 2008; PENSUPA et al., 2017).

From cellulose sheets, acetate rayon and viscose rayon follow different routes. The viscose goes through a caustic soda bath and then through sub-processes of grinding, sulfurization and maturation, to finally be extruded and take the form of continuous filament or cut fiber (**Figure 07**). The acetate goes initially through a sulfuric acid bath, dilution in acetone, extrusion and, finally, through an acetone evaporation operation (ABRAFAS - ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FIBRAS ARTIFICIAIS E SINTÉTICAS, 2020a; EL SEOUD et al., 2020).

Figure 07 – Flowchart of the Viscose Production



Source: Adapted from (ABRAFAS - ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FIBRAS ARTIFICIAIS E SINTÉTICAS, 2020a; LOBO; LIMEIRA; MARQUES, 2014)

Rayon was the first man-made artificial chemical fiber. Although chemist Hilaire Bernigaud introduced this fiber only in 1889, he had been researching and testing it for years. Rayon's development began in 1878, by dissolving nitrocellulose in a mixture of alcohol and ether. Passing through a fine orifice and making the final treatment with the aid of an oven. He obtained the patent for the process in 1884, and at an exhibition in Paris in 1889 he presented the fiber to the world. Only in 1891 did the fiber begin to be commercially produced and was called 'artificial silk'. After further experimentation, viscose and acetate were created (**Figure 08**) (ABRAFAS - ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FIBRAS ARTIFICIAIS E SINTÉTICAS, 2020a; LOBO; LIMEIRA; MARQUES, 2014; PEZZOLO, 2017).

Figure 08 – Artificial Fibers

Source: Author

Viscose comes from a viscous solution obtained by treating cellulose. Its yarns and fibers are similar to cotton in moisture absorption, tensile strength, soft touch and fit. However, it is a weak fiber when wet, it shrinks and crumples easily. Acetate is produced through the reaction between cellulose, acetic anhydride, and acetic acid in the presence of sulfuric acid. The resulting fabric is soft, silky, glossy or matte, and because of its characteristics it is widely used in lingerie and summer clothes (ABRAFAS - ASSOCIAÇÃO BRASILEIRA DE

PRODUTORES DE FIBRAS ARTIFICIAIS E SINTÉTICAS, 2020a; LOBO; LIMEIRA; MARQUES, 2014; PEZZOLO, 2017).

As more ecological options, lyocell and modal were developed. Lyocell is obtained from the pulp of the wood pulp of specific trees, from reforestation, genetically molded in order to produce a fiber of better quality and color, reducing the need for chemical products for bleaching (ABRAFAS - ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FIBRAS ARTIFICIAIS E SINTÉTICAS, 2020a; EL SEOUD et al., 2020).

Modal is also seen as an ecologically produced fiber, derived from wood cellulose, and has characteristics such as comfort to the touch, softness and softness to fabrics. It is 33% more absorbent than cotton and evaporates 4 times faster (EL SEOUD et al., 2020; PEZZOLO, 2017).

3.4.1.3 Synthetic Fibers

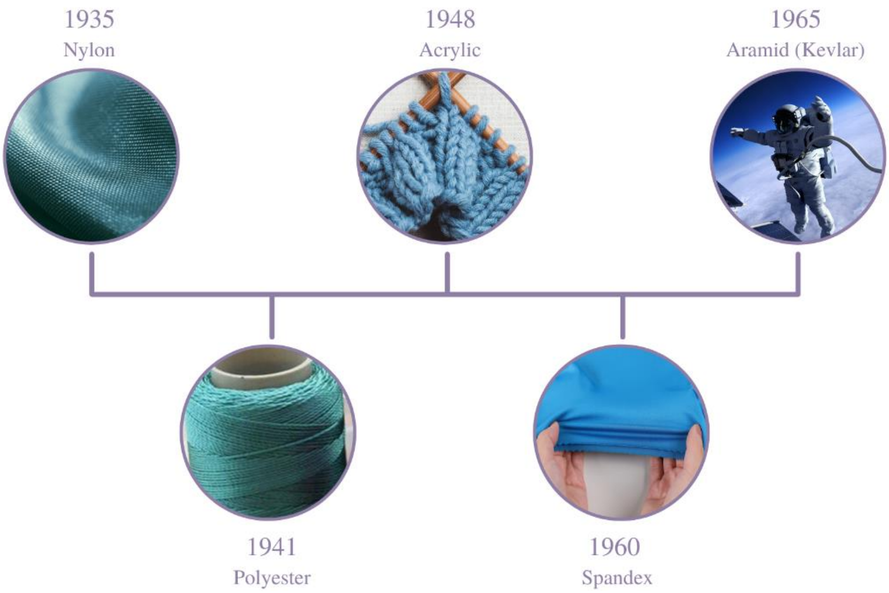
Textile production until the 17th century employed predominantly fibers such as wool, cotton, silk, hemp, and linen. Along with the Industrial Revolution, there was intensive mechanization of the production process, allowing the emergence of new and fast methods of production. The first artificial or manufactured fibers, namely regenerated cellulose fibers, were developed at the end of the 19th century, although their industrial production started at the beginning of the 20th century. Synthetic fibers were only developed in the late 1930s and peaked after World War II (SINCLAIR, 2015). These fibers were developed to create an improved copy of natural fibers given that they could be produced faster and cheaper, increasing all their characteristics and qualities without the need to wait for the planting cycle and not being vulnerable to the difficulties of agricultural production (PEZZOLO, 2017).

Synthetic fibers are mostly obtained from petroleum extraction - it can also come from mineral coal, and despite having been launched in the late nineteenth century, they were only developed and applied throughout the twentieth century (PEZZOLO, 2017).

The American Wallace H. Carothers, of du Pont during the investigation of polymers, led to the eventually discovery of “nylon”, giving rise to synthetic fibers (**Figure 09**). This polyamide fiber caused an impact in the textile industry due to its strength and fineness (PEREIRA, 2009).

In 1941, J. T. Dickson and J. R. Whinfield of the Calico Printers' Association in England made a synthetic fiber from polyethylene terephthalate by condensing ethylene glycol with terephthalic acid (MORTON; HEARLE, 2008).

Figure 09 – Timeline of the Synthetic Fibers Development



Source: Author

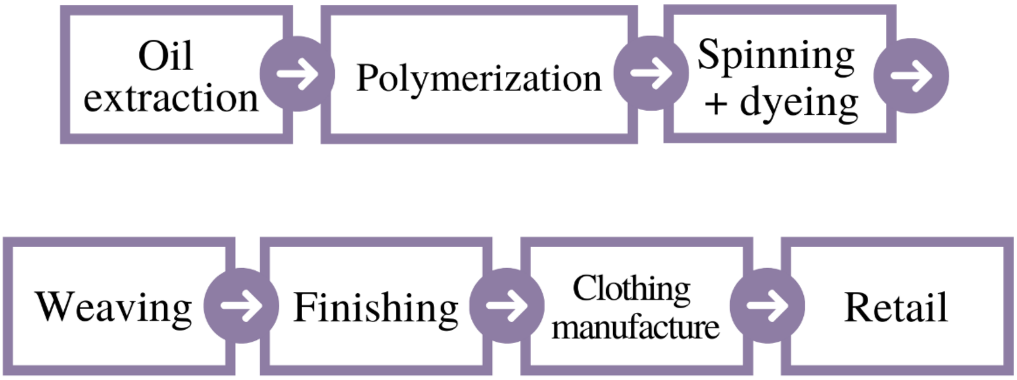
In Brazil, artificial fibers were introduced almost simultaneously abroad. Production on a commercial scale began around 1931, by the Companhia Brasileira Rhodiaceta, now Rhodia with the acetate textile filament. Synthetic fibers emerged after World War II, but were only produced on Brazilian soil after 1955, also by the company Rhodia. The first fiber produced was nylon, followed by polyester in 1961, and acrylic in 1968. In 1993, the production of synthetic fibers already surpassed that of artificial ones (PEZZOLO, 2017).

Synthetic fibers, polyester being the most commonly used in the textile industry, are defined as any long-chain synthetic polymer composed of at least 85% by weight of an ester of a substituted aromatic carboxylic acid, including, but not restricted to, units of substituted terephthalate and parasubstituted hydroxybenzoate units (SINCLAIR, 2015). Synthetic fibers, in general, follow the same production process, by extrusion, the first steps being the polymerization by condensation that occurs when acid and alcohol react under vacuum at elevated temperatures. The polymerized material is extruded in the form of a ribbon onto a casting chute or cooling wheel. After the tape hardens, it is cut into chips. The chips are dried and then placed in funnel-shaped reservoirs for melting. Polyester is melted before being spun, which means it is heated in a paste form, and then pressing the resin, through very fine holes in a piece called a spinneret and filaments coming out of these holes are immediately solidified when in contact with air. It is then wound around cylinders. Fibers take their final shape through stretching, carried out through two basic processes; in the first, the fibers are stretched during the solidification process; in the second, the stretch is done after they are solidified. In both cases the fiber diameter is reduced, and its tensile strength is increased (LOBO; LIMEIRA; MARQUES, 2014; PEREIRA, 2009).

Because of their various qualities, synthetic fibers have many uses. They are widely used in protective clothing due to their high tenacity (polyester up to 85 cN/tex) and durability. Insulating properties can be incorporated in addition to its natural ability to be hydrophobic (LOBO; LIMEIRA; MARQUES, 2014; SINCLAIR, 2015).

In the next figure (**Figure 10)** the steps of polyester production are shown.

Figure 10 – Flowchart of the Polyester Production



Source: Adapted from (PEZZOLO, 2017; SINCLAIR, 2015)

3.4.1.4 Blended Fibers

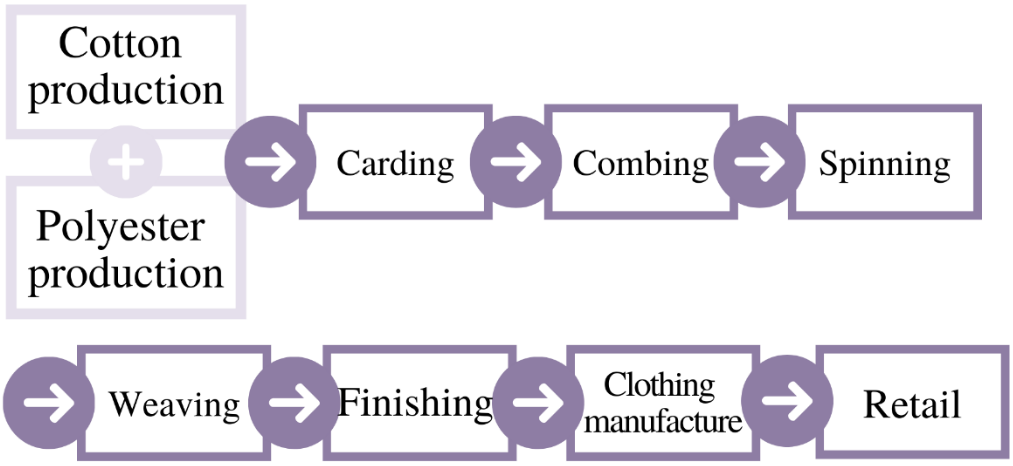
It is necessary to note that no fiber, natural or chemical, fulfills all the needs of the textile industry. Thus, the blending of fibers can help bring better materials and lower the costs (PEZZOLO, 2017). According to the report of the National Bank for Economic and Social Development:

> No single fiber, whether chemical or natural, fulfills all the needs of the textile industry; however, the blending of chemical fibers with natural fibers, notably cotton, brought them better performance, strength, durability, and presentation. The use of synthetic fibers is currently widespread, covering all sectors of the textile industry (BNDES - BANCO NACIONAL DO DESENVOLVIMENTO ECONÔMICO E SOCIAL, 1995).

Blended fabrics are generally the result of a blending of natural and synthetic fibers. The best known is polyester and cotton (PES-CO). Polyester is a strong fiber, which maintains its shape, does not knead easily, absorbs colors easily, and does not withstand high temperatures. Cotton is a light, fresh, comfortable, and absorbent fiber. The combination of these two fibers results in a versatile fabric inheriting the best of each one. The blended fabric is fresh and light like cotton, but stronger, more durable, and more difficult to wrinkle. It is an easy-to-sew fabric and, when washed, dries faster without wrinkling. Manufacturers may, for example, use cotton/polyester blends to create easy-care fabrics (SINCLAIR, 2015).

The production of blended fibers combines both manufactures of cotton and polyester, passing through the entire process of each fiber before being combined to start producing textile with PES-CO blend as composition. Fiber blending is carried out mainly for apparel end uses and for special yarns is carried out in staple fiber form before spinning during the fiber-processing stage (SENAI, 2015) (**Figure 11).**

Figure 11 – Flowchart of the PES-CO Blend Production



Source: Adapted from (SENAI, 2015; SINCLAIR, 2015)

Also, according to this author, many reasons are found to blend fibers, like compensate for weaker attributes or properties of one fiber, improve general performance, enhance or provide a particular appearance, and even reduce costs in production.

> A single-component fiber such as 100% polyester can provide excellent strength, abrasion resistance, durability and easy-care properties. On the other hand, 100% polyester would be clammy, slippery and uncomfortable to the wearer. Similarly, 100% cotton or viscose fibers due to their hygroscopicity and thermal conduction properties provide excellent comfort properties to the wearer but have disadvantage of creasing, the need for repeated laundering, low color stability and low abrasion properties (SINCLAIR, 2015).

There are many reasons to the blend of fibers, the addition of acrylic to wool can make the costs lower, elastomeric fiber to nylon for stretch, and polyester to cotton for an all-round performance. The opportunity to create a unique yarn is enabled by the blend of natural and manmade fibers, however, the types of staples must be considered, as well as the compatibility of the previous treatments of each fiber and the final ratio. The most common ratios of fibers in the blends are 80/20, 60/40, 55/45, and 50/50 percent of cotton/polyester. The ratio is controlled to attain the required end-product property (MORTON; HEARLE, 2008; ROMERO et al., 1995; SINCLAIR, 2015).

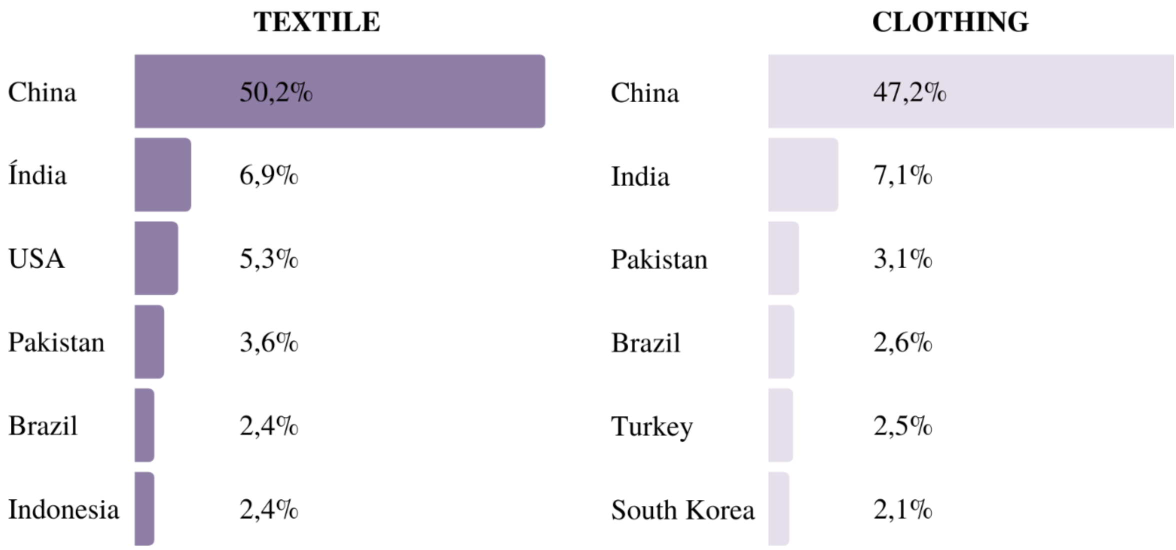
3.4.3 Overview of the Brazilian Textile Industry

The Brazilian economy is highly based on textile production, with an average production of 9.04 billion garments in 2019, and 2.04 million tons of textiles in the same period (ABIT - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA TÊXTIL E DE CONFECÇÃO, 2020). Until 2020, Brazil had 1.5 million direct employees and 8 million additional employees and the income effect, of which 75% were female. As a result, the textile sector becomes the 2nd largest income generator in the country, representing 16.7% of jobs and 5.7% of the manufacturing industry's revenues in 2020 (ABIT, 2020); by 2021 it represented 19,5% of jobs and 6% of the manufacturing industry's revenues (ABIT, 2022). The investments in the sector in 2019 were around US$730 million and US$630 million in 2018, respectively.

In 2018, the production of Brazilian textile manufactures reached 2 million tons, which represents a turnover in the order of US$ 50.3 billion, with estimations that this production would exceed 2.07 million tons in 2019, which indicates revenue of around US$ 53.8 billion (IEMI- INSTITUTO DE ESTUDOS E MARKETING INDUSTRIAL LTDA, 2018). Despite the large production of textiles, this is mostly for domestic trade, making Brazil the 41st in the overall ranking of main exporters, 26th in textiles, and 79th in clothing, whose total share is only 0.3% (IEMI- INSTITUTO DE ESTUDOS E MARKETING INDUSTRIAL LTDA, 2018).

Brazil is a world reference in beachwear, jeanswear, and homewear design has also grown in the fitness and lingerie segments. It is the fourth-largest producer and consumer of jeans in the world, as well as the fourth-largest producer of knitwear (ABIT - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA TÊXTIL E DE CONFECÇÃO, 2020). In 2018, Brazil was the 4th largest producer of clothing and 5th of textile in the world (**Figure 12**) (IEMI- INSTITUTO DE ESTUDOS E MARKETING INDUSTRIAL LTDA, 2018).

Figure 12 – Brazilian Participation in The World's Textile and Clothing Production



Source: (IEMI- INSTITUTO DE ESTUDOS E MARKETING INDUSTRIAL LTDA, 2018)

Furthermore, it is self-sufficient in cotton production and is the largest complete textile chain in the West, which produces from fiber to retail (ABIT - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA TÊXTIL E DE CONFECÇÃO, 2020). In 2019, the revenue of the textile and apparel chain was next to US$ 36.7 billion, surpassing US$ 1.72 billion the revenue of 2018. Exports, without adding the cotton fiber to the account, were US$ 3.6 billion; that is US$ 1 billion more than the previous year (ABIT - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA TÊXTIL E DE CONFECÇÃO, 2020).

According to ABRAPA (2021) with 115,243 tons of cotton sold, the country increased the volume registered in May 2020 by 66%. It became the best month of May in the entire history of Brazilian cotton production, exporting a total of 2,235 million tons. Even with two months to go before the business year ends, the performance so far is 23% higher than the numbers for the 2019/20 season. China leads the ranking of the largest buyers of Brazilian cotton in the 2020/21 season, importing even greater volumes than those carried out in the 2019/20 cycle. Taking into account the importation of 23.7 thousand tons in May of 2020, the country surpassed 700 thousand tons in the 2020/21 cycle, increasing by 22% the total registered in the previous period. Thus, imports of China surpass the average domestic consumption of the Brazilian textile industries (ABRAPA - ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE ALGODÃO, 2021).

In 2020, the apparent consumption of synthetic fibers (for all sectors, including the textile industry) was 646 thousand tons, however, only 211,438 tons were produced in Brazil. Focusing on polyester fibers for the textile industry, there was a production of 71,584 tons, being 98.74% for the internal market, along with the need for the 242,985 tons of imported polyester fibers (ABRAFAS - ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FIBRAS ARTIFICIAIS E SINTÉTICAS, 2020b).

According to ABRAFAS (2020b), in 2019, 18.4 thousand tons of artificial fibers and 488.7 thousand tons of synthetic fibers were imported. In turn, exports were 4.8 thousand tons of artificial fibers and 16,300 tons of synthetic fibers.

Based on statistical projection models and a study of the monthly behavior curve of the situation in this segment, it is estimated growth of 10.4% in the production of textiles in volume in 2021 (FCEM, 2021). In values, a total revenue close to US$ 28 billion is estimated, which would represent an increase of 12.3% in nominal values (US$); concerning clothing, an increase of 22.1% in production in terms of garments is forecast, and an increase of 23.4% in nominal values (US$), compared to 2020 (IEMI- INSTITUTO DE ESTUDOS E MARKETING INDUSTRIAL LTDA, 2020).

3.5 PLASTICS IN THE TEXTILE INDUSTRY

3.5.1 History of Plastic

The name 'plastic' characterizes a series of materials with different structures, quality and compositions. Its applications are so varied that they often replace traditional materials such as wood and glass (MICHAELI et al., 1995). However, all plastics are composed by the folding or linking of long chains of molecules, called macromolecules. These macromolecules are chains composed of the repetition of a basic unit, called monomer (mono = one, meros = part), also known as polymers (poly = many) (GORNI, 2015; MICHAELI et al., 1995).

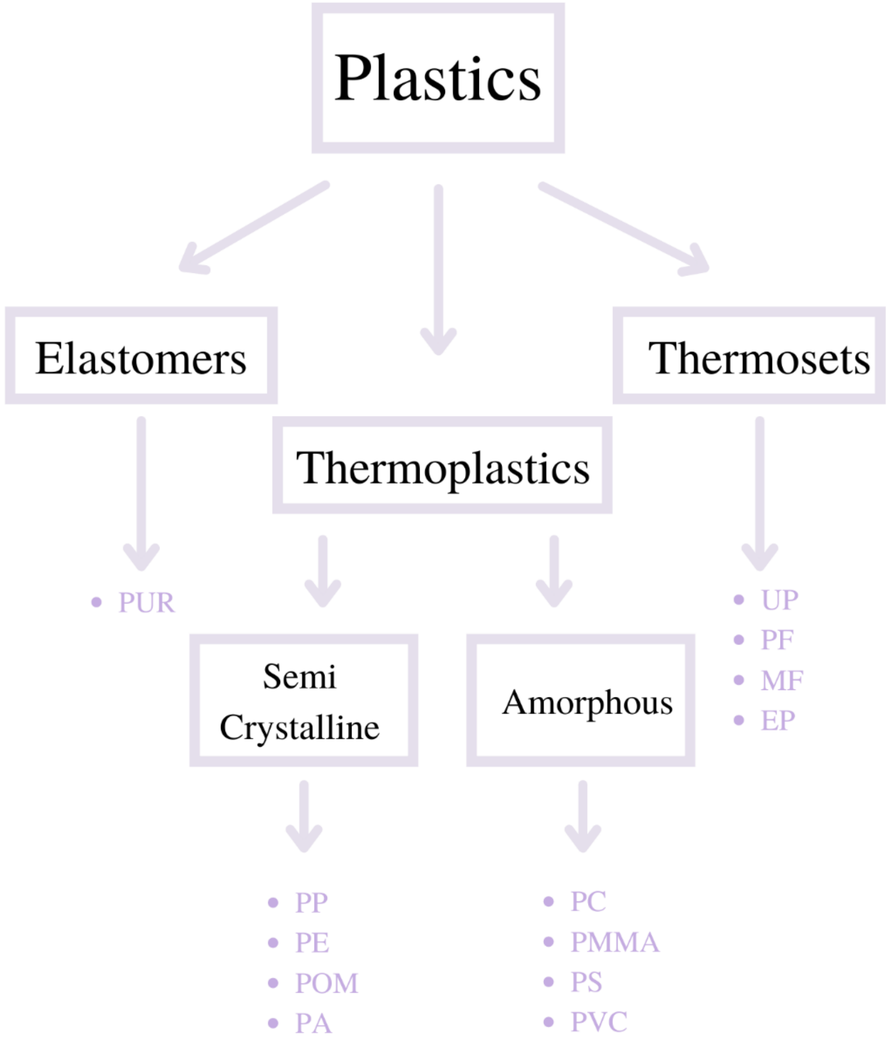
The main raw materials for monomer are oil and natural gas. It is possible to produce monomer using coal and even CO2, since the main component for its manufacture is carbon, however production using oil has a lower cost (MICHAELI et al., 1995). In the past, monomers were obtained from fuel production residues. Today, the consumption of polymers is so high that these “waste” of yesteryear has to be intentionally produced in refineries to account for consumption (GORNI, 2015; MICHAELI et al., 1995).

The term 'polymers' was created by the German chemist J. Berzelius (1779 - 1848) in 1832, in an attempt to create a name that would differentiate organic molecules that had the same chemical elements, but not necessarily the same chemical proportions. At first, these molecules were called isomeric and later Berzelius clarified that butene molecules, having four carbon atoms and eight hydrogen atoms, would be the polymeric state of ethylene molecules, which, according to him, had one carbon atom and two hydrogen atoms. Thus, the term polymer was used to represent butene molecules as being made up of many (poly) ethylene (mer) units. At that time, the concept of macromolecules was not known, being established in 1920 by Hermann Staudinger (HAGE JR., 1998; NUNES; LOPES, 2014)

In the 19th century, scientists carried out the first experiments with natural polymers, such as natural rubber, starch, cellulose and proteins. Natural rubber and cellulose were mainly responsible for the polymer industry. In the middle of the 20th century, cellulose was used to manufacture textile fibers through a regeneration process, until then the industrialization of polymers occurred only through modification processes in the structure of natural polymers (NUNES; LOPES, 2014).

In 1907, Lord Baekeland (1863 – 1944) patented the synthesis process of an essentially synthetic polymeric material, the phenol-formaldehyde resin, commercially known as Bakelite, in honor of its inventor. However, the term 'polymer' only began to be used after 1922, when the German scientist Hermann Staudinger (1881 - 1965) proposed the theory of the macromolecule. These materials were presented as compounds formed by large molecules, the high molecular compounds, an idea strongly opposed at the time. Years later, in 1953, Staudinger received the Nobel Prize in Chemistry (HAGE JR., 1998; NUNES; LOPES, 2014). The emergence of regenerated polymers, and later synthetic ones, in the early 20th century caused the current technological revolution. Plastics can be divided into three major groups, namely thermoplastics, thermoplastics (or thermosets) and elastomers (**Figure 13**):

Figure 13 – Division of Plastic Groups



Source: Adapted from (MICHAELI et al., 1995)

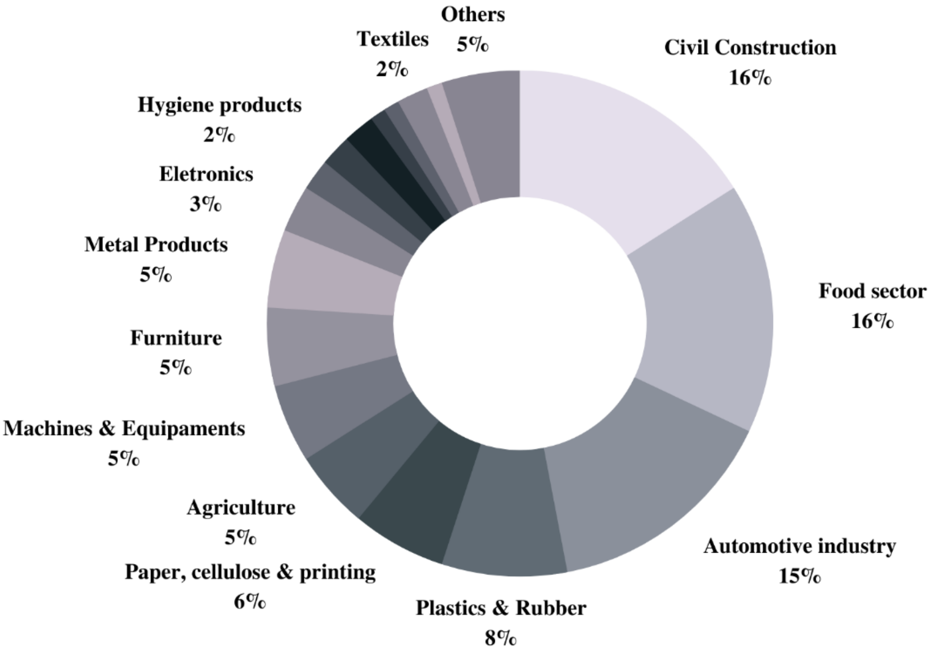
Thermoplastics refer to those that are fusible and soluble (thermo = heat). They can be melted repeatedly and easily solubilized. At room temperature they can vary from malleable to rigid or brittle. The main feature of these polymers is that they can be melted several times. Depending on the type of plastic, they can also dissolve in various solvents. Therefore, its recycling is possible, a very desirable characteristic for transformation companies that use recycled material in fractions, added to virgin resins, keeping its properties and characteristics unchanged, guaranteeing the quality of the products. They are differentiated between amorphous thermoplastics, which have a state of molecular order similar to glass and are transparent, and semicrystalline thermoplastics, presenting an opaque appearance. The thermoplastics category represents most plastics (NUNES; LOPES, 2014; NUNES; SANTOS, 2015).

Thermosets are rigid and tightly bonded in all directions. They are not deformable or fusible, and therefore are extremely stable to changes in temperature, and are brittle and firm at room temperature. They are resistant and durable materials, have high resistance to high temperatures of continuous use, good mechanical and chemical resistance, can be rigid or flexible, can form composites with the addition of fillers and reinforcements such as fibers, for example. They are commonly liquid resins, which when mixed with initiators or catalysts, initiate their polymerization reaction, forming crosslinks between the chains during the process called resin curing, becoming infusible. Elastomers, on the other hand, are not fusible, they are insoluble, but they can be softened. It has a molecular structure composed of a spaced chain and therefore it is quite elastic at room temperature (MICHAELI et al., 1995; NUNES; LOPES, 2014).

3.5.2 Thermoplastics: Characteristics and Use in the Textile Industry

Thermoplastic polymers can be used to manufacture products in various market segments, they are extremely versatile materials, which can be molded by various transformation processes, and can be applied from extremely simple parts to technical parts, with complex geometries. Despite continuous growth in the consumption of synthetic fibers in the textile industry, only 2% of all thermoplastic production in Brazil in 2009 went to the clothing and footwear sector (**Figure 14**).

Figure 14 – Main Buyers of Thermoplastics in Brazil



Source: Adapted from (NUNES; SANTOS, 2015)

As the graph shows, there are several applications for thermoplastics, however some stand out in the textile industry, such as polyesters, polyamides and polyolefins.

Polyolefins are formed by long-chain synthetic polymers having at least 85% by weight of ethylene, propylene or other olefin units. Polypropylene (PP) and polyethylene (PE) are two common members of the family. PP is extremely versatile as a fiber-forming material, unlike PE. Its manufacture began in the 50s, and since then the number of products manufactured with polypropylene has increased exponentially. The base cost of fiber production decreases with time and high demand, in addition to the continuous improvement in the quality of the final product and the possibility of application in a wide range of fibrous forms, such as geotextiles, filtration and hospital materials, disposable diapers, automotive fabrics and even protective clothing (LOBO; LIMEIRA; MARQUES, 2014; NUNES; SANTOS, 2015).

The characteristics of olefin fibers are good coverage and lightness, it has the lowest specific weight among all fibers. It is highly resistant to abrasion, chemical deterioration, mildew, perspiration and weather. Low moisture absorption, sunlight resistance, good washability. It is thermally bondable, moldable easily, resilient and pleasant to the touch (HAGE JR., 1998; LOBO; LIMEIRA; MARQUES, 2014; WILSON, 2011).

PP fibers are composed of amorphous regions and crystalline regions. Their developed filaments can vary in size from a micrometer to centimeters in diameter. The degree of crystallinity of the fibers is normally between 50% and 65%, depending on its processing. The crystallization rate of polypropylene is fast at low temperatures and decreases with increasing crystallization temperatures and with increasing molecular weight (LOBO; LIMEIRA; MARQUES, 2014; NUNES; LOPES, 2014).

Polyamide was developed in the 1930s by chemist Wallace Hume Caruthers and his team at DuPont, and nylon became the first commercially available synthetic fiber. This fiber is derived from a diamine and a dicarboxylic acid. There is a wide variety of diamines and dicarboxylic acids, so there are several materials available to produce nylon fibers. The most common versions on the market are nylon 66 (polyhexamethylene diamide) and nylon 6 (polycaprolactam) (LOBO; LIMEIRA; MARQUES, 2014; NUNES; LOPES, 2014; WILSON, 2011)

Nylon, as it is produced by chemical spinning, can be found in cut fiber, monofilament and multifilament, with excellent durability and excellent physical properties. They are semicrystalline polymers, providing hydrogen bonds between the amide chains, which makes the material highly resistant to extreme temperatures (high or low), in addition to properties such as rigidity, abrasion resistance, good chemical resistance, and low coefficient friction (LOBO; LIMEIRA; MARQUES, 2014).

This fiber has high durability and remarkable physical properties. Its high melting point makes it perform well at high temperatures. Because it is not considered a fiber that is pleasant to the touch, and together with its great resistance, it is ideal for use in rugs and carpets. It can be found with a mixture of fibers in nonwovens, increasing tear resistance, but it is not extremely common due to its relatively high cost (LOBO; LIMEIRA; MARQUES, 2014; NUNES; LOPES, 2014).

Polyesters are a combination of alcohols and carboxylic acids, and their first characteristics were developed in 1941, then called Terylene. Because it is a cheap, durable and relatively easy to obtain fiber, its expansion was rapid and continuous, appearing in textile factories with the intention of offering customers clothes with lower value (HAGE JR., 1998; LOBO; LIMEIRA; MARQUES, 2014; PEREIRA, 2009).

Its name refers to the connection of several ester monomers inside the fiber, formed from the reaction between an alcohol and a carboxylic acid. It is defined as a long-chain polymer chemically composed of at least 85% by weight of an ester, a dihydric alcohol and a terephthalic acid (MICHAELI et al., 1995; PEREIRA, 2009).

Due to its qualities, polyester fabrics have several applications. They are highly tenacious and durable, are resistant and withstand friction, have hydrophobic properties, in addition to being able to incorporate insulating capabilities. Because they do not wrinkle easily, it is common to find garments such as pants, shirts and suits made from this material, in addition to rugs, filters, sheets, and films (LOBO; LIMEIRA; MARQUES, 2014).

3.6 RECYCLING

3.6.1 Solid Waste

The constant emergence of new consumer goods, the result of constant technological growth, brings a material ‘need’, such as the latest generation cell phones, computers that perform functions more quickly, ‘fashionable’ clothing, etc. These new needs, together with existing ones (food, safety, transport, health, etc..) have caused the volume of disposable materials to increase considerably in the environment, compromising essential aspects for sustainable development (ABRELPE - ASSOCIAÇÃO BRASILEIRA DE EMPRESAS DE LIMPEZA PÚBLICA E RESÍDUOS ESPECIAIS, 2020; MANO; PACHECO; BONELLI, 2010).

After the production or use of solid materials, whether in urban, industrial or agricultural areas, residues remain. These wastes are discarded at random, especially in less developed areas. Solid waste is often called 'garbage', being considered as something useless, however there is a difference between the terms 'waste', 'garbage' and 'rejects' (BARBOSA; IBRAHIN, 2014; MANO; PACHECO; BONELLI, 2010):

- Garbage: Considered by its generators as unwanted, useless or disposable remains of its industrial and social activities, with no possibility of reuse.
- Waste: Any material, substance, object or good that is discarded resulting from human activities in society but can be reincorporated into other production processes as a secondary raw material.
- Rejects: Leftover of any substance submitted to a procedure and cannot be used again. They can be classified according to their origin (domestic, commercial, public, hospital, industrial, agricultural and debris); its chemical composition (organic or inorganic); presence of moisture (dry or humid); or their toxicity (hazardous, non-hazardous inert, and non-hazardous inert) (BARBOSA; IBRAHIN, 2014; MANO; PACHECO; BONELLI, 2010).

Solid waste from the textile sector covers a range of materials, including fabrics of different compositions (natural, artificial and synthetic fibers), as well as other materials (plastic, metal, paper, cardboard, thread), discarded and disposed of improperly, affecting directly affect social and environmental systems. In this sense, the garment manufacturing industry must follow the recommendations of the National Solid Waste Policy (PNRS). This is because, correctly discarded textile waste can become raw material for the industry itself or for other purposes, through recycling (FASHION REVOLUTION, 2020).

The management of disposal of solid textile waste from the clothing manufacturing industries presents possibilities for changing social and economic practices. The lack of waste management within a textile industry can lead to the following problems, among many others: climate change due to the incineration of production waste, adverse effects on water and its cycles, chemical pollution, these two caused by dyes and others chemicals, loss of biodiversity, excessive or inappropriate use of non-renewable resources, negative effects on human health. Concern about the impacts brought about by the increase in this waste is intensified by the non-reuse of most of these materials and their inappropriate destination (FASHION REVOLUTION, 2020; MENEGUCCI et al., 2015).

3.6.2 Types of Textile Recycling

When dealing with recycling, it should be considered that the term does not refer to the clothing, but to the fabric. It is necessary to do the dismantling and separation stage to finally send the parts for recycling (AMARAL et al., 2018). There are 04 recycling options. Incineration or energy recycling; Mechanical recycling, which is currently the most used and consists of recovering textile fibers from mechanical manipulation, using different methods such as shredding, disentangling and grinding. It is a less aggressive process than the chemical one and requires less energy and fewer chemicals; Chemical recycling process, where the regeneration of synthetic fibers is carried out from dissolution processes that partially or completely depolymerize the molecules of the textile fibers. It is more used in Asia and Europe, although it is still underdeveloped for large scale; And the enzymatic method, which is still being studied (AMARAL et al., 2018; NAVONE et al., 2020; SINDITÊXTIL - SP, 2012; VEZZÁ; COTAIT, 2006)

3.6.2.1 Mechanical

Mechanical recycling is the method most used globally to give new uses to waste, whatever it may be. In the case of plastics, it consists of mechanically transforming this material without changing its chemical structure, so that it can be used in the production of new materials (BRASKEM, 2021a).

The mechanical recycling process is the most used when talking about large-scale textile recycling and can also be called defibration. In this process, fabric scraps and leftovers, regardless of their composition, are used according to the capacity of the machine and the desired final product (MENEGUCCI et al., 2015).

Generally, recycling companies that opt for this method have machines that tear and shred the fabric. They are equipment capable of shredding from 50 to 3 thousand kilos of fabric per hour. The crushed fibers are transformed into bales and used by industries to produce stuffing for sofas, punching bags, comforters, carpets and other products (AMARAL, 2016; SINDITÊXTIL - SP, 2012).

3.6.2.2 Chemical

Chemical recycling is the most complex process of the three and offers the potential to create a new fiber of equal or higher quality. It involves the chemical processing of a material in order to fully recover the raw materials that went into it. In this model, the fibers are reprocessed, transforming their chemical structure for use as raw material for different segments or as a basic input to produce new textile fibers. However, chemical recycling is more expensive and requires large amounts of input to be economically viable (BRASKEM, 2021b; LI, 2020).

The chemical recovery of polyester, a material also found in PET bottles and other plastic products, consists of crushing, drying, cleaning, placing it in a melting and extrusion process (forcible output) at a temperature of 295° Celsius to obtain threads and textile filaments. The process with the polyamide and elastane fabric separates the fibers according to the color and quality of the yarn. Afterwards, they are placed inside a steel tank with formic acid. The contents of the tank pass through a filter that retains a solid part that forms, a kind of foam. This material is washed to remove any polyamide or elastane. The remaining liquid is heated in a condenser to 50°C, causing the formic acid to evaporate. In this process, the fabric becomes a thick mass that can be reused in the textile or chemical industry in the production of plastics (AMARAL, 2016; SADEGHI et al., 2021a).(AMARAL, 2016; SADEGHI et al., 2021a)

3.6.2.3 Thermoenergetical

Conventional thermal processing refers to the combustion of solid waste and its conversion into energy. As solid waste from the textile industry has a high energy content, it can be used as a raw material for generating thermal energy (PANASHE; DANYUO, 2020; PENSUPA et al., 2017)

Energy recycling and incineration are different things: in energy recycling, waste is used as fuel and energy is reused. Already in incineration, the energy of the materials is lost to the environment (BRASKEM, 2021c).

Thermoenergetic recycling is a practical treatment widely used to deal with textile waste, but it causes dioxin emissions during its process. Dioxin has been accumulating for a long time in the environment and in the food chain. These chemicals have been found to have a deleterious effect on human health, causing immune system damage, hormone disruptions and potentially cancer. Although this treatment can reduce about 95% of the waste mass, the formation of toxic compounds is still an environmental concern (PENSUPA et al., 2017).

3.6.2.4 Enzimatic

Enzymatic textile recycling involves the use of enzymes to break down the fibers in textile waste so that they can be separated and reused. Usually, the process involves five different steps, the initial sorting of fibers, the pre-treatment where the textile is cleaned and prepared for the enzymatic process, the enzymatic treatment, the separation of remaining fibers and the reuse (EGAN et al., 2023; NAVONE et al., 2020).

This method has several advantages over others, because it is able to producer higher quality recycled fibers with fewer impurities. In addition, enzymatic recycling is considered to be more ecofriendly, as it requires less water and energy, and produces fewer toxic emissions (EGAN et al., 2023).

4 METHODOLOGIES

4.1 RESEARCH TYPE

The present study has a qualitative character with a propositional sense in the end. It can be classified, as to its nature, as applied and exploratory in its purpose, in addition to having a bibliographic and empirical character. Exploratory research brings familiarization with the problem, in order to clarify it, and includes a bibliographic survey, interviews with professionals related to the topic and technical visits to industries (GIL, 2008). When related to the methods and procedures, can be classified as survey research to search, for data on fibers and their processes, as well as to gather as much information as possible about blended fiber separation processes and recycling methods available through interviews with textile and recycling companies.

4.2 METHODS

4.2.1 Analysis of environmental impacts of synthetic and blended fibers

4.2.1.1 Systematic literature review (SLR)

A first SLR was carried out to obtain information on the global and Brazilian environmental impacts of the synthetic fiber, blended fiber and plastic industry. It was carried out in Web of Science database, combining the topics of "fiber", "mixed", "blend", "textile", "separation", "recycling", "sustainable", "polyester", "cotton" and "process" resulted in a broader approach.

After further analysis, it was noted that the combinations between the terms 'fiber', 'blend’, 'separation', 'process' resulted in an improved view of the state-of-the-art concepts and processes around blended fiber textile recycling. After that, articles were selected considering the relevance of the contents. The bibliographic will be focused on textile fibers, in particular the emergence and use of synthetic fibers, characteristics of consumption behavior that enabled its great popularization, as well as the execution of the synthetic fiber manufacturing process from virgin material. A literature survey on blended fibers, their benefits, and disadvantages from the point of view of sustainability, and search for recycling processes that can be used. Also, a study on the concepts of circular economy and sustainable development.

4.2.1.2 Analysis of Sectoral Reports and Documents

This part consisted of a database search in reports and documents analyses, within different organizations and institutions, such as ABIT, ABRELPE, ABIPET, among others, to map out existing debates and knowledge about the impacts caused by industries that are part of the clothing production cycle, especially of pieces with composition from fossil sources and also how to have a better assessment of the impacts caused to the environment by such industries, and the identification of parameters so that the damage minimized. Understanding the circular economy concepts and how they can be applied in the recycling process. Theoretical data on circular economy that can be applied in the practice of recycling, obtained through visits and interviews with industries that use recycled fibers in their production and recycling cooperatives; In addition to studies on sustainability concepts and how they can be applied in the recycling process to minimize or cancel the damage caused to the environment. Search for sustainability concepts that can be applied in the practice of recycling.

4.2.2 Structured interviews

This part was the survey of companies that could be connected and that would benefit from such symbioses, aiming to reduce unnecessary material disposal and improve waste management from such industries. In order to better understand the process and the environmental impacts that occur during the production and recycling process, an SLR (systematic literature review) was developed to seek the highest environmental impact indicators seen in textile and recycling industries, and from this review the questions applied to the textile recycling industries, companies that work with textile waste management and reverse logistics and companies that use waste as raw material for their production. The SLR was carried out at ethe Scopus database, combining the topics of "sustainability", "circular economy", "indicators", "textile", "recycling", "sustainable", "polyester", "cotton" and "process" resulting in approximately 168 articles, after further analysis 47 articles were selected based on its content.

During the research, it was necessary to develop and apply a questionnaire with experts in the recycling sector. For the formulation of the questions, the systematic review of the literature presented in the previous topic was used. From the presenter indicators, those that have the greatest influence on the recycling industry and those that were addressed more frequently by the authors were selected.

5 RESULTS AND DISCUSSION

5.1 IMPACTS ON THE ENVIRONMENT

5.1.1 Textile Industry

The textile and clothing sector is a very important part of the Brazilian and world scenario in terms of its production and consumption capacity. In 2011, its revenues were US 60 billion, mainly due to the domestic market, which held 92% of national production. Economically, the sector represents 3.5% of the national GDP (Gross Domestic Product) and 5.5% of the GDP of the manufacturing industry, with a growth of over 10% since 2010 (ABIT - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA TÊXTIL E DE CONFECÇÃO, 2020; GARCIA; NÄÄS; VENDRAMETTO, 2012). Brazil is in fifth place among the countries with the largest production of textile manufacturing in the world and fourth place among the largest producers of clothing, second only to China, India, and Pakistan (FERREIRA et al., 2015).

However, due to its dimensions and the tendencies for accelerating production, the textile industry contributes heavily to the collapse of a sustainable system. The textile industry is responsible for 20% of the water contamination with toxic chemicals and heavy metals along the entire course of activity, in addition to using 387 billion liters of water annually (ZHU et al., 2020). The energy consumed is also a great concern, 1 trillion kW/h per year, along with releasing 10% of the total amount of CO_2 in the atmosphere (KALLIALA; NOUSIAINEN, 1999; ZHU et al., 2020). In addition to the environmental impact, there is social damage, such as the work conditions, the contact with chemicals during the oil extraction or cotton plantation. Brazil is prominent in the cotton production scenario due to the quality of its cotton. It presents 85% of all production certified by the Responsible Brazilian Cotton (ABR) program, which incorporates the criteria of the BCI (Better Cotton Initiative). In 2017, it reached 170 million tons, an increase of 12% in comparison to the last few years (FCEM, 2020), with 667 tons consumed in 2016/2017 according to ABRAPA (2017). The production process of Brazilian cotton textiles involves seven fundamental stages: farming, spinning, weaving, dyeing, finishing, clothing industry, and retail distribution.

Due to the number of pesticides and chemicals such as defoliants, used so that the leaves come off the plants and without staining the fibers, in cotton farming, and the dust generated in the spinning process, the harvest and manufacture of cotton have great environmental impact (HSIEH, 2007; TAUSIF et al., 2018).

Even before the fibers can be processed into textile products, they go through a bath of detergents or aqueous sodium hydroxide to dissolve the waxy outer layer in a process named "scouring". Such chemical products are also used in the improvement of the overall quality and adhesion of dyes. In addition, prior to the dyeing process, the cotton is bleached so that its natural color does not interfere with pigmentation, improving the final color. Although the carcinogenic property of formaldehyde is known and a great concern, it is still used to provide a durable finish and decrease the wrinkles in fabrics (GROSE, 2009; ZONATTI, 2013).

Despite its “natural” and “green” image, cotton production has become increasingly associated with grievous fertilizers (manure) and water contamination (CHEN; BURNS, 2006). Even though some types of responsible cotton have been introduced to the market, conventional white cotton still counts for most of it. Organic cotton, for example, accounts for only about 2% of total US cotton production in 2006 (HSIEH, 2007), since then, the global cultivation of organic cotton grew 10% in 2018 compared to 2017 (TAUSIF et al., 2018). In Brazil, there was a significant increase in the number of organic cotton farmers, which went from 232 to 308 in 2017, and the farming of naturally colored organic cotton (**Figure 15**) (THE TEXTILE EXCHANGE, 2018).

Figure 15 – Comparison Between Conventional Cotton and Naturally Colored Organic Cotton

Source: Author

On the other hand, polyester has become a fiber commonly employed in the manufacture of clothing in Brazil, being a strong competitor to cotton, especially when used in blended fibers. According to ABRAFAS (ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FIBRAS ARTIFICIAIS E SINTÉTICAS, 2019), the apparent consumption of synthetic fibers in 2019 was 709,848 tons, of which around 79% is polyester. Fabrics made from synthetic fibers allow wide applications due to their better physical and chemical characteristics in comparison with natural fibers, such as excellent dimensional stability and robustness, a high degree of resistance to wrinkles, good mass elasticity, and handling while hot (LADCHUMANANANDASIVAM, 2006; PEZZOLO, 2017).

Regarding its production, the impacts of polyester start with the extraction of oil, a finite natural resource, with great energy consumption, highlighting the burning of fuel oil and firewood in boiler houses (LADCHUMANANANDASIVAM, 2006; SINCLAIR, 2015). The resin is melted in an autoclave, without the use of solvents, and the polymeric solution is extruded through a spinneret. The filaments are then solidified in the air by cooling. After cooling and centrifuging, the fibers are ready to be used without another cleaning or washing process (CHEN; BURNS, 2006; MAJUMDAR et al., 2020). After the formation of the fiber, there is no need for finishing and coloring processes in most cases, everything is done before the formation of the fiber. However, it is in this part of the process that the greatest environmental impacts are found.

During the manufacturing process, nitrous oxide gas is emitted, a more harmful cause for global warming and greenhouse effect than carbon dioxide (GOYENA, 2019). In addition, chemical dyes and other products are used to modify the physical and chemical properties of the fiber. The use of polyester is not free from pollution, during its production volatile organic compounds and effluents containing antimony are emitted into the atmosphere. In addition, fabrics composed of this fiber when washed release amounts of microfibers that pollute the environment (KLEIN et al., 2020). Environmental damage must be considered for the spinning processes, since the machinery used is complex and demands a large use of energy, often from non-renewable sources. Also, it is originated from the extrusion part, which demands energy and a high control in the machinery temperature, since any unforeseen changes can modify the structure of the polymer generating waste and making the commercialization unfeasible (SANDIN; PETERS, 2018a).

Recycling non-degradable plastics significantly reduces this waste environmental damage by reducing the accumulation in the environment and reducing the need for oil mining (SADEGHI et al., 2021a). High recycling rates lead to high net environmental benefits, so the use of PET waste to manufacture products is increasing social and environmental values (SADEGHI et al., 2021a).

Table 04 summarizes the impacts caused by the production processes of organic cotton, conventional cotton, conventional polyester, and recycled polyester.

Table 04 – Comparison Between the Environmental Impacts of the Production Processes of Organic Cotton, Conventional Cotton, Conventional Polyester, and Recycled Polyester

Conventional Cotton	Organic Cotton	Conventional Polyester	Recycled Polyester
• Uses high quantities of water • Pollution of soil and water • High amout of harmful pesticides used • Chronic diseases (infertility, weakness) due to the use of pesticides • Biodegradable	• Lower use of water compared to conventional cotton • Eco-balance between pests and beneficial insects • No use of pesticides • Biodegradable	• Environment contamination with microplastics • Non renewable source • High intake of energy • Releases toxic chemicals during production • Non-biodegradable	• Uses less water and energy when compared to conventional polyester • Needs toxic chemicals during recycling process • Environment contamination with microplastics • Non-biodegradable

Source: Adapted from (CHEN; BURNS, 2006; SADEGHI et al., 2021; TAUSIF et al., 2018)

As shown in Table 04**,** besides the impacts caused by production, the damage is also noted in the recycling of fibers, even if on a small scale and outweighed by its benefits (ABBASI; MOHADES MOJTAHEDI; KOTEK, 2020). According to studies from the Institute of Economic and Applied Research (IPEA - INTITUTO DE PESQUISA ECONÔMICA E APLICADA, 2012), mechanical recycling has less impact compared to chemical and energy recycling. This form also presents a larger consumer market for recycled fibers, with a lower cost of the final product.

5.1.2 Plastic Industry

The petrochemical industry is a subdivision of the chemical industry responsible for the development and processing of petroleum products, through the improvement of raw materials such as naphtha and natural gas. In Brazil, the petrochemical sector is distributed in industrial poles, such as the productive chains of Cubatão-SP, Camaçari-BA, and Triunfo-RS. To meet the wide demand, they are divided into three production lines (BARBOSA; IBRAHIN, 2014):

- First generation: Producers of basic petrochemicals, using chemical processes such as cracking, pyrolysis, etc. Its main primary products are olefins (ethene, propylene and butadiene) and aromatics (benzene, toluene and xylenes) and secondarily solvents and fuels.

- Second generation: Producers of thermoplastic resins (polyethylene and polypropylene) and intermediates such as PVC, polystyrene, thermosetting resins, synthetic fibers, etc.
- Third generation: These are transformation companies that supply packaging, parts and utensils for the food, civil construction, electronics, automotive industry, etc. sectors.

There is great diversity in the use of polymers, and on the one hand, it is possible to find benefits in relation to their use, such as replacing the use of raw materials from natural sources (fauna and flora), which if not well managed, can lead to the depletion of natural resources and the extinction of species in this ecosystem. The major problem related to the plastics industry is the abusive use of the main raw material naphtha, which, being derived from petroleum, is not a renewable source (BARBOSA; IBRAHIN, 2014; GORNI, 2015).

With the growth of the disposable culture, the increase in consumption and the disposal of non-biodegradable materials in the environment, the companies' environmental liabilities and the environmental pollution resulting from the high volume of plastic waste have considerably increased (**Figure 16**), especially in the large urban center (BARBOSA; IBRAHIN, 2014). In the report carried out by Break Free From Plastic (2020) a comparison is made that if the use of plastic were a country, it would be the fifth largest emitter of greenhouse gases in the world. Like a fossil fuel, plastic is a polluter from the moment it is extracted and continues to cause pollution until the last stage of its life cycle.

Figure 16 - Egrets and Cows as They Gather on the Top of a Waste Dump in Meulaboh, Indonesia

Source: AFP/Chaideer Mahyuddin at (BFFP - BREAK FREE FROM PLASTIC, 2019)

According to the Heinrich Böll Foundation (2020) Brazil produced about 79 million tons of garbage, with plastics representing 13.5% of that volume, or 11.3 million tons. The number makes the country the fourth largest producer of plastic waste in the world. Of this number, only 145 thousand tons are recycled, 1.28% of the total, compared to the global average of 9% and rates of 34.6% and 21.9% in the United States and China, respectively.

According to the Atlas of Plastic (HEINRICH BÖLL STIFTUNG, 2020), studies were carried out on the amount of garbage on 170 Brazilian beaches, results show that 54% of these places are in a dirty or extremely dirty situation. According to the same study, in the ranking of the biggest polluters of the ocean by plastic, Brazil occupies the 16th position. From 1950 to 2017, humanity produced more than 9 billion tons of plastic, representing more than a ton for every person alive on the planet today.

Concerns about single-use plastic are intensifying, especially with the Covid-19 pandemic. According to ABRELPE (2020) there was an increase of 25% to 30% in the collection of recyclable materials during the pandemic in early 2020, representing a major problem for Brazil, where only 1% of the 11 million tons of plastics are recycled produced per year. For comparison purposes, this index reaches 97% in the case of aluminum cans.

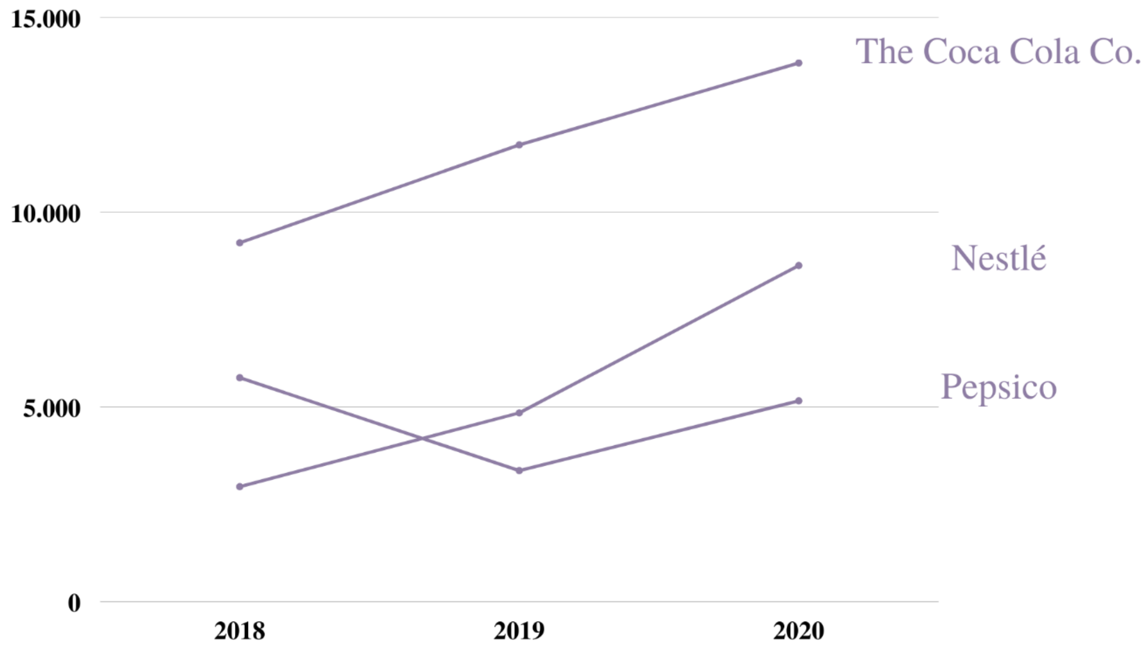
Parker (2020) a columnist for National Geographic Brazil, states that the amount of plastic waste dumped into the oceans every year will almost triple by 2040, reaching 29 million metric tons. On the other hand, the petrochemical industry plans to increase the pace of world plastics production by 40% by 2030 and hundreds of billions of dollars are being invested, perpetuating the current situation (BFFP - BREAK FREE FROM PLASTIC, 2020)

Most single-use plastics simply cannot be recycled or are not economically viable to be recycled, especially when the cost of virgin plastic is cheaper. And even in countries where the plastic recycling system is advanced, recycling rates remain extremely low and most plastics end up being incinerated, in landfills or thrown into the environment (BFFP - BREAK FREE FROM PLASTIC, 2020). Outdoor plastic incineration and burning is on the rise, and if there are no major changes, it could go from 49 million metric tons in 2016 to 133 million metric tons in 2040 (PARKER, 2020).

According to the brand audit carried out by the BFFP (BREAK FREE FROM PLASTIC, 2020), which engaged 14,734 volunteers in 55 countries, 346,494 pieces of wasted plastic were collected. Coca-Cola, Nestlé, and PepsiCo are the top three single-use plastic polluters, followed by Unilever; Mondelez International; Mars, Inc.; Procter & Gamble; Philip Morris International; Colgate-Palmolive; and Perfetti Van Melle.

Seven of these biggest polluters have joined the New Plastics Economy Global Commitment - an Ellen MacArthur Foundation project that brings together hundreds of companies to work towards a better use of plastic through voluntary commitments, however little effort has been made on the part of brands, and when done, it is only on a superficial level. In the last three years, it is possible to see an increase in the disposal of single-use plastics associated with the three main polluting companies (**Figure 17**) (BFFP - BREAK FREE FROM PLASTIC, 2020).

Figure 17 – Three-Year Comparison of the Number of Plastics Found by the BFFP Brand Audit



Source: Adapted from (BFFP - BREAK FREE FROM PLASTIC, 2020)

It is often claimed by the plastic industry that incinerating plastic is an environmentally friendly method of disposing of plastic. Several municipalities incinerate plastic waste as a normal way of disposing of it instead of putting it in landfills, in addition to using it as fuel in cement kilns or to generate energy in "waste-to-energy" plants. However, incinerating plastic creates serious problems, Gaia (2019) researchers found that incineration emits carcinogenic toxins, chemicals that can cause hormone problems, and other dangerous pollutants (BFFP - BREAK FREE FROM PLASTIC, 2020; GAIA, 2019). In the United States and the United Kingdom, incinerators are wrongly located around communities, raising concerns about the impact on air quality, noise and traffic pollution, and the impact on your health. The amount of waste incinerated in the UK increased from 4.9 million tons in 2014 to 10.8 million tons in 2017-18 (THE GUARDIAN, 2020).

5.2 EFFORTS TO REDUCE THE ENVIRONMENTAL IMPACT

Concerns about environmental issues have forced the textile industry to respond gradually by introducing textiles into environmentally safe manufacturing processes. During the processing of textiles, pollution also comes from the finishing and dyeing/printing processes. So far, several new technologies or materials have been used to reduce the production of waste by-products together with air and water pollution (ZHU et al., 2020).

Pollution from fiber production is the area least addressed by the textile industry. As discussed earlier, herbicides and pesticides have been used extensively during cotton cultivation. Although some environmentally responsible alternatives have been developed, the heavy pollution from conventional cotton cultivation still poses a major threat to the environment and human health worldwide.

For cotton, organic enzymes have been used for cleaning that is much more benign from an environmental point of view compared to sodium hydroxide (KALLIALA; NOUSIAINEN, 1999; THE TEXTILE EXCHANGE, 2018). In addition, ultrasound, an environmentally friendly tool, has been used to increase enzyme activity during the treatment of cotton fibers (CHEN; BURNS, 2006). In addition, the first caustic soda recovery system in a textile factory was installed to capture and distill caustic soda, with sulfuric acid being used to neutralize it for reuse.

The first air pollution control unit was also installed in a textile factory in the United States (HAHLADAKIS; IACOVIDOU, 2019; RODIE, 2002). In textile dyeing, a series of measures have been implemented to reduce pollution, such as the use of supercritical CO_2 to replace the water in textile coloring without effluents (PENSUPA et al., 2017) along with environmentally friendly low sulfide dyes have been used in cotton dyeing (RODIE, 2002).

Efforts to recycle plastic fiber wastes have grown over the past two decades. Certainly, not all plastics can be as easily recycled as others, and not as many times. The fiber composition influences greatly the process. PET bottles can easily be transformed into a fabric of great quality, and at the same time, prevent what would be waste if incorrectly discarded (ABBASI; MOHADES MOJTAHEDI; KOTEK, 2020; THIOUNN; SMITH, 2020). Many fashion companies are forming alliances with NGOs (non-governmental organizations) such as Adidas and Parley for the Oceans (**Figure 18**) (CICLO VIVO, 2020). In Brazil, there are many companies already trading fabrics made with recycled PET bottles, such as Pettenati, Macias Têxtil and Aradefe. Also, clothing brands such as C&A and Osklen already present items with recycled polyester in their stores.

Figure 18 – Ocean Cleanup by the NGO and the End Result of the Collab Between Adidas And Parley For The Oceans

Source: Adapted from (ADIDAS, 2021)

Relative to the process, the use of cleaner production actions can be easily implemented, although the initial cost can be high. In Brazil, this practice is already disseminated, for example, Cermatex Indústria de Tecidos Ltd., located in Sao Paulo and one of the first in the country to invest not only in ecological products but also green process, substituted natural raw starch with soluble starch for yarn sizing through the installation of gum storage tanks. This resulted in a 50% reduction in the organic load of the generated effluent. In addition to a 10% reduction in water and energy consumption (GIANNETTI; ALMEIDA, 2006; SADEGHI et al., 2021a).

Furthermore, the use of natural energies, such as solar, winds, and biomass, although not yet highly implemented, may come as a less polluting option for the textile production process. Solar energy has a great advantage over other energy sources because it is not polluting, does not contribute to the greenhouse effect, does not need turbines or generators and its cost is rapidly decreasing, especially in Brazil, wherein any part of the territory, good levels of insolation are found (MANO; PACHECO; BONELLI, 2010).

Creating clothing that reduce the impact caused by consumer care, such as the part of the life cycle in which the piece is washed, dried and ironed, brings enormous benefits in relation to its use (BERLIM, 2012; SALCEDO, 2014). Polyester clothing, for example, can use 4x more energy during use than is spent on fiber fabrication and garment making (FLETCHER; GROSE, 2011). Of course, this depends on the purpose of each outfit, winter coats are washed much less often when compared to a basic garment that is worn more often. There are two important actions that can be identified for better consumption such as the increase of durability by encouraging cultural changes, consumption of quality products, so that less replacement frequency is needed, use of multifunctional products, and even visiting to seamstresses for repairs to be made. The second is the awareness of use labels, these tags have crucial information for each piece of clothing to last longer (BERLIM, 2012; FLETCHER; GROSE, 2011; GIANNETTI; ALMEIDA, 2006). Furthermore, respecting the washing temperature means that less energy is wasted. Levi's analyzed the life cycle of one of its products and revealed that in a single pair of jeans, 60% of the total CO_2 emissions are attributed to consumer care, and that of a total of 3480.5 liters used in the cycle of the life of a piece, domestic washing is responsible for 2000 liters. This led the brand to create a consumer education campaign, talking about the benefits of washing with low temperature and less frequently, in addition to using a label on the pieces explaining that when the piece was no longer used, it could be donated to Goodwill (**Figure 19**) (FLETCHER; GROSE, 2011).

Figure 19 - Levi’s Consumer Education Campaign

Source: (FOLLOW THE COLORS, 2016)

Some actions concerning the use of materials can also be applied to reduce the overall impact of fashion industry, such as a relative reduction in the amount of material per unit of product, along with the increase in material circulation in the system before final disposal; Decrease the use of water with modifications during the manufacturing process, encouraging water reuse, and modifying the conditions of use; Design for reuse either in the same or in other functions, remanufacture or reform, creating a product that is optimized for repair, or easy to disassemble and separate for later reuse of parts and components, and for recycling, giving preference to monofiber parts -which are made with only one class of material- (BERLIM, 2012; FLETCHER; GROSE, 2011; GIANNETTI; ALMEIDA, 2006).

5.3 TEXTILE LIFE CYCLE

The life cycle is the set of all the steps necessary for a product to fulfill its function in the productivity chain, from its development (design and production), through its distribution, use, disposal, to the last treatment of the materials that the product contains. compose for reuse (CAMPOS; GOULART, 2017; FLETCHER; GROSE, 2011).

Life cycle thinking expands the concept of cleaner production from the beginning of the process to also include environmental, social and economic impacts. It aims to reduce the use of natural resources and emissions into the environment, in addition to improving socioeconomic points (BRAUNGART; MCDONOUGH, 2002; FLETCHER; GROSE, 2011).

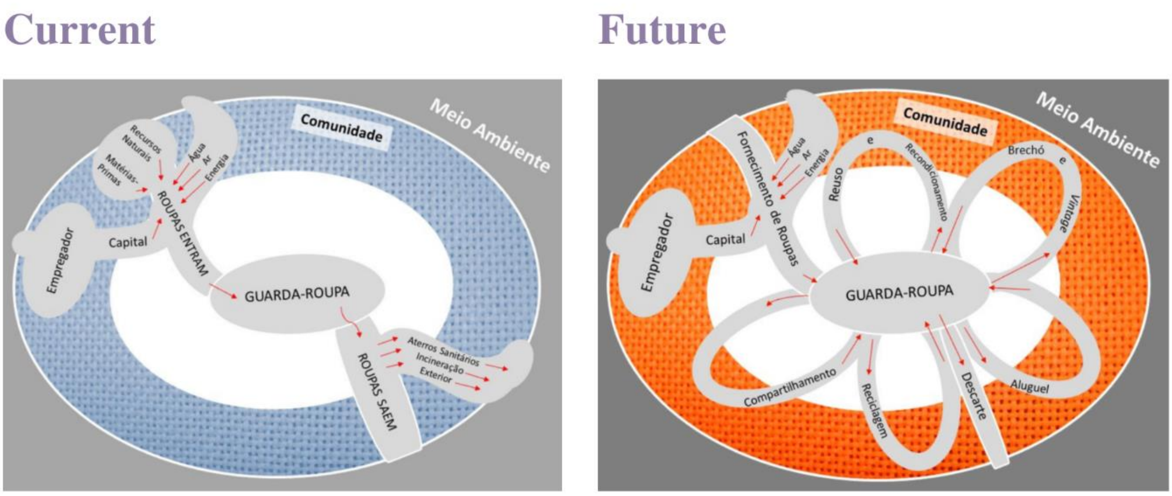
- Understanding and changes in the lifecycle mechanism: It is taken into account that the garment has a lifecycle that extends beyond its arrival at a store. The supply chain is very concerned with the design, manufacture and marketing of clothing, but it is vital to consider the use and disposal phases. It is up to the designer to influence consumer decisions in these two stages, questioning the speed and concept of fashion.
- Designer's responsibility: The designer is responsible for coordinating the entire collection development process and needs to act as a link between many people (both consumers and future clients, employees and partners) during the cycle. It is necessary that the designer actively acts as a supervising agent of the entire process, so that the approach to sustainable fashion does not become just symbolic and is weakened with the practice of greenwashing.
- Innovations and Improvements: There are several resources available that offer information on raw materials, textile techniques, production, and consumer care, but as the designer becomes increasingly aware of sustainable fabrics, fibers, and techniques. It is a challenge to engage with sustainability while meeting the large number of goals and targets established by the collection brief. It is necessary that the life cycle of a piece be considered from the beginning of the development of a

collection, identifying possible impacts that the piece may cause, creating solutions and improvements. A good prior organization is necessary, as well as a great knowledge of the activities and detailing of the steps foreseen for the life cycle of a part.

The authors Fletcher and Grose (2011) bring the idea of a wardrobe metabolism (**Figure 20**), which shows in a summarized way the difference between life cycles of a piece, one in the current system of linear economy, and the other showing the metabolism 'of future'. In the current version, natural resources and raw materials enter the system from the environment, and through processes, are transformed into clothes, which go to our closets, where they are used until they are discarded in landfills, incineration, or incorrectly in nature.

As for the future metabolism, it is possible to notice the recurring cycles that the pieces go through, which may start from virgin raw material, or from products that have already been recycled. Within this cycle, the garment undergoes several transformations in order to remain as long as possible 'in the wardrobe', with processes such as reuse, recycling, shopping at thrift stores, repairing, sharing and renting as some steps (FLETCHER; GROSE, 2011).

Figure 20 - Metabolism of a Wardrobe



Source: (FLETCHER; GROSE, 2011)

Life cycle assessment (LCA) is a method used to assess the environmental impact of goods and services. The analysis of a product, process or activity is a systematic evaluation that quantifies the flows of energy and materials during the life cycle of the product (GIANNETTI; ALMEIDA, 2006). It considers the stages "from cradle to grave", when considering the life of the product ended after the use for which it was intended. The steps "from cradle to cradle" can also be considered, when reverse logistics is applied to the product after disposal, that is, when the waste returns as raw material at the beginning of another process. This assessment includes all stages of a product's life, from raw material extraction, through manufacturing processes, transport and distribution, consumption, possible recycling route and final disposal (BRAUNGART; MCDONOUGH, 2002; GIANNETTI; ALMEIDA, 2006).

The main focus of LCA is the product, taking into account all the processes involved that are analyzed to determine the amount of raw materials, energy, waste, and emissions associated with the product's life cycle (GIANNETTI; ALMEIDA, 2006).

The use of LCA is extremely useful in the textile sector, as a way of proving, for example, which type of fiber or garment performs a better function for the intended process, as well as verifying its ability to be recycled (ZONATTI, 2016).

The stages for carrying out an LCA can be classified according to ISO 14040 as defining the objectives and limits of the study, choosing the functional unit; Inventory of inputs and outputs of energy and materials relevant to the system under study; Assessment of the environmental impact associated with inputs and outputs of energy and materials, or the comparative assessment of products or processes; Interpretation of data necessary for a correct analysis by the reader of the results obtained (GIANNETTI; ALMEIDA, 2006).

The systems evaluated by the LCA are open, making it important to develop a plan to carry out the procedure. The reasons why the evaluation will be carried out must be established, in addition to defining the boundaries of the system, the objective of the evaluation and a strategy for collecting and analyzing the data, as well as the method used for the collection (GIANNETTI; ALMEIDA, 2006).

Conducted in the United States by Franklin Associates in 1992, the first study on LCA sought to quantify and compare the consumption of water, energy, and emissions to air, soil and water related to disposable diapers and sanitized fabric diapers in domestic washing procedures and commercial. The functional unit considered was one day using diapers, considering the consumption of 9.7 cloth diapers/day, and 5.4 disposable diapers/day. According to Levan (1998), it was concluded that fabric diapers sanitized in a domestic washing procedure consume more energy compared to disposable ones, and that the same ones when washed in a commercial washing procedure consume more water. Regarding emissions to the environment, the highest atmospheric emissions are related to fabric diapers sanitized in a domestic washing procedure, the largest generation of solid waste to disposable diapers.

When related to the textile industry, the life cycle assessment allows the comparison between different fibers, being able to point out the viability of recycling or reuse and its real environmental benefit (ZONATTI, 2013) as can been seen in table 05:

Table 05 – Environmental Impacts of Different Fiber Types for Lifecycle Assessment

	Polyester	Cotton	Viscose	Polyester-Cotton Blend
Energy Use (MJ/kg)	49-75	10-29	47-103	29-54
Water Use (L/kg)	54-91	7,000-29,000	1,500-3,500	1,600-2,800
Ecological Footprint in Pt during Virgin Fiber Production	5.6-7.6	3.3-3.9	6.5-8.5	5.5-6.5
Ecological Damage - Human Health in Pt during Virgin Fiber Production	0.6-0.8	0.6-0.8	0.8-1.2	0.6-0.8
Ecological Footprint in Pt due to Landfilling	0.4-0.6	0.4-0.6	0.4-0.6	0.4-0.6
Ecological Damage - Human Health in Pt due to Landfilling	0.05-0.1	0.05-0.1	0.05-0.1	0.05-0.1

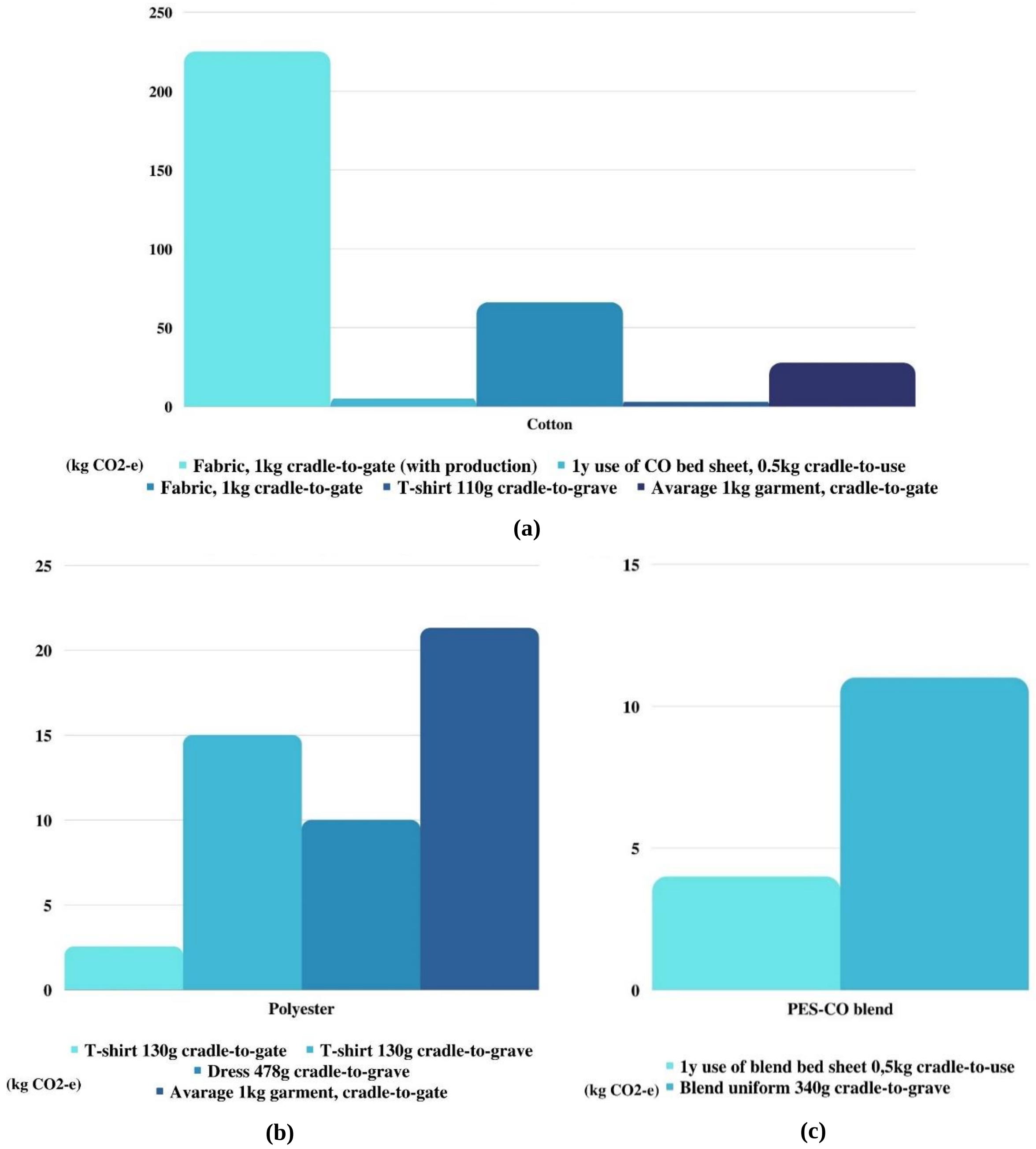
Source: (LIU et al., 2020a; MADIVAL et al., 2009; PERIYASAMY; MILITKY, 2020; VAN DER VELDEN; PATEL; VOGTLÄNDER, 2014a)

However, a related challenge is that part of LCA data available could be outdated or not transparent enough. In addition, due to the diversity of textile products, the evaluation of the environmental performance by textile products becomes difficult, but its impacts can be evaluated considering each product composition (LIU et al., 2020b; PENSUPA et al., 2017).

The textile industry has been fairly late in terms of carbon footprint studies, although the literature about the LCA of fabric and clothing production is exponentially growing. Generally, carbon footprint calculations of textile industries are made within the context of an environmental management system (EMS). However, as material and waste are lost throughout the production processes, this means the data in the literature on the carbon footprint of a given material do not transfer correctly to the carbon footprint of the final product unless all material loss data were studied in detail. Manufacturing and use are typically the biggest contributors to the carbon footprint, due to high energy use (mainly in washing) and fossil fuel use (mainly in logistics) (PETERS et al., 2015; ZHU et al., 2020).

Due to the variables regarding the results of LCA studies, practitioners and decision-makers should interpret these results based on the specific methodology and assumptions of each considerate study. These differences are shown in **Figures 21a**, **21b**, and **21c**, which detail the carbon footprint of various textiles and their singular studied scope.

Figure 21 - Carbon Footprints of (a) Cotton Textile Products; (b) Polyester Textile Products; and (c) 50/50 PES-CO Blend Textile Products



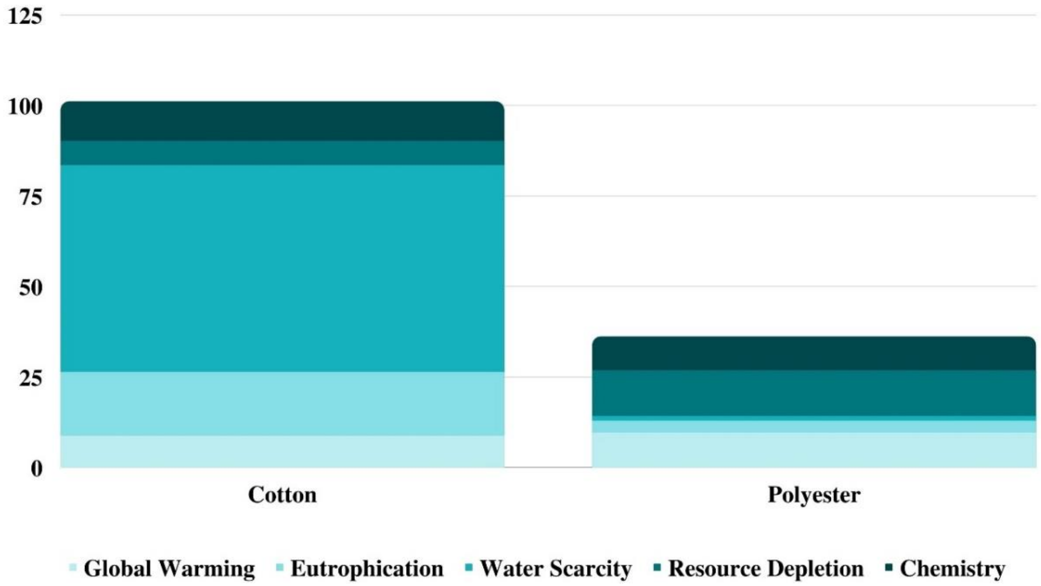
Source: Adapted from (PETERS et al., 2015; VAN DER VELDEN; PATEL; VOGTLÄNDER, 2014b)

Considering the blend fibers, such as PES-CO, the carbon footprints can be diminished about individual fibers due, among other factors, to the dyeing process of fiber before spinning, which can keep its energy-saving, reduce emissions and environmental impact (PETERS et al., 2015; WAGAYE; ADAMU; JHATIAL, 2020).

According to the Higg Index, the technology platform that shares environmental fashion data from the Sustainable Apparel Coalition (SAC), there are five different impact areas: (1) greenhouse gases; (2) water efficiency; (3) eutrophication; (4) fossil abiotic depletion; and (5) chemistry. It tries to come up with a measurement for the average cradle-to-gate impact associated with a kilogram of material, whether it is natural or synthetic fibers (SUSTAINABLE APPAREL COALITION - SAC, 2020a). However, it cannot be used as a singular method of determining environmental sustainability, since it only considers how the materials are manufactured, and not used, end of cycle, or the social impacts of the products. Siqueira et al. (2022) mention that efficient management based on sustainable criteria urgently requires programs to evaluate new methods and possibilities, especially concerning the end of lifecycle of a product.

Polyester has an impact of 44 scores per kilo. Other thermoplastics used in the textile industry, such as PP, PU, PTT, PLA, have similar impact values, ranging from 37 to 54 scores per kilo (SUSTAINABLE APPAREL COALITION - SAC, 2020b). For cotton fiber from conventional production, the impact is 60.6 scores per kilo, but organic cotton fiber has an impact of only 11.2 (SUSTAINABLE APPAREL COALITION - SAC, 2020a). The comparison between cotton and polyester fibers is shown in **Figure 22**. Since the Higg is cradle-to-gate, the toxic impacts of treatments to provide different proprieties to the fabric, commonly water/stain proofing and fire retardant, are not included in the MSI (Material Sustainability Index) score, since it occurs downstream in fabric use and disposal.

Figure 22 - Comparison Between Cotton And Polyester Fiber According To the Higg Index Different Impact Areas



Source: Adapted from SUSTAINABLE APPAREL COALITION – SAC (2020b, 2020a)

Recycled cotton yarns present far fewer environmental impacts than virgin cotton yarns, mainly concerning the land occupation and water irrigation needed for cotton cultivation (KALLIALA & NOUSIAINEN 1999; LIU et al. 2020; SUBRAMANIAN et al. 2020).

The impacts on climate change, water usage, fossil depletion, and human issues due to toxic chemicals have been observed, although all impacts are lessened in the recycling of cotton fibers, along with lower use of energy, water for cultivation, and land use for planting. In this way, between the recycled and virgin cotton yarns, the most noticeable impacts are focused on cotton cultivation, which the recycled material does not need, and the spinning process (LIU et al. 2020).

Regarding the LCA of post-consumer PET recycling, there have been reports about better environmental gains achieved from mechanical recycling when compared to landfill disposal or incineration, and the total energy required to recycle PET bottles are 14–17% of the virgin PET manufacture (GERE & CZIGANY 2020; SADEGHI et al. 2021).

Table 06 – Life Cycle of Regular vs. Recycled Polyester

Aspect	Regular Polyester	Recycled Polyester
Raw Material	Petroleum-based	Post-consumer PET
Extraction	Drilling, refining, chemical processing	Collection, sorting, cleaning, shredding
Production	Spinning, weaving, finishing	Spinning, weaving, finishing
Energy Use in Production (MJ/kg)	High: 49-75	Low/Moderate: 18-52
Water Use in Production (L/kg)	High: 54-91	Low/Moderate: 6-51
Emissions (kg CO2 eq/kg)	High: 4.7-7.6 (Greenhouse gases, air pollutants)	Lower: 1.5-5.5 (due to recycling process)
Waste Generated (kg/kg)	High: 0.2-0.4 (Landfill waste)	Lower: 0.01-0.2 (due to recycling process)
Distribution	Transportation of raw materials, finished product	Transportation of raw materials, finished product
Use	Depends on application	Depends on application
End of Life	Non-biodegradable, contributes to microplastic pollution	Recyclable, reduces landfill waste and need for virgin polyester production

Source: **(MADIVAL et al., 2009; PERIYASAMY; MILITKY, 2020; SHEN; WORRELL; PATEL, 2010; VAN DER VELDEN; PATEL; VOGTLÄNDER, 2014a)**

Recycled PET, when compared to virgin PES fibers (**Table 06**), can save between 45-85% of non-renewable energy use, being connected with the reduction of global warming potential (GWP). These recycling processes show the reduction of the environmental impacts (**Table 07**), being 76% from mechanical recycling, 54% via semi-mechanical recycling, and around 24 – 36% via chemical recycling in relation to the virgin polyester production (PERIYASAMY & MILITKY 2020; SADEGHI et al. 2021; THIOUNN & SMITH 2020).

Table 07 – Environmental Benefits of Recycling versus Incineration

	Polyester	**Cotton**	**Viscose**
Energy conserved in kW hours per ton (a)	7203	3531	4889
Energy generated in kW hours per ton (b)	1761	611	611
(a) Substituting secondary materials for recycled materials **(b) Incinerating municipal solid waste**			

Source: (MADIVAL et al., 2009; VAN DER VELDEN; PATEL; VOGTLÄNDER, 2014a)

According to studies presented by van der Velden et al. (2014), the thinner the yarn, the higher the environmental pollution per kilogram, since with yarn sizes less than 150 dtex (Tex is the yarn count number represented as the mass in grams per 1,000 meters), the spinning and weaving process consume more energy, which has greater eco-impact than the production of cotton fiber (LIU, ZHU et al., 2020; VAN DER VELDEN et al. 2014). It is also shown that a higher count number for the yarn can lessen the environmental burden since there is a decrease in energy during the processes of spinning and weaving thicker materials (LIU, HUANG, et al. 2020; VAN DER VELDEN et al. 2014).

The LCA also takes into consideration the type of dyes used in which kind of fiber. Polyester is dyed with disperse dyes, along with dye carriers that, when used for dyeing processes, present concerns about the toxicity and volatility of this group of chemicals, whereas cotton is dyed with reactive dyes. In the case of fiber blends, the PES fibers need to be dyed separately from the cotton fiber, therefore, blends tend to have larger environmental impacts than non-blended fibers (PERIYASAMY & MILITKY 2020; VAN DER VELDEN et al. 2014).

5.4 SUSTAINABILITY INDICATORS IN THE TEXTILE INDUSTRY

When talking about sustainability in the textile industry, there are several indicators to measure the potential for damage to the environment, animals and humans (MAGALHÃES; SILVEIRA; SEIBEL, 2020; MUTHU et al., 2012b). These indicators are essential to objectively quantify the ecological performance of industries and may indicate progress or setbacks in the proposed sustainable objectives (MUTHU et al., 2012b; SHIRVANIMOGHADDAM et al., 2020; VELENTURF; PURNELL, 2021).

Sustainability indicators are also a way of ensuring the company's transparency and responsibility towards the environment and society in general. These indicators and objectives can be within a wide range of variety, from the use of materials with less environmental impact, control and reduction of polluting gases, garbage and waste management, even the implementation of actions with a positive impact (GHISELLINI; CIALANI; ULGIATI, 2016; KANT HVASS; PEDERSEN, 2019; MUTHU et al., 2012b).

Based on this need to understand the use of indicators in the textile recycling industry, a systematic review of the literature was carried out, seeking the indicators most frequently used by companies. This SLR resulted in the results shown in **Table 08**:

Table 08 – Systematic literature review of Indicators for Sustainability

Author	Indicators for Sustainability
(GHISELLINI; CIALANI; ULGIATI, 2016)	• Circular economy principles • Design for reuse and recycling • Use of renewable energy
(CEID - CIRCULAR ECONOMY INICIATIVE DEUTSCHLAND, 2021)	• Design for reuse and recycling • Production of items with long lifecycle
(MAJUMDAR et al., 2020)	• Use of biodegradable materials • Use of recycled materials
(SANDVIK; STUBBS, 2019)	• Design for reuse and recycling • Production of items with long lifecycle • Reduction of waste
(DE OLIVEIRA NETO et al., 2019)	• Use/ Reuse/ treatment of water • Treatment of toxic metal waste • Use of renewable energy • Use of biodegradable materials • Reduction of CO2 emissions
(SHERWOOD, 2020)	• Industrial symbioses • Closed loop cycle • Design for reuse and recycling • Decrease in the use of toxic chemicals
(HOLTSTRÖM; BJELLERUP; ERIKSSON, 2019)	• Design for reuse and recycling • Business model focusing on innovation and sustainability • Use of renewable resources • Decrease in the use of toxic chemicals
(MUTHU et al., 2012a)	• Carbon footprint • Design for reuse and recycling
(PETERS et al., 2015)	• Carbon footprint • Design for reuse and recycling • Decrease in Greenhouse gases emissions
(BARCELOS, 2012)	• Use of recycled materials • Use of renewable energy • Use/ Reuse/ treatment of water • Decrease in Greenhouse gases emissions

Continues

Author	Indicators for Sustainability
(GABRIELA BENDERÓVICZ MENDES RIBEIRO, 2019)	• Use of renewable energy • Effluent management and treatment • Decrease in Greenhouse gases emissions • Decrease in gases with high toxicity emissions
(VELENTURF; PURNELL, 2021)	• Use of recycled materials • Design for reuse and recycle
(KANT HVASS; PEDERSEN, 2019)	• Reverse logistics • Use of recycled materials • Use of biodegradable materials • Production of items with long lifecycle
(BAKKER et al., 2014)	• Use of recycled materials • Design for reuse and recycle
(GHOREISHI; BHANDARI; FRANCONI, 2022)	• Use of recycled materials • Design for reuse and recycle • Clean production process • Ecological package and transportation • Reverse logistics • Restreability
(MAGALHÃES; SILVEIRA; SEIBEL, 2020)	• Use of renewable resources • Decrease in Greenhouse gases emissions • Decrease in gases with high toxicity emissions • Clean production process • Ecological package and transportation • Reverse logistics • Restreability
(ABDELMEGUID; AFY-SHARARAH; SALONITIS, 2022)	• Circular economy • Use of biodegradable materials • Design for reuse and recycle • Reverse logistics
(SHIRVANIMOGHADDAM et al., 2020)	• Use/ Reuse/ treatment of water • Treatment of toxic metal waste • Use of renewable energy • Use of biodegradable materials • Reduction of CO2 emissions • Design for reuse and recycle • Production of items with long lifecycle
(SANDIN; PETERS, 2018)	• Use/ Reuse/ treatment of water • Treatment of toxic metal waste • Use of renewable energy • Reduction of CO2 emissions • Design for reuse and recycle • Decrease in Greenhouse gases emissions • Decrease in gases with high toxicity emissions
Continues	

Author	Indicators for Sustainability
(PETERS; SANDIN; SPAK, 2019)	• Decrease in Greenhouse gases emissions • Decrease in gases with high toxicity emissions • Ecotoxicity • Use of renewable energy • Use/ Reuse/ treatment of water
(CRISTINA REFOSCO, 2012)	• Use of biodegradable materials • Effluent management and treatment • Decrease in Greenhouse gases emissions • Decrease in gases with high toxicity emissions
(ARYAN; YADAV; SAMADDER, 2019)	• Use of renewable energy • Effluent management and treatment • Treatment of solid waste • Decrease in Greenhouse gases emissions • Decrease in gases with high toxicity emissions • Ecotoxicity
(VAN DER VELDEN; PATEL; VOGTLÄNDER, 2014a)	• Decrease in Greenhouse gases emissions • Use of renewable energy • Decrease in gases with high toxicity emissions • Ecotoxicity
(GOMES; VISCONTE; PACHECO, 2019)	• Use of recycled materials • Decrease in Greenhouse gases emissions • Ecotoxicity • Ozone depletion
(SILVA, 2020)	• Decrease in the use of toxic chemicals • Use of natural dyes • Use of recycled materials • Circular economy
(DAMAYANTI et al., 2021)	• Design for reuse and recycle • Decrease of waste generated • Circular economy
(MUTHU et al., 2012b)	• Use of renewable resources • Use of renewable energy • Use / reuse / treatment of water • Decrease in Greenhouse gases emissions
(VELENTURF; PURNELL, 2021)	• Circular economy • Use of renewable resources • Effluent management and treatment • Treatment of solid waste
(GUPTA; SHUKLA; AGARWAL, 2019)	• Decrease in the use of toxic chemicals • Use of recycled materials • Design for reuse and recycle • Treatment of solid waste
Continues	

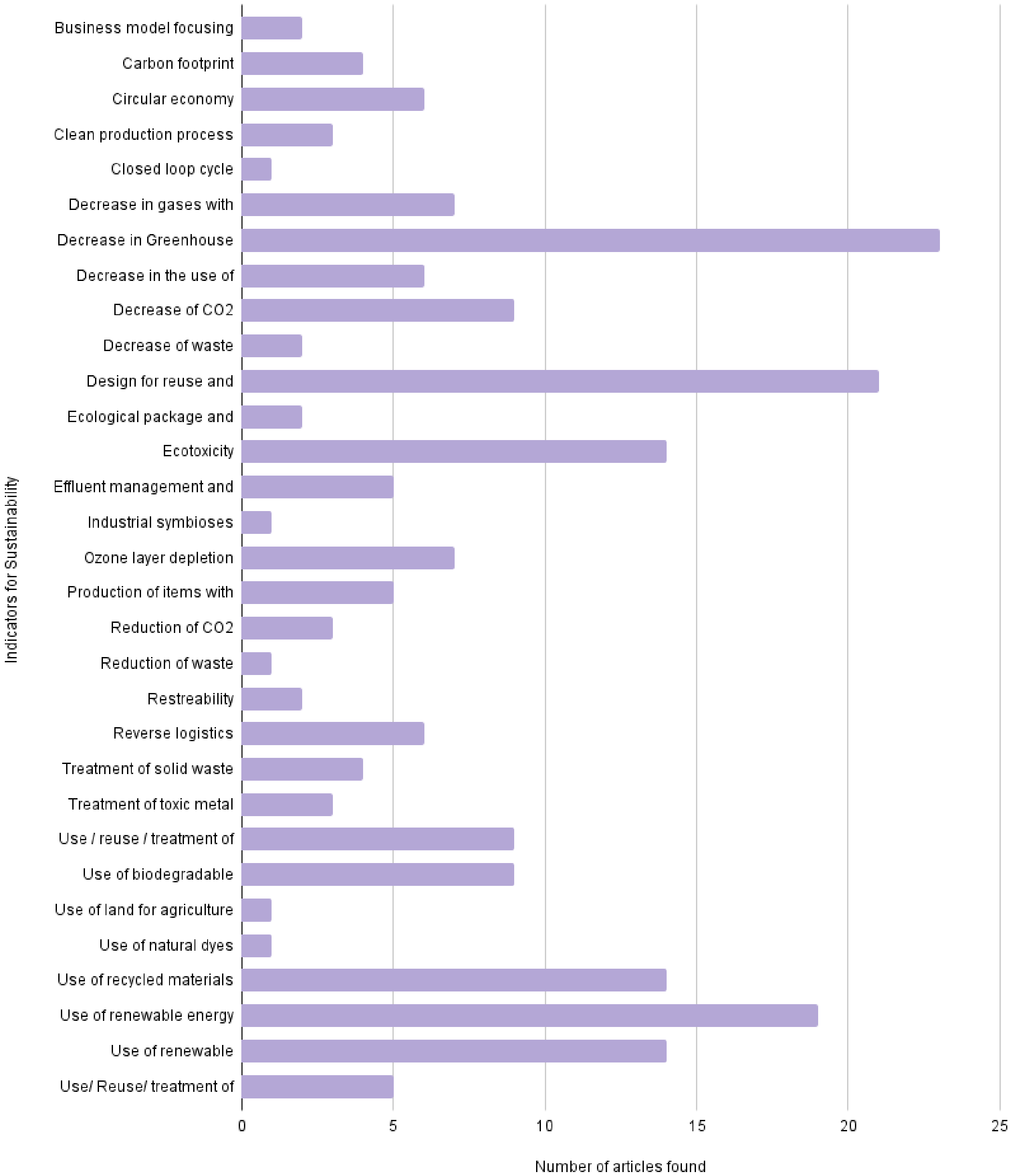
Author	Indicators for Sustainability
(BOUZON; GOVINDAN, 2015)	• Design for reuse and recycle • Use of recycled materials • Reverse logistics
(JANAINA et al., 2020)	• Ecotoxicity • Use of recycled materials • Use of biodegradable materials • Use of renewable resources • Use of renewable energy • Use / reuse / treatment of water • Production of items with long lifecycle
(DE OLIVEIRA et al., 2016)	• Ecotoxicity • Use of recycled materials • Use of biodegradable materials • Use of renewable resources • Use of renewable energy • Use / reuse / treatment of water
(HARMSEN; SCHEFFER; BOS, 2021)	• Design for reuse and recycling • Business model focusing on innovation and sustainability • Use of renewable resources • Use / reuse / treatment of water
(PASQUALINO; MENESES; CASTELLS, 2011)	• Use of renewable energy • Decrease in Greenhouse gases emissions
(KANT HVASS; PEDERSEN, 2019)	• Design for reuse and recycle • Use of recycled materials • Circular economy • Reverse logistics
(KAHOUSH; KADI, 2022)	• Design for reuse and recycle • Decrease of waste generated • Circular economy
(PENSUPA et al., 2017)	• Use of recycled materials • Use of biodegradable materials • Use of renewable resources • Use of renewable energy • Use / reuse / treatment of water • Decrease in the use of toxic chemicals
(MUTHU et al., 2012c)	• Design for reuse and recycle • Carbon footprint
(TONIOLO et al., 2013)	• Use of renewable energy • Use / reuse / treatment of water • Ecotoxicity • Use of land for agriculture • Decrease in Greenhouse gases emissions
Continues	

Author	Indicators for Sustainability
(PAPONG et al., 2014)	• Decrease in Greenhouse gases emissions • Ozone layer depletion • Ecotoxicity • Use of renewable energy • Decrease of CO2 emissions
(MADIVAL et al., 2009)	• Ecotoxicity • Use of renewable resources • Decrease of CO2 emissions • Decrease in Greenhouse gases emissions
(LEEJARKPAI; MUNGCHAROEN; SUWANMANEE, 2016)	• Use of renewable energy • Decrease of CO2 emissions • Decrease in Greenhouse gases emissions • Clean production process
(CHILTON; BURNLEY; NESARATNAM, 2010)	• Ecotoxicity • Use of renewable resources • Use / reuse / treatment of water • Decrease of CO2 emissions • Decrease in Greenhouse gases emissions • Design for reuse and recycling • Ozone layer depletion • Use of renewable energy
(CHEN; PELTON; SMITH, 2016)	• Use of renewable energy • Decrease in Greenhouse gases emissions • Use / reuse / treatment of water • Decrease in the use of toxic chemicals • Ozone layer depletion
(KUCZENSKI; GEYER, 2013)	• Ozone layer depletion • Ecotoxicity • Decrease of CO2 emissions • Decrease in Greenhouse gases emissions • Use of renewable resources • Effluent management and treatment • Treatment of solid waste
(SHEN; WORRELL; PATEL, 2010)	• Use of renewable resources • Carbon footprint • Decrease of CO2 emissions • Decrease in Greenhouse gases emissions • Use / reuse / treatment of water • Ozone layer depletion
(KANG; AURAS; SINGH, 2017)	• Ecotoxicity • Decrease of CO2 emissions • Decrease in Greenhouse gases emissions
(KOMLY et al., 2012)	• Ecotoxicity • Decrease of CO2 emissions • Decrease in Greenhouse gases emissions • Use of renewable resources
(GIRONI; PIEMONTE, 2011)	• Ecotoxicity • Decrease of CO2 emissions • Decrease in Greenhouse gases emissions • Ozone layer depletion • Use of renewable resources

Source: Author

After the RSL study was done, the sustainability indicators were tabulated so that the number of times each topic appeared in the articles found could be noted (**Figure 23**). From this number, the topics with the highest recurrence were chosen to follow the formulation of the interview questions.

Figure 23 – Number of Mentions of each Sustainability Indicator



Source: **Author**

The Brazilian Textile and Apparel Industry Association (ABIT - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA TÊXTIL E DE CONFECÇÃO, 2021) points to the need to incorporate the Sustainable Development Goals (SDGs) proposed by the United Nations (UN) as a way of overcoming the challenges imposed by sustainability. The SDGs (Sustainable Development Goals) are a global agenda adopted by the United Nations in 2015, consisting of 17 interconnected goals that encompass four main topics: Social, environmental, economic and institutional (**Figure 24**). Each objective has specific goals that must be achieved by 2030, with 169 goals in all, with the aim of guiding actions by governments, companies and civil society in the search for a more sustainable and fairer world (UN - UNITED NATIONS, 2023).

Figure 24 – Sustainable Development Goals

Source: (UN - UNITED NATIONS, 2023)

In the textile industry there are some SDGs that can be applied to help the development of sustainability indicators. In **Table 09** can be seen the SDGs and how they can act in the fashion sector:

Table 09 - SDGs Relevant to the Fashion Industry

SDG: Sustainable Development Goals	
SDG 5: Gender Equality	This SDG is important in the fashion industry because it highlights the need to promote gender equality and empower women throughout the supply chain.
SDG 6: Clean Water and Sanitation	This SDG is becoming increasingly important in the fashion industry as water consumption and pollution are significant issues in textile production.
SDG 7: Affordable and Clean Energy	The fashion industry can work to reduce energy usage and greenhouse gas emissions in textile production and transportation.
SDG 8: Decent Work and Economic Growth	This SDG is relevant to the fashion industry because it foucuses on promoting decent working conditions and economic growth, particularly in developing countries where many textile and garment factories are located.
SDG 12: Responsible Consumption and Production	This is one of the most commonly used SDGs in the fashion industry, as it relates directly to reducing waste and improving the sustainability of production processes.
SDG 13: Climate Action	This SDG is also highly relevant to the fashion industry, as reducing greenhouse gas emissions and mitigating the impacts of climate change are key priorities for many companies.
SDG 14: Life Below Water	The fashion industry can work to reduce water pollution from textile production and improve sourcing practices for sustainable and non-toxic materials.
SDG 15: Life On Land	The fashion industry can work to reduce land pollution and promote sustainable farming practices for natural fibers.

Source: (UN - UNITED NATIONS, 2023)

Based on all the indicators found in the literature review and the ODSs applied to the fashion industry, four main topics were chosen to be addressed in the questionnaire, the topics are related to the use of water, energy use, use of toxic chemicals and emission of polluting gases and finally the disposal waste. Each topic was connected with the related ODS (**Table 10**):

Table 10 – Sustainability Indicators and Corresponding ODS

Indicators used for the questionnaire	Related Sustainable Development Goals	References
Use / reuse / treatment of water	• SDG 6: Clean Water and Sanitation • SDG 14: Life Below Water	(BARCELOS, 2012; CHEN; PELTON; SMITH, 2016; CHILTON; BURNLEY; NESARATNAM, 2010; DE OLIVEIRA et al., 2016; DE OLIVEIRA NETO et al., 2019; HARMSEN; SCHEFFER; BOS, 2021; JANAINA et al., 2020; MUTHU et al., 2012b; PENSUPA et al., 2017; PETERS; SANDIN; SPAK, 2019; SANDIN; PETERS, 2018; SHEN; WORRELL; PATEL, 2010; SHIRVANIMOGHADDAM et al., 2020; TONIOLO et al., 2013)
Use of renewable energy	• SDG 7: Affordable and Clean Energy	(ARYAN; YADAV; SAMADDER, 2019; BARCELOS, 2012; CHEN; PELTON; SMITH, 2016; CHILTON; BURNLEY; NESARATNAM, 2010; DE OLIVEIRA et al., 2016; DE OLIVEIRA NETO et al., 2019; GABRIELA BENDERÓVICZ MENDES RIBEIRO, 2019; GHISELLINI; CIALANI; ULGIATI, 2016; JANAINA et al., 2020; LEEJARKPAI; MUNGCHAROEN; SUWANMANEE, 2016; MUTHU et al., 2012b; PAPONG et al., 2014; PASQUALINO; MENESES; CASTELLS, 2011; PENSUPA et al., 2017; PETERS; SANDIN; SPAK, 2019; SHIRVANIMOGHADDAM et al., 2020; TONIOLO et al., 2013; VAN DER VELDEN; PATEL; VOGTLÄNDER, 2014a)
Use of toxic chemicals and Greenhouse Gases	• SDG 13: Climate Action • SDG 15: Life on Land	(ARYAN; YADAV; SAMADDER, 2019; BARCELOS, 2012; CHEN; PELTON; SMITH, 2016; CHILTON; BURNLEY; NESARATNAM, 2010; CRISTINA REFOSCO, 2012; DE OLIVEIRA NETO et al., 2019; GABRIELA BENDERÓVICZ MENDES RIBEIRO, 2019; GIRONI; PIEMONTE, 2011; GOMES; VISCONTE; PACHECO, 2019; GUPTA; SHUKLA; AGARWAL, 2019; HOLTSTRÖM; BJELLERUP; ERIKSSON, 2019; KOMLY et al., 2012; KUCZENSKI; GEYER, 2013; LEEJARKPAI; MUNGCHAROEN; SUWANMANEE, 2016; MADIVAL et al., 2009; MAGALHÃES; SILVEIRA; SEIBEL, 2020; MUTHU et al., 2012b; PAPONG et al., 2014; PASQUALINO; MENESES; CASTELLS, 2011; PENSUPA et al., 2017; PETERS et al., 2015b; PETERS; SANDIN; SPAK, 2019; SANDIN; PETERS, 2018; SHEN; WORRELL; PATEL, 2010; SILVA, 2020; TONIOLO et al., 2013; VAN DER VELDEN; PATEL; VOGTLÄNDER, 2014a)
Waste, Recycling and Sustainability	• SDG 8: Decent Work and Economic Growth • SDG 12: Responsible Consumption and Production • SDG 15: Life on Land	(ABDELMEGUID; AFY-SHARARAH; SALONITIS, 2022; ARYAN; YADAV; SAMADDER, 2019; BOUZON; GOVINDAN, 2015; CHILTON; BURNLEY; NESARATNAM, 2010; DAMAYANTI et al., 2021; DE OLIVEIRA et al., 2016; GOMES; VISCONTE; PACHECO, 2019; GUPTA; SHUKLA; AGARWAL, 2019; HARMSEN; SCHEFFER; BOS, 2021; JANAINA et al., 2020; KAHOUSH; KADI, 2022; KANT HVASS; PEDERSEN, 2019; KUCZENSKI; GEYER, 2013; MUTHU et al., 2012c; PENSUPA et al., 2017; SANDIN; PETERS, 2018; SHIRVANIMOGHADDAM et al., 2020; SILVA, 2020; VELENTURF; PURNELL, 2021)

Source: Authors

To assess the level of awareness and implementation of sustainable practices in the Brazilian textile recycling industry, a questionnaire was carried out with professionals in the area, with the aim of identifying the most relevant sustainability indicators for the sector and how they are being applied in industries.

For this, the questions shown in **Table 11** were developed for each topic of indicator. The data collection instrument for the survey was built on the Google Forms platform and sent to all companies via E-mail and WhatsApp. The data collection period extended from October 2022 to January 2023. Of the 32 companies contacted, 06 questionnaires were answered.

Table 11 – Questionnaire Based on Indicators for Sustainability

Indicators used for the questionnaire	References	Questions proposed
Use / reuse / treatment of water	(BARCELOS, 2012; CHEN; PELTON; SMITH, 2016; CHILTON; BURNLEY; NESARATNAM, 2010; DE OLIVEIRA et al., 2016; DE OLIVEIRA NETO et al., 2019; HARMSEN; SCHEFFER; BOS, 2021; JANAINA et al., 2020; MUTHU et al., 2012b; PENSUPA et al., 2017; PETERS; SANDIN; SPAK, 2019; SANDIN; PETERS, 2018; SHEN; WORRELL; PATEL, 2010; SHIRVANIMOGHADDAM et al., 2020; TONIOLO et al., 2013)	• What actions does your company have related to the use and treatment of water during its processes? • Does the company reuse water within its processes? • Are there chemicals used in your process that require treatment of your effluents? If yes, which ones? • Does your company have initiatives to protect water resources from contact with polluting chemicals?
Use of renewable energy	(ARYAN; YADAV; SAMADDER, 2019; BARCELOS, 2012; CHEN; PELTON; SMITH, 2016; CHILTON; BURNLEY; NESARATNAM, 2010; DE OLIVEIRA et al., 2016; DE OLIVEIRA NETO et al., 2019; GABRIELA BENDERÓVICZ MENDES RIBEIRO, 2019; GHISELLINI; CIALANI; ULGIATI, 2016; JANAINA et al., 2020; LEEJARKPAI; MUNGCHAROEN; SUWANMANEE, 2016; MUTHU et al., 2012b; PAPONG et al., 2014; PASQUALINO; MENESES; CASTELLS, 2011; PENSUPA et al., 2017; PETERS; SANDIN; SPAK, 2019; SHIRVANIMOGHADDAM et al., 2020; TONIOLO et al., 2013; VAN DER VELDEN; PATEL; VOGTLÄNDER, 2014a)	• What energy source does your company use? • Which processes would you say use the most energy in your company? • Are there actions that could be applied to save energy use in your company? • Does the company give preference to eco-efficient equipment?
Continues		

Indicators used for the questionnaire	References	Questions proposed
Use of toxic chemicals and Greenhouse Gases	(ARYAN; YADAV; SAMADDER, 2019; BARCELOS, 2012; CHEN; PELTON; SMITH, 2016; CHILTON; BURNLEY; NESARATNAM, 2010; CRISTINA REFOSCO, 2012; DE OLIVEIRA NETO et al., 2019; GABRIELA BENDERÓVICZ MENDES RIBEIRO, 2019; GIRONI; PIEMONTE, 2011; GOMES; VISCONTE; PACHECO, 2019; GUPTA; SHUKLA; AGARWAL, 2019; HOLTSTRÖM; BJELLERUP; ERIKSSON, 2019; KOMLY et al., 2012; KUCZENSKI; GEYER, 2013; LEEJARKPAI; MUNGCHAROEN; SUWANMANEE, 2016; MADIVAL et al., 2009; MAGALHÃES; SILVEIRA; SEIBEL, 2020; MUTHU et al., 2012b; PAPONG et al., 2014; PASQUALINO; MENESES; CASTELLS, 2011; PENSUPA et al., 2017; PETERS et al., 2015b; PETERS; SANDIN; SPAK, 2019; SANDIN; PETERS, 2018; SHEN; WORRELL; PATEL, 2010; SILVA, 2020; TONIOLO et al., 2013; VAN DER VELDEN; PATEL; VOGTLÄNDER, 2014a)	• Is there the use of chemical products during the process used by the company? If so, what is the destination given to the waste of these materials? • Does the company have any indicator or measurement related to the emission of greenhouse gases? • Does the company have any type of carbon offset issued? If yes, which one? (eg: reforestation system) • Is there monitoring of toxic gases that may occur during the production process?
Waste, Recycling and Sustainability	(ABDELMEGUID; AFY-SHARARAH; SALONITIS, 2022; ARYAN; YADAV; SAMADDER, 2019; BOUZON; GOVINDAN, 2015; CHILTON; BURNLEY; NESARATNAM, 2010; DAMAYANTI et al., 2021; DE OLIVEIRA et al., 2016; GOMES; VISCONTE; PACHECO, 2019; GUPTA; SHUKLA; AGARWAL, 2019; HARMSEN; SCHEFFER; BOS, 2021; JANAINA et al., 2020; KAHOUSH; KADI, 2022; KANT HVASS; PEDERSEN, 2019; KUCZENSKI; GEYER, 2013; MUTHU et al., 2012c; PENSUPA et al., 2017; SANDIN; PETERS, 2018; SHIRVANIMOGHADDAM et al., 2020; SILVA, 2020; VELENTURF; PURNELL, 2021)	• What are the main raw materials used by the company? • Does the company use waste as raw material? If yes, which ones? • What recycling methods are adopted by the company? • What actions does the company take to reduce waste disposal? • How do you see the future of sustainability in the textile industry?

Source: Authors

As a result of the research of the 32 companies contacted, 06 questionnaires were answered. It should be noted that this topic presents the results found and their analyses. For better visualization, the topic was structured in five sections, following the order of the proposed questions and their respective topics of sustainability indicators. The first section 5.4.1 presents the data referring to the profile of the consulted companies. In section 5.4.2, the results are presented within the scope of the first proposed indicator, referring to the use, reuse and treatment of water (SDGs 6 and 14). Section 5.4.3 refers to the results under the second sustainability indicator, which deals with the use of energy from renewable sources (SDG 7). Section 5.4.4 presents data within the scope of the third proposed indicator, referring to the use of chemical products and emission of polluting gases (SDGs 13 and 15). Section 5.4.5 deals with the results of the fourth specific objective, referring to waste disposal, recycling and sustainability in the sector (SDGs 8, 12 and 15).

5.4.1 Introduction and Companies Profiles

To carry out the interview, a survey was carried out of all textile recycling companies and companies that work with waste collection and management, the result of this research will be discussed in greater depth in the next topic (5.6).

From the companies contacted, 06 responses were received from the questionnaire carried out through Google Forms, due to the use of this method, the research has a structured nature.

Of the six companies interviewed, two of them are small with up to 50 employees, four are medium-sized with between 50 and 500 employees according to the IBGE classification (IBGE - INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2021). There were no large companies among those consulted.

The average time of experience in the textile area of the professionals who answered the questionnaire is 15-30 years, only one respondent has 05 years of experience in the textile recycling industry (**Table 12**).

Table 12 – Introduction and Company Profiles

Companies	Number of employees	Years of experience	Region
Company A	Medium – 50 to 500 employees	21 Years	South
Company B	Small – up to 50 employees	17 Years	Southeast
Company C	Medium – 50 to 500 employees	26 Years	Southeast
Company D	Medium – 50 to 500 employees	5 Years	South
Company E	Medium – 50 to 500 employees	20 Years	South
Company F	Small – up to 50 employees	29 Years	South

Source: Author

The companies interviewed will be kept anonymous according to the preference of the majority of the entrepreneurs who participated.

5.4.2 Use, Reuse and Treatment of Water

When it comes to the use and treatment of water, only company D has water treatment, since its company has the textile dyeing part. According to the interviewed manager, there is an internal water treatment process, so that a large part can be reused in other processes, and what needs to be discarded can be done without impacting the environment. In addition, the company reported that there are no chemicals used that are harmful to human or animal health.

The other companies reported that water is not used in any of their processes, therefore, there is no type of treatment.

5.4.3 Use of Renewable Energy

Regarding the use of renewable energy, only one company – Company F – partially uses energy from a renewable source. According to the company's report, there is a store attached to the industry, where products made with shredded waste are sold. In this store, 100% solar energy is used, part of the solar energy is also used in the industry, but there is a part with a different network that still comes from hydroelectric plants (electric company CEEE is used by the company). One of the companies, Company C, reported not being sure which energy source is used in the company. The others use the most common form, hydroelectric.

When asked about which processes require the most energy, five of the companies reported that the defibration part of the fabrics is what consumes the most. Company B, for working only with waste management and not having recycling inside its factory, reported that energy is used only for the offices.

All companies reported that they prefer equipment that is more economical and more eco-responsible, but that often this technology is not available on the market.

5.4.4 Use of Toxic Chemicals and Greenhouse Gases

Of the companies interviewed, all reported that they do not use materials that are toxic or harmful to health or the environment. Company D is the only one that uses some type of treatment for recycled fabric, having dyeing as part of its process, however it reported that it has a rigorous process for treating its effluents.

When asked about indicators or measurement related to gas emissions, the companies commented that there was no measurement, only Company C said it had a measurement for the use of energy within the company. All companies also stated that they did not emit toxic gases in their processes.

Company F was the only company to adhere to some method of offsetting the carbon emitted, even if focused on packaging and shipping. The company has the EuReciclo and FreteNeutro certification. The other companies stated that they do not have any compensation method at the moment of the interview.

5.4.5 Waste, Recycling and Sustainability

This topic was initiated by questioning the companies about what type of waste they used, whether pre-consumer or post-consumer, and which fibers were used for recycling.

Only Companies C and E work both with pre-consumer and post-consumer waste. At Company C, synthetic and natural fibers are used, choosing to work with polyester, cotton and different percentages of their mixtures. Company E recycles only polyester fabrics, both pre- and post-consumer.

Company B is the only one that works exclusively with post-consumer fabrics. The company collects, sorts and separates fibers and fabrics from cotton and jeans uniforms.

Companies A, D and F work exclusively with pre-consumer waste from other clothing companies. In the case of Company A, only cotton fibers are recycled. Company D uses polyester, polypropylene, cotton and viscose waste. Company F works with all types of synthetic or natural fibers (**Table 13**).

Table 13 – Fiber Types Recycled by the Companies

Companies	Pre Consumer	Post Consumer
Company A	Cotton	-
Company B	-	Uniforms, mostly cotton and jeans
Company C	Natural and Synthetic	Natural and Synthetic
Company D	PES, PP, Cotton and Viscose	-
Company E	Polyester	Polyester
Company F	Natural and Synthetic	-

Source: Author

According to the answers to the questionnaire, five companies use mechanical recycling in their processes. Company B only collects, separates by color and sells waste to other companies.

When asked about the actions taken to reduce the disposal of waste in their productions, Companies A and D stated that they manage to recycle all the raw materials they receive, while Company B claims to have partners who collect all types of material that the company does not recycle.

Company C claimed to have internal processes to avoid the generation of waste. In the case of company F, its production residues or excess raw material collected is sold to other companies in the same field. Company E claims that it does not have a concrete method for managing its own waste, but that its disposal is minimal.

To close the questionnaire, companies were asked how they saw the future of sustainability in the sector. For most companies, the search for new technologies and education about recycling are important points. Company B states that there is a need for public policies that increase the engagement of small clothing and cutting workshops. Company D states that it is necessary to disseminate the benefits of using raw materials from recycled sources. Company E, on the other hand, says that greater investment is needed in this sector for it to grow.

5.5 SUSTAINABILITY CERTIFICATIONS IN THE TEXTILE SECTOR

5.5.1 Worldwide

As it is known as the second most polluting industry, since it consumes an enormous amount of natural resources and is responsible for emitting large amounts of gases associated with the greenhouse effect and global warming, the textile industry has been increasingly aware of these impacts and seeking to incentives and recognition of sustainable practices (HERVA; ÁLVAREZ; MARCON; DE MEDEIROS; RIBEIRO, 2017; YOUSEF et al., 2020). As a way of making these practices adopted by companies official, several certifications have emerged.

These certifications have guidelines and standards to be followed by companies, so that the resulting processes and products can have a guarantee that they will be considered sustainable (BERLIM, 2012; FLETCHER; GROSE, 2011; MAGALHÃES; SILVEIRA; SEIBEL, 2020).

The measures chosen by the certifications may vary, but normally they approach the topics of use of natural and non-renewable resources, emission of polluting gases in the atmosphere, use of polluting chemicals, fair and ethical work for professionals in the chain and human health of those who enter into contact with the processes or final products.

There are several certifications that can be acquired by the companies, as shown in **Table 14**:

Table 14 – Worldwide Sustainable Certifications

Worldwide certifications	
Global Organic Textile Standard (GOTS)	This certification ensures that textiles are produced using organic and environmentally friendly methods throughout the entire supply chain, including farming, manufacturing, and distribution.
Fairtrade	This certification guarantees that workers involved in the production of a product are paid fairly, and that the product is produced in a way that is socially responsible.
Bluesign	This certification evaluates the environmental impact of the entire textile production process, from raw material to finished product.
Cradle to Cradle	This certification focuses on creating products that are designed to be reused or recycled, rather than discarded.
OEKO-TEX Standard 100	This certification ensures that textile products are free from harmful substances, including chemicals and heavy metals.
B Corporation Certification	This certification is awarded to companies that meet rigorous social and environmental standards, including those related to sustainability in the fashion industry.

Source: Author

By January 2023 there were more than 10,000 companies distributed in 71 countries that had GOTS certification, including textile product manufacturers, fashion brands, fiber producers, among others (GOTS - GLOBAL ORGANIC TEXTILE STANDART, 2023). Fairtrade (2023) certification has already been applied to more than 1,800 companies throughout the textile chain, having more than 1.9 million farmers working, and can be found in 73 countries. The Cradle-to-Cradle certification is available in 44 countries and applied to more than 500 companies from different sectors, not just connected to the textile industry, and more than 34.5000 products have this certification (C2C - CRADLE TO CRADLE CERTIFICATION, 2023).

5.5.2 Brazil

In Brazil, in addition to using national certifications, mainly Fairtrade, OEKO-TEX and GOTS (FAIRTRADE, 2023; GOTS - GLOBAL ORGANIC TEXTILE STANDART, 2023; OEKO-TEX, 2023) certifications created here are also used.

The first initiative created in Brazil linked to sustainability was in 1993 with the creation of the Procel Seal, this certification serves to evaluate the energy efficiency of equipment and is granted to products and equipment that meet the energy efficiency criteria established by the program. Although Procel is an energy-focused program, it is considered one of Brazil's first efforts to promote sustainability on a large scale (PROCEL, 2023).

Some certifications are more linked to the production of raw materials, such as BCI, IBD and ABVTEX (ABVTEX - ASSOCIAÇÃO BRASILEIRA DO VAREJO TÊXTIL, 2023; BCI - BETTER COTTON INICIATIVE, 2023; IBD - INSTITUTO BIODINÂMICO DE DESENVOLVIMENTO RURAL, 2023). Others are more closely linked to reverse logistics and packaging compensation, as is the case with EuReciclo (EURECICLO, 2023) or like PETA (PETA - PEOPLE FOR THE ETHICAL TREATMENT OF ANIMALS, 2023) are more concerned with the wellbeing of animals that could be use as material for the products (**Table 15**).

Table 15 – Brazilian Sustainable Certifications

Brazilian certifications	
PROCEL	It was created with the aim of indicating to consumers the equipment and appliances available in the domestic market that have the highest energy efficiency rates in each category. In addition, it encourages the manufacture and sale of more efficient products from an energy point of view, minimizing environmental impacts in the country.
ABVTEX	This is a certification program developed by the Brazilian Textile Retail Association (ABVTEX) that focuses on promoting responsible production and working conditions in the textile and garment industry.
Eureciclo	This is a certification program for recycled materials, including textiles, that aims to promote the circular economy and reduce waste.
PETA-Approved Vegan	This is a certification program developed by People for the Ethical Treatment of Animals (PETA) that identifies clothing and accessories made without the use of animal products.
IBD Certification	This is a certification program that focuses on promoting organic and sustainable agriculture and production, including in the textile and garment industry.
The BCI	The Better Cotton Initiative (BCI) is a certification program that promotes sustainable cotton production, including environmental and social best practices. Some Brazilian cotton farmers and textile companies have obtained BCI certification.

Source: Author

In addition to certifications, in Brazil there are a series of standards to ensure that production is within the expected standards of sustainability. The ABNT (Associação Brasileira de Normas Técnicas) (2023) serves as the main guide to standards for all areas, including textiles and sustainability. The main one’s approach topics as sustainable development, proper use of water and renewable energy along with its implementation and evaluation plans, sustainable purchase of material input, social responsibility, and others as can be seen in **Table 16**:

Table 16 – Brazilian Sustainability Standards

Brazilian standards for the sustainability in fashion industry	
ABNT NBR 20400	This document provides guidance for organizations, regardless of their activity or size, to integrate sustainability into purchasing, as described in ABNT NBR ISO 26000. It is intended for interested parties, involved or impacted by purchasing processes and decisions.
ABNT NBR 17080	This Standard presents the requirements for the elaboration, implementation and evaluation of water safety plans with the purpose of ensuring the supply of safe and potable water, through a risk assessment and management approach from the source or source to the point of consumption, regardless of their size and treatment technologies used.
ABNT NBR 16001	This Standard sets out the minimum requirements relating to a social responsibility management system, enabling the organization to formulate and implement a policy and objectives that take into account its commitments to: a) accountability; b) transparency; c) ethical behavior; d) respect for the interests of interested parties; e) compliance with legal requirements and other requirements subscribed by the organization; f) respect for international standards of behavior; g) respect for human rights; and h) the promotion of sustainable development.
ABNT NBR 50004	This one provides practical guidelines and examples for establishing, implementing, maintaining and improving an energy management system (EMS) in accordance with the systematic approach of ABNT NBR ISO 50001:2018. The guidance in this document is applicable to any organization.
ABNT NBR ISO 14001	This International Standard specifies requirements for an environmental management system that an organization can use to enhance its environmental performance. This International Standard is intended for use by an organization seeking to manage its environmental responsibilities in a systematic way that contributes to the environmental pillar of sustainability.
ABNT NBR ISO 26000	This International Standard provides guidance for all types of organizations, regardless of size or location, on concepts, terms and definitions relating to social responsibility; the history, trends and characteristics of social responsibility; principles and practices related to social responsibility; the central themes and issues related to social responsibility; integration, implementation and promotion of socially responsible behavior throughout the organization and through its policies and practices within its sphere of influence; stakeholder identification and engagement; and communicating commitments, performance and other information regarding social responsibility.
ABNT NBR ISO 50001	This standard provides guidelines for energy management systems. It covers aspects such as energy efficiency, renewable energy, and carbon emissions reduction.

Source: Adapted from (ABNT - ASSOSSIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2023)

When the interview was conducted, some respondents volunteered the information that they had certifications to make their production more sustainable, or for this to serve as an indicator of sustainability. However, none of the companies complied with all the standards proposed by ABNT.

5.6 OVERVIEW OF TEXTILE DISPOSAL AND RECYCLING IN BRAZIL

Textile recycling generally refers to the reprocessing of pre- or post-consumer textile waste for use in new textile or non-textile products (SANDIN; PETERS, 2018a). Pre-consumption consists of by-products from the production of fibers, yarns, or fabrics, and post-consumer waste consists of any type of clothing or home textile articles that the owner no longer needs and decides to discard. Approximately 75% of pre-consumer textile waste is diverted from landfills in the US and recycled into new raw materials for the automotive, furniture, mattress, decorative items, and paper industries (CHEN; BURNS, 2006).

Among the post-consumer textile waste recovered around the world, only about 48% is recycled as second-hand clothing (most sold to developing countries), while the rest is disposed of in the trash and goes to municipal landfills (CAMILLERI, 2020). Although the recycling of pre-consumer waste has a good recycling rate, the industry still has difficulty regarding the amount of post-consumer waste that ends up being incorrectly disposed of and the difficulty in recycling post-consumer waste due to the presence of different components in a product, like different fibers, dyes and all kinds of accessories (CHEN; BURNS, 2006; ROBAINA et al., 2020).

Textile recycling can usually be classified as mechanical, chemical, or, less often, energy (SANDIN; PETERS, 2018a). Generally, there are two methods used for PET recycling: mechanical and chemical. In the chemical method (16% of recycling), the reverse of the polymerization reaction (i.e., depolymerization) occurs and the primary monomers are obtained (SADEGHI et al., 2021a). The mechanical method, which accounts for 84% of recycling, includes collection, sorting, washing, and shredding (SADEGHI et al., 2021a), and due to the disadvantages of chemical recycling, mechanical recycling and products from mechanical recycling use are the best solutions for managing this waste (LIMA; FELIPE; FELIPE, 2020). They are processes for recovering the fabric and/or fiber so that it can be reused for the same purpose or processes that recover different materials to become a fiber (ABBASI; MOHADES MOJTAHEDI; KOTEK, 2020; CHEN; BURNS, 2006).

Another classification in recycling is related to the final product, it is called downcycling when the recycled material is of lower value (or quality) than the original product. In contrast, if a product made from recycled material is of higher value (or quality) than the original product, it is called upcycling (SANDIN; PETERS, 2018a). It is possible to separate the recycling classification as open or closed circuits. Since open circuits (open-loop, also called cascade recycling) refers to processes in which the material in one product is recycled and used in another product and, closed -circuit (closed-loop) refers to when the material from a product is recycled and used in an identical (more or less) product (AMARAL, 2016).

The textile industries present themselves as major generators of different solid residues, among the sectors with the highest waste, the cutting of pieces deserves attention, mainly because there is no correct preparation of the modeling fitting (MENEGUCCI et al., 2015). The change in the way garment companies dispose of their waste is a slow process, but it has been changing over the years, since there is still disposal in the open, i.e., in illegal dumps and landfills without any type of control, there is also through incineration, a process that is highly polluting when done without the right measures.

Brazil imported more than 223 thousand tons of discarded waste between 2008 and 2009, at a cost of US$ 257.9 million. In the same period, the country failed to earn about US$ 12 billion for not recycling 78% of the solid waste generated internally, due to the lack of selective waste collection (AMARAL et al., 2018; O ESTADO DE SÃO PAULO, 2009).

In the Bom Retiro region in São Paulo alone, more than 1,200 clothing companies operate, handling approximately US$ 690 million per year, each of which produces, on average, 20 thousand items per month. Approximately 12 tons of textile waste (scraps) per day are generated by these garments, representing 2% of the scraps generated annually in Brazil (SINDITÊXTIL - SP, 2012). In 2014, 170 thousand tons of fabric waste were produced due to the lack of selective recycling. However, this volume of scraps could be recycled, generate income and reduce expenses of US$5.8 million in the import of equivalent waste (ABIT - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA TÊXTIL E DE CONFECÇÃO, 2020).

In Brazil, most of the collected MSW (municipal solid waste) is disposed of in landfills, registering an increase of 10 million tons in a decade, from 33 million tons per year to 43 million tons. On the other hand, the amount of waste that is discarded to inadequate units (dumps and controlled landfills) also increased, from 25 million tons per year to just over 29 million tons per year (ABRELPE - ASSOCIAÇÃO BRASILEIRA DE EMPRESAS DE LIMPEZA PÚBLICA E RESÍDUOS ESPECIAIS, 2020). Dry recyclable waste totals (35% of MSW), consist mainly of plastics (16.8%), paper and cardboard (10.4%), glass (2.7%), metals (2.3%), and multilayer packaging (1.4%). Non-recyclable, in turn, accounts for 14.1% of the total and mainly comprises sanitary materials. Textile, leather, and rubber waste accounts for 5.6% (ABRELPE, 2020).

Despite a large amount of pre-consumer textile leftovers and the growing demand for recycled fabrics, there is a small portion that is actually recycled. Possible causes could be related both to the failure in public policies and to the low number of textile recycling companies regarding the number of clothing companies.

A survey of 25 companies, small to medium/large, which recycle textile materials, both pre- and post-consumption was carried out. **Table 17** shows these companies, the region in Brazil where they are based and the type of recycled product.

Table 17 – Brazilian Companies Working with Recycled Fibers

Company's Name	Region	Product	Website
Benetex	South	100% Cotton	http://www.benetex.com.br/
Cartonagem Ipiranga	Southeast	Natural and synthetic fibers	http://www.cartonagemipiranga.com.br/
Ecofabril	Southeast	R-PET	https://www.ecofabril.com.br/
Ecofios	South	100% Cotton	http://ecofios.com.br/
Ecosimple	Southeast	R-PET	https://ecosimple.com.br/
Etruria	Southeast	R-PET	http://www.etruria.com.br/
Euro Fios	South	Natural and synthetic fibers	https://grupoeurofios.com.br/
Euroroma	South	Natural fibers	http://euroroma.com.br/
Fava Têxtil	South	Natural and synthetic fibers	https://www.favatextil.com.br/
Fibrapet	Southeast	R-PET	http://www.fibrapet.com.br/
Fibratex	Southeast	R-PET	http://fibratex.com.br/sobre
Flocos Fibra	Southeast	Natural and synthetic fibers	https://www.flocosfibra.com.br/
Grupo Wolf	Southeast	Synthetic	http://www.grupowolf.com.br/
JF Fibras	Southeast	Natural and synthetic fibers	http://www.jffibras.com.br/
LI Tecidos	Southeast	Natural and synthetic fibers	https://litecidos.com.br/
Lonatex	Southeast	100% Cotton / R-PET	http://www.lonatex.com.br/
Maxitex	South	100% Cotton / R-PET	https://www.maxitex.com.br/
Multicor	Northeast	Natural fibers	http://www.multicor.ind.br/
Patamuté	Northeast	Natural fibers	http://www.fiacaopatamute.com.br/
Plumatex Reciclagem	Southeast	Natural and synthetic fibers	
Recitex	South	100% Cotton / R-PET	http://recitex.com.br/
Renovar	Southeast	Natural and synthetic fibers	https://www.renovartextil.com.br/
Retalhar	Southeast	Natural and synthetic fibers	https://www.retalhar.com.br/
Semear Ecotêxtil	South	Natural and synthetic fibers	https://www.semearecotextil.com.br/
Superfios	Northeast	100% Cotton	http://www.superfios.com.br/

Source: Author

In addition to the companies that work directly with recycled fibers and their recycling, there are companies specialized in the collection, management and logistics of treatment of waste related to the textile industry. The South region is where most of these companies are located. 07 medium to large companies were found that have a complete chain in relation to the collection and distribution of textile waste to recycling and reuse companies (**Table 18**).

Table 18 – Brazilian Companies Working with Textile Waste Management

Company's Name	Region	Company Segment	Website
Eco Têxtil	South	Reverse logistics - Waste management	https://www.ecotextil.ind.br/
Edu têxtil	South	Reverse logistics - Waste management	https://edu-textil.negocio.site/
Momo Ambiental	Southeast	Reverse logistics - Waste management	https://www.momoambiental.com.br/
MR Gestão de resíduos	South	Reverse logistics - Waste management	http://www.mrgestaoderesiduos.com.br/
Recicla Brasil	Southeast	Reverse logistics - Waste management	https://www.reciclabrasil.com.br/empresa/
Workday	Southeast	Reverse logistics - Waste management	https://workdayresiduos.com.br/
Zm Residuos texteis	Southeast	Reverse logistics - Waste management	https://zm-residuos-texteis.negocio.site/

Source: Author

Among the recycling textile companies, some of them employ PET bottles to produce polyester fiber. PET recycling in Brazil is one of the most developed in the world, having a high recycling rate and a huge range of applications for recycled material, creating a constant and guaranteed demand (ABIPET - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA DO PET, 2020).

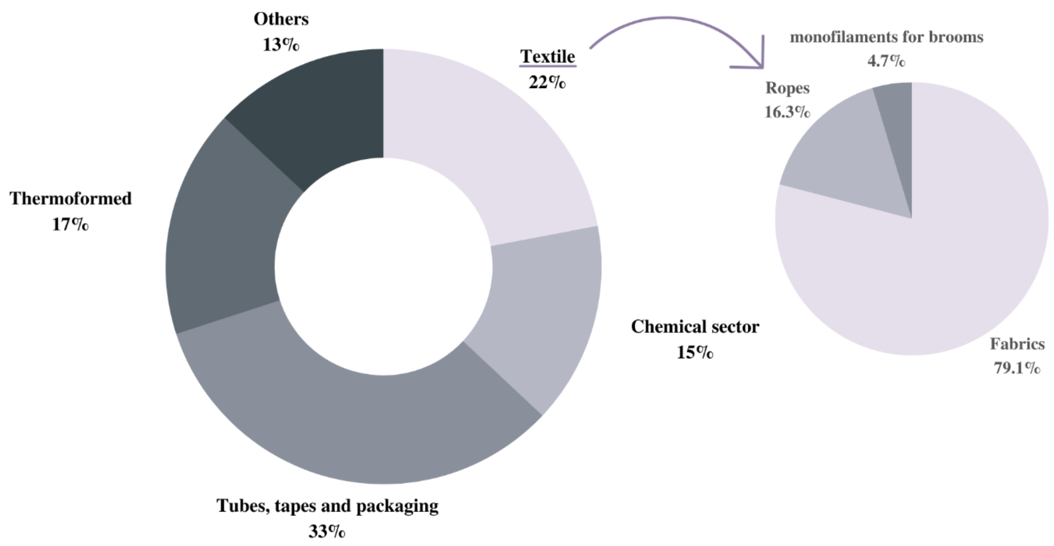
The first step in the recycling of plastic waste is its collection. It can be collected directly from industries, major retailers, local NGOs, and selective collection. In the recent years, plastic bottles and containers have been major collected by the means of curbside drop-off, buyback, and deposit/refund methods (SHANMUGAM et al., 2020).

The ABIPET census confirms PET recycling as a growing activity, 331 thousand tons of PET packaging were collected in 2019, pointing to a 12% growth in PET recycling (ABIPET - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA DO PET, 2020). The correct disposal of each of these bottles was guaranteed, being fully recycled and used in new products. The revenue generated exceeded US$ 710 million, corresponding to 36% of the total revenue of the PET sector in Brazil (CICLO VIVO, 2020).

The Brazilian performance is superior to that of developed countries such as the United States, for example, which recycle 29% of their PET packaging. Even the European Union, which collects 58.2% of post-consumer PET, does not recycle the totality of this material and sends much of it to be processed to other poorer countries (ABIPET - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA DO PET, 2020).

The wide use of recycled PET occurs because Brazil is a world leader in different applications for recycled PET, which generates demand for the product, reverting to revenue and income for various society sectors. The main consumers/applicators of recycled PET in Brazil are the manufacturers of preforms and bottles (**Figure 23**), with 23% of the total, in a process known as "bottle to bottle", mainly due to the increased production of food-grade packaging, which in recent years has shown great technological evolution.

Figure 25 - Uses for recycled PET in Brazil



Source: Adapted from (ABIPET - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA DO PET, 2020)

About 17.4% of PET bottles collected for recycling in Brazil become textiles and, consequently, garments. A bottle containing 50 grams of PET (2-liter packaging, for example) will generate 50 grams of polyester fiber, and its manufacture can save up to 70% energy considering the entire process from the exploration of the primary raw material to the final product (AMARAL et al., 2018). **Figure 24** is an example of the PET bottle recycling cycle into textile products.

Figure 26 – Production Cycle of a PET textile

Source: Adapted from (AMARAL, 2016; MR FLY - MODA SUSTENTÁVEL, 2011)

There is no possibility of zeroing out the use of synthesized fibers in fashion and, therefore, using recycled plastic can be a solution for items that really need to be produced with plastic, such as sportswear, accessories, and products with spandex. However, this recycled plastic must come from the industry itself, not only to promote a really closed cycle but also to handle the discarded polyester, nylon, elastane, and polyamide.

6 FINAL CONSIDERATIONS

Taking in account the ever-growing global consumption, there is concern about the environmental impacts of the textile production and waste. The production impacts can include the renewability of the raw materials, the chemicals used and/or released along the process, and also the problems caused by the incorrect disposal of waste. Many of this concerns propelled companies to reexamine their manufacture processes and conform them to the sustainable guidelines.

The Brazilian textile and apparel industry presents great socioeconomic importance. Its participation in the GDP and the number of direct jobs show the influence of the Brazilian internal market. The quantity and quality of textile waste produced in Brazil represents considerable effect on environmental degradation.

Recycling and reuse processes contribute to the management and conservation of raw materials that would otherwise be discarded, decreasing the need for a new exploration of natural resources to produce new goods and products. There is difficulty in separating textile waste in the recycling industries because the pieces of a certain clothing model are not bothered by using different types and colors of fabrics, as long as the production time and, consequently, costs are controlled to be minimized.

In Brazil, an attempt to reduce environmental impacts is the recycling of textile to produce yarns, which is being largely demanded, since the mechanical recycling of textiles has been the main form of reprocessing discarded garment scrap. Many of the technologies for recycling PET chemically are still in the experimental stage or are not disseminated.

Considering that techniques for recycling and reusing textile waste are widespread in Brazil, even though in small and medium scale, the business initiatives surveyed show that the country is on the right path to industrial sustainability, following a beneficial and essential trend for society.

As seen in the research, according to the life cycle analysis of textile products made with virgin fibers of cotton, polyester and polyester and cotton blends compared to the life cycle analysis of the same fibers in their recycled form, the environmental impact caused by both recycling and the use of products with recycled fibers is smaller than the production of new fibers from virgin raw materials.

The environmental impacts generated by the PET recycling industry for textile use or pre- and post-consumer textile recycling are mainly concentrated in the use of energy from unclean sources. The fabric defibration part consumes a large amount of electricity, and the machinery used often does not have updates with more eco-efficient versions.

Another issue of great impact is the difficulty in separating fabrics by type of fiber, the process is often done manually and becomes slow, which ends up making it difficult and increasing the final value of the product. Currently, the market for this type of fiber is growing, along with a wave of sustainability that can be connected to the marketing of companies, but there is still not a considerable use of this type of product that can overcome the demand for virgin raw material.

The use of sustainability indicators within companies is often seen as unnecessary or out of reach for companies. It is often in the lack of knowledge that lies the great instability of sustainability in the textile recycling industry. When questioned about the future of sustainability, many interviewees answered that there is a lack of legislation, support from public authorities or even a basis to follow. However, it was seen through research that there are several Brazilian standards, national and international certifications and even programs that help to bring sustainability concepts to companies.

Finally, based on the research carried out and the interviews carried out with professionals related to the textile recycling industry, it is possible to identify great common difficulties between them, mainly in being able to identify the needs of the companies themselves in relation to sustainable and eco-efficient processes.

7 CONCLUSION

In this study, a SRL and review of reports were carried out regarding the production processes of thermoplastic fibers, blended fibers and natural fibers, in addition to their recycling processes to better understand and be able to quantify the environmental impact caused by each process. Details of the production and recycling processes were found, managing to identify the main impacts on each type of fiber and also more eco-responsible options.

Within the research, data on the assessment of the life cycle of fibers were also found, seeking to verify and validate the hypothesis that fiber recycling has a lower environmental impact than the production of fibers from virgin raw material. Among the results, it was found that the recycling of pure cotton and polyester fibers have the lowest environmental impact when compared to production from virgin raw material and can be easily transformed into fabrics for the production of articles in the fashion industry. Blended polyester-cotton fibers have greater difficulty in recycling, but they work with mechanical recycling and there are already advances in chemical recycling, even if it is not yet applied on a large scale.

Seeking to understand how textile recycling companies worked in practice, a survey was carried out of all companies that work with the recycling of fabrics and fibers before and after consumption in Brazil. Of the companies found, a large majority is located in the South and Southwest regions of the country, this makes the logistics process difficult so that a greater amount of textile waste can be recycled Considering the low number of recycling companies in the North, Northeast and Midwest, companies were sought that work only with the logistics of collection, treatment and management of waste, but like textile recycling companies, these companies are concentrated in the South and Southeast of the country. This generates a low rate of textile recycling in other regions and makes it difficult for waste to be used.

In order to better understand the environmental impacts on recyclers and textile waste management companies, a study was carried out to seek the sustainability indicators most discussed in the literature. From this search, four topics of indicators related to the SDGs (Sustainable Development Goals) and finally a questionnaire was prepared to be applied to professionals in the sector.

Finally, based on the observations made during the analysis of the questionnaire, it was possible to identify the points of greatest environmental impact within the production process, mainly identifying problems related to logistics, lack of a large market for these fibers and difficulty in obtaining machinery that be more eco-responsible.

8 BIBLIOGRAPHIES

ABBASI, Marjan; MOHADES MOJTAHEDI, Mohammad Reza; KOTEK, Richard. Experimental study on texturability of filament yarns produced from recycled PET. **Textile Research Journal**, *[S. l.]*, v. 90, n. 23–24, p. 2703–2713, 2020. DOI: 10.1177/0040517520925859.

ABDELMEGUID, Aya; AFY-SHARARAH, Mohamed; SALONITIS, Konstantinos. **Investigating the challenges of applying the principles of the circular economy in the fashion industry: A systematic review**. **Sustainable Production and Consumption**Elsevier B.V., , 2022. DOI: 10.1016/j.spc.2022.05.009.

ABIPET - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA DO PET. **Censo da Reciclagem de PET**. 2020. Disponível em: http://www.abipet.org.br/index.html?method=mostrarInstitucional&id=7.

ABIT - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA TÊXTIL E DE CONFECÇÃO. Relatório de atividades 2020. *[S. l.]*, 2020. Disponível em: https://s3-sa-east-1.amazonaws.com/abit-files.abit.org.br/site/relatório_atividades/2020/Relatorio_Abit2020-imp.pdf.

ABIT - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA TÊXTIL E DE CONFECÇÃO. **Campanha incentiva que empresas estimulem seus colaboradores a praticar ODS da ONU**. 2021. Disponível em: https://www.abit.org.br/noticias/campanha-incentiva-que-empresas-estimulem-seus-colaboradores-a-praticar-ods-da-onu. Acesso em: 25 mar. 2023.

ABIT - ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA TÊXTIL E DE CONFECÇÃO. **Relatório de atividades 2022**. 2022. Disponível em: https://www.abit.org.br/cont/perfil-do-setor. Acesso em: 20 mar. 2023.

ABNT - ASSOSSIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **Catálogo de normas ABNT**. 2023. Disponível em: https://www.abntcatalogo.com.br/default.aspx. Acesso em: 26 mar. 2023.

ABRAFAS - ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FIBRAS ARTIFICIAIS E SINTÉTICAS. Estatísticas Ano 2019. *[S. l.]*, 2019.

ABRAFAS - ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FIBRAS ARTIFICIAIS E SINTÉTICAS. **Fibras Manufaturadas**. 2020a. Disponível em: http://www.abrafas.org.br/site/vitrine-noticias/index/materia/fibras-manufaturadas/c/b6f.

ABRAFAS - ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FIBRAS ARTIFICIAIS E SINTÉTICAS. **Estatísticas 2020**. 2020b. Disponível em: http://www.abrafas.org.br/site/vitrine-noticias/index/materia/estatisticas-/c/b6e.

ABRAMOVAY, Ricardo; SPERANZA, Juliana Simões; PETITGAND, Cécile. **Lixo zero: Gestão de resíduos sólidos para uma sociedade mais próspera**. São Paulo: Planeta sustentável : Instituto Ethos, 2013.

ABRAPA - ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE ALGODÃO. Consumo mundial de algodão. *[S. l.]*, 2017.

ABRAPA - ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE ALGODÃO. **Exportações de algodão já batem desempenho de 2020**. 2021. Disponível em: https://www.abrapa.com.br/Paginas/Notícias Abrapa.aspx?noticia=698. Acesso em: 1 jun. 2021.

ABRELPE - ASSOCIAÇÃO BRASILEIRA DE EMPRESAS DE LIMPEZA PÚBLICA E RESÍDUOS ESPECIAIS. Panorama dos Resíduos Sólidos no Brasil 2020. *[S. l.]*, p. 51, 2020. Disponível em: https://abrelpe.org.br/panorama-2020/.

ABVTEX - ASSOCIAÇÃO BRASILEIRA DO VAREJO TÊXTIL. **Sobre o Selo ABVTEX**. 2023. Disponível em: https://www.abvtex.org.br/selo-abvtex/. Acesso em: 26 mar. 2023.

ADIDAS. **Adidas Parley**. 2021. Disponível em: https://www.adidas.com.br/parley.

AICEP - PORTUGAL GLOBAL. Economia Circular: O caminho para a sustentabilidade. **Revista Portugalglobal**, *[S. l.]*, n. 140, p. 1–52, 2021. Disponível em: https://portugalglobal.pt/PT/RevistaPortugalglobal/2021/Documents/revista-140-marco.pdf.

ALMEIDA, Jalcione Pereira; NAVARRO, Zander. Reconstruindo a agricultura: idéias e ideais na perspectiva do desenvolvimento rural sustentável. *Em*: Porto Alegre: Editora da UFRGS, 1997. p. 33–55.

AMARAL, Mariana Correa Do. Reaproveitamento e Reciclagem Têxtil no Brasil: ações e prospecto de triagem de resíduos para pequenos geradores. *[S. l.]*, p. 123, 2016. Disponível em: http://www.teses.usp.br/teses/disponiveis/100/100133/tde-11112016-104321/publico/Mariana_Amaral_final.pdf.

AMARAL, M. C.; ZONATTI, W. F.; SILVA, K. L.; JUNIOR, D. K.; NETO, J. A.; RAMOS, J. B. Industrial textile recycling and reuse in Brazil: case study and considerations concerning the circular economy. **Gestão e Produção**, *[S. l.]*, p. 31–443, 2018.

ARYAN, Yash; YADAV, Pooja; SAMADDER, Sukha Ranjan. Life Cycle Assessment of the existing and proposed plastic waste management options in India: A case study. **Journal of Cleaner Production**, *[S. l.]*, v. 211, p. 1268–1283, 2019. DOI: 10.1016/j.jclepro.2018.11.236.

BAKKER, Conny; WANG, Feng; HUISMAN, Jaco; DEN HOLLANDER, Marcel. Products that go round: Exploring product life extension through design. **Journal of Cleaner Production**, *[S. l.]*, v. 69, p. 10–16, 2014. DOI: 10.1016/j.jclepro.2014.01.028.

BALLOU, R. H. **Logística empresarial: Transportes, administração de materiais e distribuição física**. São Paulo: Atlas, 2011.

BARBOSA, Rildo Pereira; IBRAHIN, Francini Imene Dias. **Resíduos Sólidos: Impactos, manejo e gestão ambiental**. 1. ed. ed. São Paulo: Érica, 2014.

BARCELOS, Silvia Mara Bortoloto. **Indicadores de sustentabilidade em indústrias de vestuário no APL de Maringá - Cianorte PR**. 2012. *[S. l.]*, 2012.

BAUWENS, Thomas; HEKKERT, Marko; KIRCHHERR, Julian. Circular futures: What Will They Look Like? **Ecological Economics**, *[S. l.]*, v. 175, n. April, p. 106703, 2020. DOI: 10.1016/j.ecolecon.2020.106703. Disponível em: https://doi.org/10.1016/j.ecolecon.2020.106703.

BBC NEWS. **Qual é a indústria que mais polui o meio ambiente depois do setor do petróleo?** 2017. Disponível em: https://noticias.uol.com.br/meio-ambiente/ultimas-noticias/bbc/2017/03/13/qual-e-a-industria-que-mais-polui-o-meio-ambiente-depois-do-setor-do-petroleo.htm.

BCI - BETTER COTTON INICIATIVE. **O que é Better Cotton?** 2023. Disponível em: https://bettercotton.org/pt/. Acesso em: 26 mar. 2023.

BERLIM, Lilyan. **Moda e Sustentabilidade: Uma reflexão necessária**. São Paulo: Estação das Letras e Cores Editora, 2012.

BFFP - BREAK FREE FROM PLASTIC. **Indonesia returns five containers of waste to the US**. 2019. Disponível em: https://www.breakfreefromplastic.org/2019/06/19/indonesia-returns-five-containers-of-waste-to-the-us/.

BFFP - BREAK FREE FROM PLASTIC. **Brand Audit Report**. [s.l: s.n.].

BNDES - BANCO NACIONAL DO DESENVOLVIMENTO ECONÔMICO E SOCIAL. **Relatório Setorial: fibras artificiais e sintéticas**. [s.l: s.n.].

BÓSIO CAMPELLO, Livia Gaigher; DE SOUZA-LIMA, José Edmilson; MOSER, Manoela Pereira. Meio Ambiente E Sustentabilidade. **Relações Internacionais no Mundo Atual**, *[S. l.]*, v. 1, n. 22, p. 201, 2019. DOI: 10.21902/revrima.v1i25.3871.

BOUZON, Marina; GOVINDAN, Kannan. Reverse Logistics as a Sustainable Supply Chain Practice for the Fashion Industry: An Analysis of Drivers and the Brazilian Case. *Em*: **Springer Series in Supply Chain Management**. [s.l.] : Springer Nature, 2015. v. 1p. 85–104. DOI: 10.1007/978-3-319-12703-3_5.

BRAAT, Leon C.; DE GROOT, Rudolf. The ecosystem services agenda:bridging the worlds of natural science and economics, conservation and development, and public and private policy. **Ecosystem Services**, *[S. l.]*, v. 1, n. 1, p. 4–15, 2012. DOI: 10.1016/j.ecoser.2012.07.011. Disponível em: http://dx.doi.org/10.1016/j.ecoser.2012.07.011.

BRASIL. Lei Nº 6.803 de 02 de julho de 1980. Lei de Zoneamento Industrial nas Áreas Críticas de Poluição. . 1980.

BRASIL. Lei Nº 6.938, de 31 de agosto de 1981. Política Nacional do Meio Ambiente. . 1981.

BRASIL. Lei Nº 7.347 de 24 de julho de 1985. Lei de Ação Civil Pública. . 1985.

BRASIL. Lei Nº 8.171, de 17 de janeiro de 1991. Lei de Política Agrícola. . 1991.

BRASIL. Lei Nº 9.605 de 12 de fevereiro de 1998. Lei de Crimes Ambientais. . 1998.

BRASIL. Lei Nº 12.305 de 02 de agosto de 2010. Política Nacional de Resíduos Sólidos. . 2010.

BRASKEM. **Como funciona a reciclagem mecânica**. 2021a. Disponível em: https://bluevisionbraskem.com/inteligencia/infografico-como-funciona-o-processo-de-reciclagem-mecanica/.

BRASKEM. **Como funciona a reciclagem química**. 2021b. Disponível em: https://bluevisionbraskem.com/inteligencia/infografico-como-funciona-o-processo-de-reciclagem-quimica/.

BRASKEM. **Como funciona a reciclagem energética**. 2021c. Disponível em: https://bluevisionbraskem.com/inteligencia/infografico-como-funciona-o-processo-de-reciclagem-energetica/.

BRAUNGART, Michael; MCDONOUGH, William. **Cradle to Cradle: Remaking the way we make things**. New York: North Point Press, 2002. Disponível em: www.fsgbooks.com.

C2C - CRADLE TO CRADLE CERTIFICATION. **Our Community**. 2023. Disponível em: https://c2ccertified.org/our-community/brands-manufacturers. Acesso em: 25 mar. 2023.

CAMILLERI, Mark Anthony. European environment policy for the circular economy: Implications for business and industry stakeholders. **Sustainable Development**, *[S. l.]*, v. 28, n. 6, p. 1804–1812, 2020. DOI: 10.1002/sd.2113.

CAMPOS, Alexandre De; GOULART, Verci Douglas Garcia. **Logística Reversa Integrada**. São Paulo: Érica, 2017.

CECHIN, A. D. Georgescu-Roegen e o desenvolvimento sustentável: diálogo ou anátema? **Dissertação (Mestrado em Ciência Ambiental)**, *[S. l.]*, 2008.

CEID - CIRCULAR ECONOMY INICIATIVE DEUTSCHLAND. **Circular Business Models -Overcoming Barriers, Unleashing Potentials**. [s.l: s.n.].

CHAE, Youngjin; HINESTROZA, Juan. Building Circular Economy for Smart Textiles, Smart Clothing, and Future Wearables. **Materials Circular Economy**, *[S. l.]*, v. 2, n. 1, p. 2–5, 2020. DOI: 10.1007/s42824-020-00002-2.

CHEN, Hsiou-lien; BURNS, Leslie Davis. Environmental Analysis of Textile Products. *[S. l.]*, p. 248–261, 2006. DOI: 10.1177/0887302X06293065.

CHEN, Luyi; PELTON, Rylie E. O.; SMITH, Timothy M. Comparative life cycle assessment of fossil and bio-based polyethylene terephthalate (PET) bottles. **Journal of Cleaner Production**, *[S. l.]*, v. 137, p. 667–676, 2016. DOI: 10.1016/j.jclepro.2016.07.094.

CHILTON, Tom; BURNLEY, Stephen; NESARATNAM, Suresh. A life cycle assessment of the closed-loop recycling and thermal recovery of post-consumer PET. **Resources, Conservation and Recycling**, *[S. l.]*, v. 54, n. 12, p. 1241–1249, 2010. DOI: 10.1016/j.resconrec.2010.04.002.

CICLO VIVO. **Brasil recicla 311 mil toneladas de garrafas PET em 2019**. 2020. Disponível em: https://ciclovivo.com.br/inovacao/negocios/brasil-recicla-311-mil-toneladas-de-garrafas-pet-em-2019/.

CNI - PORTAL DA INDÚSTRIA. **Economia circular: entenda o que é, suas características e benefícios**. 2020. Disponível em: http://www.portaldaindustria.com.br/industria-de-a-z/economia-circular/.

CRISTINA REFOSCO, Ereany. **Estudo do ciclo de vida dos produtos têxteis: um contributo para a sustentabilidade na moda**. [s.l: s.n.].

CRUZ SANCHEZ, Fabio A.; BOUDAOUD, Hakim; CAMARGO, Mauricio; PEARCE, Joshua M. Plastic recycling in additive manufacturing: A systematic literature review and opportunities for the circular economy. **Journal of Cleaner Production**, *[S. l.]*, v. 264, 2020. DOI: 10.1016/j.jclepro.2020.121602.

DAILY, Gretchen C.; MATSON, Pamela A. Ecosystem services: From theory to implementation. **Proceedings of the National Academy of Sciences of the United States of America**, *[S. l.]*, v. 105, n. 28, p. 9455–9456, 2008. DOI: 10.1073/pnas.0804960105.

DALY, Herman E.; FARLEY, Joshua. **Ecological Economics: Principles and Applications**. [s.l: s.n.]. v. 53

DAMAYANTI, Damayanti; WULANDARI, Latasya Adelia; BAGASKORO, Adhanto; RIANJANU, Aditya; WU, Ho Shing. **Possibility routes for textile recycling technology**. **Polymers**MDPI, , 2021. DOI: 10.3390/polym13213834.

DE OLIVEIRA, Muriel; UNICAMP, Gavira; DE, Faculdade; APLICADAS, Ciências. Sustentabilidade na indústria da moda: Um estudo exploratório. *[S. l.]*, 2016.

DE OLIVEIRA NETO, Geraldo Cardoso; FERREIRA CORREIA, José Manoel; SILVA, Paulo Cesar; DE OLIVEIRA SANCHES, Ariane Gaiola; LUCATO, Wagner Cezar. Cleaner Production in the textile industry and its relationship to sustainable development goals. **Journal of Cleaner Production**, *[S. l.]*, v. 228, p. 1514–1525, 2019. DOI: 10.1016/j.jclepro.2019.04.334.

DOBROVOLSKI, Ricardo L. **Perfis de desenvolvimento sustentável: Quantificação e análise espacial para o Rio Grande do Sul**. 2001. Universidade Federal do Rio Grande do Sul, *[S. l.]*, 2001.

EGAN, Jeannie; WANG, Siyan; SHEN, Jialong; BAARS, Oliver; MOXLEY, Geoffrey; SALMON, Sonja. Enzymatic textile fiber separation for sustainable waste processing. **Resources, Environment and Sustainability**, *[S. l.]*, v. 13, p. 100118, 2023. DOI: 10.1016/j.resenv.2023.100118.

EL SEOUD, Omar A.; KOSTAG, Marc; JEDVERT, Kerstin; MALEK, Naved I. Cellulose Regeneration and Chemical Recycling: Closing the "Cellulose Gap" Using Environmentally Benign Solvents. **Macromolecular Materials and Engineering**, *[S. l.]*, v. 305, n. 4, p. 1–21, 2020. DOI: 10.1002/mame.201900832.

ELLEN MACARTHUR FOUNDATION. Towards the circular economy. Journal of Industrial Ecology. *[S. l.]*, p. 23–44, 2013.

EURECICLO. **EuReciclo - Logística Reversa**. 2023. Disponível em: https://www.eureciclo.com.br/sobre/selo?matchtype=e&utm_source=google&utm_medium=cpc&utm_campaign=se.branded&utm_term=eureciclo&hsa_acc=4958439819&hsa_cam=1073756521&hsa_grp=54087061433&hsa_ad=642049961656&hsa_src=g&hsa_tgt=aud-1331886918667%3Akwd-417064941066&hsa_kw=eureciclo&hsa_mt=e&hsa_net=adwords&hsa_ver=3&gclid=CjwKCAjw_YShBhAiEiwAMomsEMJ4puCidgIfQsIXaic-PFs_l-M2_H_GsGwCNBeqUjoElNdXmpHnlhoC0JoQAvD_BwE. Acesso em: 26 mar. 2023.

EURONEWS. **A simbiose industrial: Quais são as vantagens**. 2015. Disponível em: https://pt.euronews.com/next/2015/06/26/a-simbiose-industrial-quais-sao-as-vantagens.

FAIRTRADE. **Fairtrade Producers Overview**. 2023.

FASHION REVOLUTION. **Resíduos têxteis: a prática de descarte nas indústrias de confecção do vestuário**. 2020. Disponível em: https://www.fashionrevolution.org/brazil-blog/residuos-texteis-a-pratica-de-descarte-nas-industrias-de-confeccao-do-vestuario/.

FCEM. Como está o mercado de produção de algodão no Brasil? **Febratex Group**, *[S. l.]*, 2020.

FCEM. **Estimativa para vendas no vestuário em 2021 é de R$ 141,7 bilhões**. 2021. Disponível em: https://fcem.com.br/noticias/estimativa-para-vendas-no-vestuario-em-2021/.

FERREIRA, M. D.; COSTA, T. N.; TEIXEIRA, F. G.; JACQUES, J. J.; CATTAN, A. Redução de Resíduos Têxteis por Meio de Projeto de Produto de Moda. **Design & Tecnologia**, *[S. l.]*, n. PGDESIGN UFRGS, p. 38–44, 2015.

FLETCHER, Kate; GROSE, Lynda. **Moda e sustentabilidade: design para a mudança**. São Paulo: Editora Senac São Paulo, 2011.

FOLLOW THE COLORS. **Levi's cria a 1º calça jeans reciclada do mundo feita a partir de cinco camisetas de algodão descartadas**. 2016. Disponível em: https://followthecolours.com.br/style/levis-jeans-reciclado/.

FRAGA, Simone Carvalho Levorato. **Reciclagem de Materiais Plásticos**. São Paulo: Érica, 2014.

FREIRE, E. P.; BARREIRA, L. P. Planos de Gestão Integrada de Resíduos Sólidos: Instrumento de Gestão de Resíduos nos Municípios Brasileiros. **Gestão Contemporânea dos Resíduos Sólidos**, *[S. l.]*, p. 15 – 28., 2015.

GABRIELA BENDERÓVICZ MENDES RIBEIRO. **INDICADORES DE SUSTENTABILIDADE EM CADEIA DE SUPRIMENTOS: ESTUDO DE CASO EM INDÚSTRIA TÊXTIL**. 2019. *[S. l.]*, 2019.

GAIA. We Have Too Much Plastic That Has Nowhere To Go ... Can We Just Burn It ? *[S. l.]*, p. 1–5, 2019.

GARCIA, S.; NÄÄS, I. A.; VENDRAMETTO, O. Algodão colorido como apoio à sustentabilidade da Indústria têxtil Brasileira. **BioEng**, *[S. l.]*, p. 47–53, 2012.

GERE, D.; CZIGANY, T. Future trends of plastic bottle recycling : Compatibilization of PET and PLA. **Polymer Testing**, *[S. l.]*, v. 81, n. July 2019, p. 106160, 2020. DOI: 10.1016/j.polymertesting.2019.106160. Disponível em: https://doi.org/10.1016/j.polymertesting.2019.106160.

GHISELLINI, Patrizia; CIALANI, Catia; ULGIATI, Sergio. A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. **Journal of Cleaner Production**, *[S. l.]*, v. 114, p. 11–32, 2016. DOI: 10.1016/j.jclepro.2015.09.007.

GHOREISHI, Malahat; BHANDARI, Kajal; FRANCONI, Alessio. Smart Fashion Economy through a Data-Driven Circular Ecosystem: A Case Study. *Em*: IOP CONFERENCE SERIES: EARTH AND ENVIRONMENTAL SCIENCE 2022, **Anais** [...]. : IOP Publishing Ltd, 2022. DOI: 10.1088/1755-1315/1009/1/012012.

GIANNETTI, Biagio F.; ALMEIDA, Cecília M. V. B. **Ecologia Industrial**. 1. ed. ed. São Paulo: Blucher, 2006.

GIL, A. C. **Como elaborar projetos de pesquisa**. 4 ed. ed. São Paulo: Atlas, 2008.

GIRONI, Fausto; PIEMONTE, Vincenzo. Life cycle assessment of polylactic acid and polyethylene terephthalate bottles for drinking water. **Environmental Progress and Sustainable Energy**, *[S. l.]*, v. 30, n. 3, p. 459–468, 2011. DOI: 10.1002/ep.10490.

GOMES, Thiago S.; VISCONTE, Leila L. Y.; PACHECO, Elen B. A. V. **Life Cycle Assessment of Polyethylene Terephthalate Packaging: An Overview**. **Journal of Polymers and the Environment**Springer New York LLC, , 2019. DOI: 10.1007/s10924-019-01375-5.

GOODLAND, Robert; BANK, The World. The concept of environmental sustainability. *[S. l.]*, p. 1–24, 1995.

GORNI, Antonio. Introdução aos Plásticos. *[S. l.]*, n. January, 2015.

GOTS - GLOBAL ORGANIC TEXTILE STANDART. **Certified Suppliers** . 2023.

GOYENA, Rodrigo. Produção De Fibras De Poliéster a Partir Da Recuperação De Garrafas Pet E Análise De Viabilidade Do Projeto. **Journal of Chemical Information and Modeling**, *[S. l.]*, v. 53, n. 9, p. 1689–1699, 2019.

GROSE, L. Sustainable cotton production. *Em*: **Sustainable Textiles**. California College of the Arts San Francisco: Woodhead Publishing Limited, 2009. DOI: 10.1533/9781845696948.1.33.

GUPTA, Richa; SHUKLA, Vinod Kumar; AGARWAL, Princy. Sustainable transformation in modest fashion through “RPET technology” and “Dry-uye” process, using recycled pet plastic. **International Journal of Recent Technology and Engineering**, *[S. l.]*, v. 8, n. 3, p. 5415–5421, 2019. DOI: 10.35940/ijrte.A1432.098319.

HAGE JR., Elias. Aspectos históricos sobre o desenvolvimento da ciência e da tecnologia de polímeros. **Polímeros**, *[S. l.]*, v. 8, n. 2, p. 6–9, 1998. DOI: 10.1590/S0104-14281998000200003. Disponível em:

http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0104-14281998000200003&lng=pt&tlng=pt.

HAHLADAKIS, John N.; IACOVIDOU, Eleni. An overview of the challenges and trade-offs in closing the loop of post- consumer plastic waste (PCPW): Focus on recycling. **Journal of Hazardous Materials**, *[S. l.]*, v. 380, n. July, p. 120887, 2019. DOI: 10.1016/j.jhazmat.2019.120887. Disponível em: https://doi.org/10.1016/j.jhazmat.2019.120887.

HARMSEN, Paulien; SCHEFFER, Michiel; BOS, Harriette. Textiles for circular fashion: The logic behind recycling options. **Sustainability (Switzerland)**, *[S. l.]*, v. 13, n. 17, 2021. DOI: 10.3390/su13179714.

HEINRICH BÖLL STIFTUNG. Atlas do plástico - Fatos e números sobre o mundo dos polímeros sintéticos. *[S. l.]*, v. 01, p. 64, 2020. Disponível em: https://br.boell.org/pt-br/2020/11/29/atlas-do-plastico.

HERVA, Marta; ÁLVAREZ, Antonio; ROCA, Enrique. Sustainable and safe design of footwear integrating ecological footprint and risk criteria. **Journal of Hazardous Materials**, *[S. l.]*, v. 192, n. 3, p. 1876–1881, 2011. DOI: 10.1016/j.jhazmat.2011.07.028.

HOLTSTRÖM, Johan; BJELLERUP, Charlotte; ERIKSSON, Johanna. Business model development for sustainable apparel consumption: The case of Houdini Sportswear. **Journal of Strategy and Management**, *[S. l.]*, v. 12, n. 4, p. 481–504, 2019. DOI: 10.1108/JSMA-01-2019-0015.

HSIEH, You-Lo. Chemical structure and properties of cotton. *Em*: **Cotton: Science and technology**. [s.l: s.n.].

IBGE - INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Demografia das Empresas**. 2021.

IBD - INSTITUTO BIODINÂMICO DE DESENVOLVIMENTO RURAL. **Who are we**. 2023. Disponível em: https://www.ibd.com.br/about-us/. Acesso em: 26 mar. 2023.

IEMI- INSTITUTO DE ESTUDOS E MARKETING INDUSTRIAL LTDA. Brasil têxtil: relatório setorial da indústria têxtil brasileira 2017. *[S. l.]*, v. 17, n. 17, 2018.

IEMI- INSTITUTO DE ESTUDOS E MARKETING INDUSTRIAL LTDA. Mercado, conjuntura atual e estimativas futuras. *[S. l.]*, 2020.

IPEA - INTITUTO DE PESQUISA ECONÔMICA E APLICADA. **Diagnóstico dos Resíduos Sólidos UrbanosRelatório de Pesquisa**. Brasilia.

IPEA - INTITUTO DE PESQUISA ECONÔMICA E APLICADA. **Resíduos sólidos urbanos no Brasil: desafios tecnológicos, políticos e econômicos**. 2020. Disponível em: https://www.ipea.gov.br/cts/pt/central-de-conteudo/artigos/artigos/217-residuos-solidos-urbanos-no-brasil-desafios-tecnologicos-politicos-e-economicos.

JAEGER, C. Limits to growth. **Encyclopedia of Ecology**, *[S. l.]*, p. 367–369, 2018. DOI: 10.1016/B978-0-444-63768-0.00630-2.

JANAINA, Alves Klein; MIGUEL, Petrere; DAVI, Butturi Gomes; BARRELLA, Walter. Textile sustainability: A Brazilian etiquette issue. **Environmental Science and Policy**, *[S. l.]*, v. 109, p. 125–130, 2020. DOI: 10.1016/j.envsci.2020.02.025.

KAHOUSH, May; KADI, Nawar. **Towards sustainable textile sector: Fractionation and separation of cotton/ polyester fibers from blended textile waste**. **Sustainable Materials and Technologies**Elsevier B.V., , 2022. DOI: 10.1016/j.susmat.2022.e00513.

KALLIALA, Eija M.; NOUSIAINEN, Pertti. Environmental profile of cotton and polyester-cotton fabrics. **Autex Research Journal**, *[S. l.]*, v. 1, n. 1, p. 8–20, 1999.

KANG, Dong Ho; AURAS, Rafael; SINGH, Jay. Life cycle assessment of non-alcoholic single-serve polyethylene terephthalate beverage bottles in the state of California. **Resources, Conservation and Recycling**, *[S. l.]*, v. 116, p. 45–52, 2017. DOI: 10.1016/j.resconrec.2016.09.011.

KANT HVASS, Kerli; PEDERSEN, Esben Rahbek Gjerdrum. Toward circular economy of fashion: Experiences from a brand’s product take-back initiative. **Journal of Fashion Marketing and Management**, *[S. l.]*, v. 23, n. 3, p. 345–365, 2019. DOI: 10.1108/JFMM-04-2018-0059.

KEEBLE, Brian R. The Brundtland Report: “Our Common Future”. **Medicine and War**, *[S. l.]*, v. 4, n. 1, p. 17–25, 1988. DOI: 10.1080/07488008808408783.

KLEIN, Janaina Alves; JR, Miguel Petrere; BUTTURI-GOMES, Davi; BARRELLA, Walter. Textile sustainability : A Brazilian etiquette issue. *[S. l.]*, v. 109, n. February, p. 125–130, 2020. DOI: 10.1016/j.envsci.2020.02.025.

KOMLY, Claude Emma; AZZARO-PANTEL, Catherine; HUBERT, Antoine; PIBOULEAU, Luc; ARCHAMBAULT, Valérie. Multiobjective waste management optimization strategy coupling life cycle assessment and genetic algorithms: Application to PET bottles. **Resources, Conservation and Recycling**, *[S. l.]*, v. 69, p. 66–81, 2012. DOI: 10.1016/j.resconrec.2012.08.008.

KUCZENSKI, Brandon; GEYER, Roland. PET bottle reverse logistics - Environmental performance of California's CRV program. **International Journal of Life Cycle Assessment**, *[S. l.]*, v. 18, n. 2, p. 456–471, 2013. DOI: 10.1007/s11367-012-0495-7.

LADCHUMANANANDASIVAM, Rasiah. Ciência dos Polímeros e Engenharia das Fibras I. *[S. l.]*, p. 2–100, 2006.

LEEJARKPAI, Thanawadee; MUNGCHAROEN, Thumrongrut; SUWANMANEE, Unchalee. Comparative assessment of global warming impact and eco-efficiency of PS (polystyrene), PET (polyethylene terephthalate) and PLA (polylactic acid) boxes. **Journal of Cleaner Production**, *[S. l.]*, v. 125, p. 95–107, 2016. DOI: 10.1016/j.jclepro.2016.03.029.

LEITE, P. R. **Logística Reversa: meio ambiente e competitividade**. São Paulo: Pearson Prentice Hall, 2003.

LEVAN, S. .. L. Life Cycle Assessment: Measuring Environmental Impact. **Lyfe cycle environmental impact analysis for forest products**, *[S. l.]*, p. 7–21, 1998.

LI, Zhi. Reconstruction of cotton-polyester blended fabric. **IOP Conference Series: Materials Science and Engineering**, *[S. l.]*, v. 768, n. 2, 2020. DOI: 10.1088/1757-899X/768/2/022071.

LIMA, Nathana Luiza Pinto De; FELIPE, Renata Carla Tavares dos Santos; FELIPE, Raimundo Nonato Barbosa. Cement mortars with use of polyethylene tereftalate aggregate: a review on its sustainability. **Research, Society and Development**, *[S. l.]*, v. 9, n. 8, 2020. DOI: 10.33448/rsd-v9i8.5640.

LIU, Yun; HUANG, Haihong; ZHU, Libin; ZHANG, Cheng; REN, Feiyue; LIU, Zhifeng. Could the recycled yarns substitute for the virgin cotton yarns: a comparative LCA. **The International Journal of Life Cycle Assessment**, *[S. l.]*, v. 25, n. 10, p. 2050–2062, 2020. a. DOI: 10.1007/s11367-020-01815-8.

LIU, Yun; ZHU, Libin; ZHANG, Cheng; REN, Feiyue; HUANG, Haihong; LIU, Zhifeng. Life cycle assessment of melange yarns from the manufacturer perspective. **The International Journal of Life Cycle Assessment**, *[S. l.]*, v. 25, n. 3, p. 588–599, 2020. b. DOI: 10.1007/s11367-019-01705-8.

LOBO, Renato Nogueirol; LIMEIRA, Erika Thalita Navas Pires; MARQUES, Rosiane do Nascimento. **Fundamentos da Tecnologia Têxtil**. São Paulo: Érica, 2014.

MADIVAL, Santosh; AURAS, Rafael; SINGH, Sher Paul; NARAYAN, Ramani. Assessment of the environmental profile of PLA, PET and PS clamshell containers using LCA methodology. **Journal of Cleaner Production**, *[S. l.]*, v. 17, n. 13, p. 1183–1194, 2009. DOI: 10.1016/j.jclepro.2009.03.015.

MAGALHÃES, Lucas; SILVEIRA, Icléia; SEIBEL, Silene. Indicadores de sustentabilidade que podem ser aplicados nas indústrias têxteis e de vestuário. *Em*: 2020, **Anais** [...]. [s.l: s.n.]

MAJUMDAR, Abhijit; SHUKLA, Sandeep; SINGH, Anshu Anjali; ARORA, Sanchi. Circular fashion: Properties of fabrics made from mechanically recycled poly-ethylene terephthalate (PET) bottles. **Resources, Conservation and Recycling**, *[S. l.]*, v. 161, p. 104915, 2020. DOI: 10.1016/j.resconrec.2020.104915. Disponível em: https://linkinghub.elsevier.com/retrieve/pii/S0921344920302330.

MANO, Eloisa Biasotto; PACHECO, Élen Beatriz Acordi Vasques; BONELLI, Cláudia Maria Chagas. **Meio ambiente, poluição e reciclagem**. 2. ed. ed. São Paulo: Blucher, 2010.

MARCON, Arthur; DE MEDEIROS, Janine Fleith; RIBEIRO, José Luis Duarte. Innovation and environmentally sustainable economy: Identifying the best practices developed by multinationals in Brazil. **Journal of Cleaner Production**, *[S. l.]*, v. 160, p. 83–97, 2017. DOI: 10.1016/j.jclepro.2017.02.101.

MENEGUCCI, Franciele; MERTELI, Leticia; CAMARGO, Maristela; VITO, Meriele. Resíduos têxteis : Análise sobre descarte e reaproveitamento nas indústrias de confecção. **Congresso Nacional de Excelência em Gestão**, *[S. l.]*, p. 12, 2015.

MICHAELI, Walter; GREIF, Helmut; KAUFMANN, Hans; VOSSEBÜRGER, Franz-Josef. **Tecnologia dos Plásticos**. São Paulo: Blucher, 1995.

MMA - MINISTÉRIO DO MEIO AMBIENTE. **Levantamento e análise da situação dos planos de resíduos sólidos no Estado de São Paulo**. 2012. Disponível em: https://www.gov.br/mma/pt-br.

MORTON, W. E.; HEARLE, J. W. S. **Physical properties of textile fibres**. 4th ed ed. USA: Woodhead Publishing Limited, 2008.

MR FLY - MODA SUSTENTÁVEL. **Como é produzida a malha PET?** 2011. Disponível em: http://www.mrflymoda.com.br/blog/moda-consciente/como-e-produzida-a-malha-pet/.

MUTHU, Subramanian Senthil Kannan; LI, Yi; HU, Jun Yan; ZE, Li. Carbon footprint reduction in the textile process chain: Recycling of textile materials. **Fibers and Polymers**, *[S. l.]*, v. 13, n. 8, p. 1065–1070, 2012. a. DOI: 10.1007/s12221-012-1065-0.

MUTHU, Subramanian Senthilkannan; LI, Y.; HU, J. Y.; MOK, P. Y. Quantification of environmental impact and ecological sustainability for textile fibres. **Ecological Indicators**, *[S. l.]*, v. 13, n. 1, p. 66–74, 2012. b. DOI: 10.1016/j.ecolind.2011.05.008.

MUTHU, Subramanian Senthilkannan; LI, Yi; HU, Jun Yan; MOK, Pik Yin. Recyclability Potential Index (RPI): The concept and quantification of RPI for textile fibres. **Ecological Indicators**, *[S. l.]*, v. 18, p. 58–62, 2012. c. DOI: 10.1016/j.ecolind.2011.10.003.

NAVONE, Laura; MOFFITT, Kaylee; HANSEN, Kai Anders; BLINCO, James; PAYNE, Alice; SPEIGHT, Robert. Closing the textile loop: Enzymatic fibre separation and recycling of wool/polyester fabric blends. **Waste Management**, *[S. l.]*, v. 102, p. 149–160, 2020. DOI: 10.1016/j.wasman.2019.10.026. Disponível em: https://doi.org/10.1016/j.wasman.2019.10.026.

NUNES, Edilene de Cássia Dutra; LOPES, Fábio Renato Silva. **Polímeros: Conceitos, Estrutura Molecular, Classificação e Propriedades**. São Paulo: Érica, 2014.

NUNES, Edilene de Cássia Dutra; SANTOS, Leandro José Dos. **Termoplásticos**. São Paulo: Érica, 2015.

O ESTADO DE SÃO PAULO. **Em 2008 o Brasil importou 175,5 mil toneladas de lixo**. 2009. Disponível em: http://www.estadao.com.br/noticias/geral,em-2008-brasil-importou-175-5-mil-toneladas-de-lixo,408583.

OEKO-TEX. **Our Standarts**. 2023. Disponível em: https://www.oeko-tex.com/en/our-standards. Acesso em: 26 mar. 2023.

PANASHE, J. A.; DANYUO, Y. Recycling of plastic waste materials : mechanical properties and implications for road construction. *[S. l.]*, p. 1305–1312, 2020. DOI: 10.1557/adv.20.

PAPONG, Seksan; MALAKUL, Pomthong; TRUNGKAVASHIRAKUN, Ruethai; WENUNUN, Pechda; CHOM-IN, Tassaneewan; NITHITANAKUL, Manit; SAROBOL, Ed. Comparative assessment of the environmental profile of PLA and PET drinking water bottles from a life cycle perspective. **Journal of Cleaner Production**, *[S. l.]*, v. 65, p. 539–550, 2014. DOI: 10.1016/j.jclepro.2013.09.030.

PARKER, Laura. **Em 2040, lixo plástico nos oceanos poderá ser o triplo do atual**. 2020. Disponível em: https://www.nationalgeographicbrasil.com/meio-ambiente/2020/07/em-2040-lixo-plastico-nos-oceanos-podera-ser-o-triplo-do-atual.

PASQUALINO, Jorgelina; MENESES, Montse; CASTELLS, Francesc. The carbon footprint and energy consumption of beverage packaging selection and disposal. **Journal of Food Engineering**, *[S. l.]*, v. 103, n. 4, p. 357–365, 2011. DOI: 10.1016/j.jfoodeng.2010.11.005.

PEARCE, David; TURNER, R. Economics of natural resources and the environment. **American Journal of Agricultural Economics**, *[S. l.]*, n. 73, 1990. DOI: 10.2307/1242904.

PENSUPA, Nattha; LEU, Shao Yuan; HU, Yunzi; DU, Chenyu; LIU, Hao; JING, Houde; WANG, Huaimin; LIN, Carol Sze Ki. Recent Trends in Sustainable Textile Waste Recycling Methods: Current Situation and Future Prospects. **Topics in Current Chemistry**, *[S. l.]*, v. 375, n. 5, 2017. DOI: 10.1007/s41061-017-0165-0.

PEREIRA, Gislaine de Souza. Materiais e Processos Têxteis. *[S. l.]*, p. 94, 2009. Disponível em: wiki.ifsc.edu.br/mediawiki/images/temp/0/07/20090218180450!MPTEX6.pdf.

PERIYASAMY, Aravin Prince; MILITKY, Jiri. LCA (Life Cycle Assessment) on Recycled Polyester. *Em*: [s.l: s.n.]. p. 1–30. DOI: 10.1007/978-981-13-9578-9_1.

PETA - PEOPLE FOR THE ETHICAL TREATMENT OF ANIMALS. PETA-Approved Vegan. *[S. l.]*, 2023. Disponível em: https://petaapprovedvegan.peta.org/. Acesso em: 26 mar. 2023.

PETERS, G.; SVANSTRÖM, M.; ROOS, S.; SANDIN, G.; ZAMANI, B. Carbon footprints in the textile industry. *Em*: **Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing**. [s.l.] : Elsevier, 2015. a. p. 3–30. DOI: 10.1016/B978-0-08-100169-1.00001-0.

PETERS, G.; SVANSTRÖM, M.; ROOS, S.; SANDIN, G.; ZAMANI, B. Carbon footprints in the textile industry. *Em*: **Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing**. [s.l.] : Elsevier Inc., 2015. b. p. 3–30. DOI: 10.1016/B978-0-08-100169-1.00001-0.

PETERS, Greg M.; SANDIN, Gustav; SPAK, Björn. Environmental Prospects for Mixed Textile Recycling in Sweden. **ACS Sustainable Chemistry and Engineering**, *[S. l.]*, v. 7, n. 13, p. 11682–11690, 2019. DOI: 10.1021/acssuschemeng.9b01742.

PEZZOLO, Dinah Bueno. **Tecidos: história, tramas, tipos e usos**. 5. ed. ed. São Paulo: Editora Senac São Paulo, 2017.

PROCEL. **PROCEL SELO - Eficiência Energética em Equipamentos**. 2023. Disponível em: http://www.procelinfo.com.br/data/Pages/LUMIS623FE2A5ITEMIDF05F4A2E14D84958A AEE698B55F104EAPTBRIE.htm. Acesso em: 26 mar. 2023.

ROBAINA, Margarita; MURILLO, Kelly; ROCHA, Eugénio; VILLAR, José. Circular economy in plastic waste - Efficiency analysis of European Countries. **Science of the Total Environment**, *[S. l.]*, v. 730, p. 139038, 2020. DOI: 10.1016/j.scitotenv.2020.139038. Disponível em: https://doi.org/10.1016/j.scitotenv.2020.139038.

RODIE, J. B. Commitment to green. **Textile World**, *[S. l.]*, p. 48, 2002.

ROMEIRO, Ademar Ribeiro. Economia ou economia política da sustentabilidade ? **Economia**, *[S. l.]*, 2001.

ROMERO, Luiz Lauro; VIEIRA, Jayme Otacilio Wehrs Mattos; MEDEIROS, Luiz Alberto R. De; MARTINS, Renato Francisco. Fibras artificiais e sintéticas. **Banco Nacional de Desenvolvimento Econômico e Social**, *[S. l.]*, v. 1, p. 54–66, 1995.

SACHS, Ignacy. **Desenvolvimento: Includente, sustentável, sustentando**. Rio de Janeiro: Garamond, 2008.

SADEGHI, Banafsheh; MARFAVI, Yousef; ALIAKBARI, Raouf; KOWSARI, Elaheh; BORBOR AJDARI, Farshad; RAMAKRISHNA, Seeram. Recent Studies on Recycled PET Fibers: Production and Applications: a Review. **Materials Circular Economy**, *[S. l.]*, v. 3, n. 1, p. 4, 2021. a. DOI: 10.1007/s42824-020-00014-y. Disponível em: http://link.springer.com/10.1007/s42824-020-00014-y.

SADEGHI, Banafsheh; MARFAVI, Yousef; ALIAKBARI, Raouf; KOWSARI, Elaheh; BORBOR AJDARI, Farshad; RAMAKRISHNA, Seeram. Recent Studies on Recycled PET Fibers: Production and Applications: a Review. **Materials Circular Economy**, *[S. l.]*, v. 3, n. 1, p. 4, 2021. b. DOI: 10.1007/s42824-020-00014-y.

SALCEDO, Elena. **Moda ética para um futuro sustentável**. 1. ed. São Paulo: Editora Gustavo Gili, 2014.

SANDIN, Gustav; PETERS, Greg M. Environmental impact of textile reuse and recycling – a review. **Journal of Cleaner Production**, *[S. l.]*, 2018. DOI: 10.1016/j.jclepro.2018.02.266. Disponível em: https://doi.org/10.1016/j.jclepro.2018.02.266.

SANDVIK, Ida Marie; STUBBS, Wendy. Circular fashion supply chain through textile-to-textile recycling. **Journal of Fashion Marketing and Management**, *[S. l.]*, v. 23, n. 3, p. 366–381, 2019. DOI: 10.1108/JFMM-04-2018-0058.

SCHMIDT, Luísa Silva. A contribuição de Georgescu-Roegen na definição jurídica de desenvolvimento sustentável. *Em*: XIII ENCONTRO NACIONAL DA SOCIEDADE BRASILEIRA DE ECONOMIA ECOLÓGICA 2019, **Anais** [...]. [s.l: s.n.] p. 283.

SENAI. **Manual Técnico Têxtil e Vestuário - Nº 01 - Fibras Têxteis**. São Paulo.

SENAI. **Fiação**. São Paulo: Editora Senai SP, 2015.

SHANMUGAM, Vigneshwaran; DAS, Oisik; NEISIANY, Rasoul Esmaeely; BABU, Karthik; SINGH, Sunpreet; HEDENQVIST, Mikael S.; BERTO, Filippo; RAMAKRISHNA, Seeram. Polymer Recycling in Additive Manufacturing: an Opportunity for the Circular Economy. **Materials Circular Economy**, *[S. l.]*, v. 2, n. 1, p. 11, 2020. DOI: 10.1007/s42824-020-00012-0.

SHEN, Li; WORRELL, Ernst; PATEL, Martin K. Open-loop recycling: A LCA case study of PET bottle-to-fibre recycling. **Resources, Conservation and Recycling**, *[S. l.]*, v. 55, n. 1, p. 34–52, 2010. DOI: 10.1016/j.resconrec.2010.06.014.

SHERWOOD, James. Closed-loop recycling of polymers using solvents. **Johnson Matthey Technology Review**, *[S. l.]*, v. 64, n. 1, p. 4–15, 2020. DOI: 10.1595/205651319x15574756736831.

SHIRVANIMOGHADDAM, Kamyar; MOTAMED, Bahareh; RAMAKRISHNA, Seeram; NAEBE, Minoo. Death by waste: Fashion and textile circular economy case. **Science of the Total Environment**, *[S. l.]*, v. 718, 2020. DOI: 10.1016/j.scitotenv.2020.137317.

SILVA, Mara. **Práticas de sustentabilidade no mundo da moda e do vestuário**. [s.l: s.n.].

SINCLAIR, Rose. **Textiles and Fashion: Materials, Design and Technology**. 1. ed. USA: Woodhead Publishing Limited, 2015.

SINDITÊXTIL - SP. Retalho Fashion – projeto de reciclagem une meio ambiente e inclusão social. **Sindicato das Indústrias de Fiação e Tecelagem do Estado de São Paulo.**, *[S. l.]*, v. Ano VII, 2012. Disponível em: http://www.sinditextilsp.org.br/jornal/sindi_25.pdf.

SIQUEIRA, Mylena Uhlig; CONTIN, Barbara; FERNANDES, Palloma Renny Beserra; RUSCHEL-SOARES, Raysa; SIQUEIRA, Philipe Uhlig; BARUQUE-RAMOS, Julia. Brazilian Agro-industrial Wastes as Potential Textile and Other Raw Materials: a Sustainable Approach. **Materials Circular Economy**, *[S. l.]*, v. 4, n. 1, p. 9, 2022. DOI: 10.1007/s42824-021-00050-2.

SUBRAMANIAN, Karpagam; CHOPRA, Shauhrat S.; CAKIN, Ezgi; LI, Xiaotong; LIN, Carol Sze Ki. Environmental life cycle assessment of textile bio-recycling – valorizing cotton-polyester textile waste to pet fiber and glucose syrup. **Resources, Conservation and Recycling**, *[S. l.]*, v. 161, n. June, p. 104989, 2020. DOI: 10.1016/j.resconrec.2020.104989. Disponível em: https://doi.org/10.1016/j.resconrec.2020.104989.

SUSTAINABLE APPAREL COALITION - SAC. **Higgs Materials Sustainability Index (MSI)**. [s.l: s.n.].

SUSTAINABLE APPAREL COALITION - SAC. **Higg Materials Sustainability Index - Polyester Fabric**. [s.l: s.n.].

TAUSIF, Muhammad; JABBAR, Abdul; NAEEM, Muhammad Salman; BASIT, Abdul; AHMAD, Faheem; CASSIDY, Thomas. Cotton in the new millennium: advances, economics, perceptions and problems. **Textile Progress**, *[S. l.]*, v. 50, n. 1, p. 1–66, 2018. DOI: 10.1080/00405167.2018.1528095.

THE GUARDIAN. **UK waste incinerators three times as likely to be in deprived areas**. 2020. Disponível em: https://www.theguardian.com/environment/2020/jul/31/uk-waste-incinerators-three-times-more-likely-to-be-in-deprived-areas.

THE TEXTILE EXCHANGE. **Organic Cotton Market Report 2018**. [s.l: s.n.].

THE TEXTILE INSTITUTE. **Textile Terms and Definitions**. 11. ed. [s.l: s.n.].

THIOUNN, Timmy; SMITH, Rhett C. Advances and approaches for chemical recycling of plastic waste. *[S. l.]*, n. December 2019, p. 1347–1364, 2020. DOI: 10.1002/pol.20190261.

TONIOLO, Sara; MAZZI, Anna; NIERO, Monia; ZULIANI, Filippo; SCIPIONI, Antonio. Comparative LCA to evaluate how much recycling is environmentally favourable for food packaging. **Resources, Conservation and Recycling**, *[S. l.]*, v. 77, p. 61–68, 2013. DOI: 10.1016/j.resconrec.2013.06.003.

ULBRA - UNIVERSIDADE LUTERANA DO BRASIL. **Desenvolvimento e Sustentabilidade**. Curitiba: Ibpex, 2009.

UN - UNITED NATIONS. **The 17 Goals of Sustainable Development**. 2023. Disponível em: https://sdgs.un.org/goals. Acesso em: 21 mar. 2023.

UNEP - UNITED NATIONS ENVIRONMENTAL PROGRAM. Towards a green economy: pathways to sustainable development and poverty eradication. *[S. l.]*, 2011.

VAN DER VELDEN, Natascha M.; PATEL, Martin K.; VOGTLÄNDER, Joost G. LCA benchmarking study on textiles made of cotton, polyester, nylon, acryl, or elastane. **International Journal of Life Cycle Assessment**, *[S. l.]*, v. 19, n. 2, p. 331–356, 2014. a. DOI: 10.1007/s11367-013-0626-9.

VAN DER VELDEN, Natascha M.; PATEL, Martin K.; VOGTLÄNDER, Joost G. LCA benchmarking study on textiles made of cotton, polyester, nylon, acryl, or elastane. **The International Journal of Life Cycle Assessment**, *[S. l.]*, v. 19, n. 2, p. 331–356, 2014. b. DOI: 10.1007/s11367-013-0626-9.

VEIGA, José Eli Da. **Desenvolvimento sustentável**. [s.l: s.n.].

VELENTURF, Anne P. M.; PURNELL, Phil. **Principles for a sustainable circular economy**. **Sustainable Production and Consumption**Elsevier B.V., , 2021. DOI: 10.1016/j.spc.2021.02.018.

VEZZÁ, C. S. B.; COTAIT, P. L. de A. **Produção de fibras para a confecção de tecidos a partir da reciclagem de PET**. 2006. Universidade de São Paulo, *[S. l.]*, 2006.

WAGAYE, Bewuket Teshome; ADAMU, Biruk Fentahun; JHATIAL, Abdul Khalique. Recycled Cotton Fibers for Melange Yarn Manufacturing. *Em*: [s.l: s.n.]. p. 529–546. DOI: 10.1007/978-981-15-9169-3_21.

WILSON, J. Fibres, yarns and fabrics: fundamental principles for the textile designer. *Em*: **Textile Design**. [s.l: s.n.]. p. 3–30. DOI: 10.1533/9780857092564.1.3.

YOUNG, R. Dilemmas and advances in corporate social responsibility in Brazil: the work of the Ethos institute. **Natural Resources Forum**, *[S. l.]*, v. 24, p. 291–301, 2004.

YOUSEF, Samy; TATARIANTS, Maksym; TICHONOVAS, Martynas; KLIUCININKAS, Linas; LUKOŠIŪTĖ, Stasė Irena; YAN, Libo. Sustainable green technology for recovery of cotton fibers and polyester from textile waste. **Journal of Cleaner Production**, *[S. l.]*, v. 254, 2020. DOI: 10.1016/j.jclepro.2020.120078.

ZHU, Juxiang; YANG, Yiduo; YI, L. I.; PINGHUA, X. U.; WANG, Laili. Water footprint calculation and assessment of viscose textile. **Industria Textila**, *[S. l.]*, v. 71, n. 1, p. 33–40, 2020. DOI: 10.35530/IT.071.01.1642.

ZIMON, Dominik; DOMINGUES, Pedro. Proposal of a concept for improving the sustainable management of supply chains in the textile industry. **Fibres and Textiles in Eastern Europe**, *[S. l.]*, v. 26, n. 2, p. 8–12, 2018. DOI: 10.5604/01.3001.0011.5732.

ZONATTI, Welton Fernando. Estudo interdisciplinar entre reciclagem têxtil e o design : avaliação de compósitos produzidos com fibras de algodão. *[S. l.]*, p. 195, 2013.

ZONATTI, Welton Fernando. **Geração de resíduos sólidos da indústria brasileira têxtil e de confecção : materiais e processos para reuso e reciclagem**. 2016. University of Sao Paulo, *[S. l.]*, 2016.

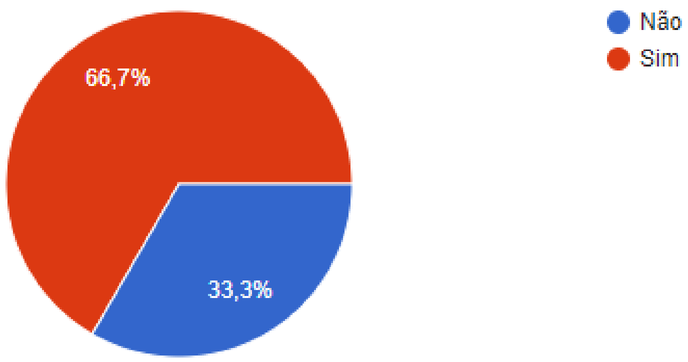
APPENDIX A - Script for the Structured Interview with Textile Recycling Companies

1) Do you wish the company to remain anonymous in publishing this work?
2) If you wish to identify yourself: What is the name of the company?
3) According to the IBGE criteria, would you classify your company as:
    a) Small – up to 50 employees
    b) Medium – 50 to 500 employees
    c) Large – more than 500 employees
4) What is your function/education, and how many years have you been working in the textile area?
5) What actions does your company have related to the use and treatment of water during its processes?
6) Does the company reuse water within its processes?
7) Are there chemicals used in your process that require treatment of your effluents? If yes, which ones?
8) Does your company have initiatives to protect water resources from contact with polluting chemicals?
9) What energy source does your company use?
10) Which processes would you say use the most energy in your company?
11) Are there actions that could be applied to save energy use in your company?
12) Does the company give preference to eco-efficient equipment?
13) Is there the use of chemical products during the process used by the company? If so, what is the destination given to the waste of these materials?
14) Does the company have any indicator or measurement related to the emission of greenhouse gases?
15) Does the company have any type of carbon offset issued? If yes, which one? (eg: reforestation system)
16) Is there monitoring of toxic gases that may occur during the production process?
17) What are the main raw materials used by the company?
18) Does the company use waste as raw material? If yes, which ones?
19) What recycling methods are adopted by the company?
20) What actions does the company take to reduce waste disposal?
21) How do you see the future of sustainability in the textile industry?

APPENDIX B – Interview Results

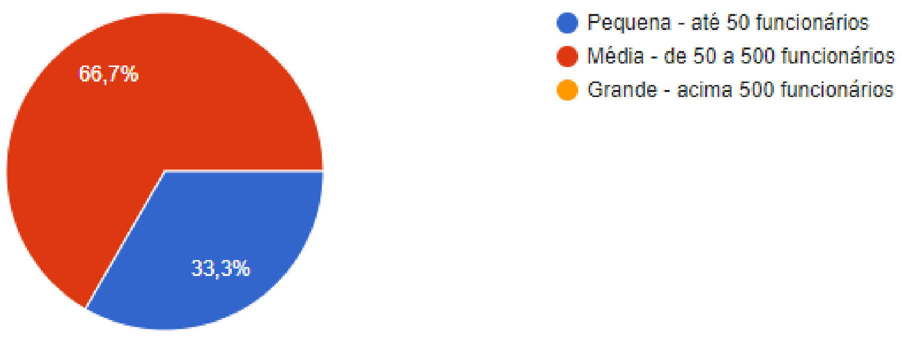
Você deseja que a empresa seja mantida anônima na publicação desse trabalho?

6 respostas



De acordo com o critério do IBGE, você classificaria sua empresa como:

6 respostas



Qual sua função/formação, e quantos anos atua na área de têxtil e moda?

6 respostas

Gestor da Empresa. Atuo no setor têxtil desde 2006

Sócio/Diretor , 26 anos de atuação no mercado textil

Engenheiro têxtil, já a 21 anos na área

triagem, atua ha 5 anos

Gestora, 20 anos de empresa

Gerente de Produção, 29 anos de carreira

Quais ações sua empresa possui relacionado ao uso e tratamento de água durante seus processos?

6 respostas

Não se aplica pois trabalhamos com resíduos sólidos

Não temos água em nosso processo

não usa água

empresa possui estação de tratamento de água usada no tingimento

Não utilizamos água em nossos processos

Não usa no processo

A empresa possui reutilização de água dentro dos seus processos?

6 respostas

Nao se aplica

Não possuimos

não

sim, água do tingimento é tratada para ser usada novamente. quase toda a agua é reaproveitada

Não utilizamos água em nossos processos

Não

Existem produtos químicos utilizados no seu processo que requerem tratamento dos seus efluentes? Se sim, quais?

6 respostas

Nao se aplica

Não temos nenhum produto químico em nosso processo

agora não

so corantes, nenhum tóxico

Não utilizamos água em nossos processos

Não

Sua empresa possui iniciativas para proteger os recursos hídricos do contato com produtos químicos poluentes?

6 respostas

Não se aplica

Sim , para produtos de manutenção.

não aplica

tratamento e reutilização

Não utilizamos água em nossos processos

Não usa água

Qual fonte de energia utilizada pela sua empresa?

6 respostas

Quais processos você diria que mais utilizam energia na sua empresa?

6 respostas

Somente ventiladores e escritório. Muito baixa utilização

Processo de desfiar os retalhos

Desfibragem e fiação

desfibragem

Triagem e trituração das fibras

Desfribragem e costura

Existem ações que poderiam ser aplicadas para poupar o uso de energia na sua empresa?

6 respostas

Não

De momento não

equipamentos melhores

não que eu conheça

Por enquanto nenhuma que possa ser aplicada na empresa

Máquinas novas e melhores

A empresa dá preferência para equipamentos ecoeficientes?

6 respostas

Sim

Quando existe esta tecnologia , sim

não existe muitos

para os processos que existe essa possibilidade, sim.

Não existem muitos para serem utilizamos no ramo

Sim

Existe o uso de produtos químicos durante o processo utilizado pela empresa? Se sim, qual a destinação dada aos resíduos desses materiais?

6 respostas

Não
No processo não , somente na manutenção e temos a destinação correta destes residuos.
não uso
não, os corantes não sãotóxicos e a água é tratada
Não
Não usa no processo

A empresa possui algum indicador ou medição relacionado à emissão de gases de efeito estufa?

6 respostas

Não se aplica
Somente o da Energia.
não emite
não
Não aparenta ser necessário
Não tem

A empresa possui algum tipo de compensação de carbono emitido? Se sim, qual? (ex: sistema de reflorestamento)

6 respostas

Nao

Não

atualmente não

não

No momento não

Tem selo EuReciclo e FreteNeutro

É realizado monitoramento de gases tóxicos que possam acontecer durante o processo produtivo?

6 respostas

não

Não

Não se aplica

Não temos gases em nosso processo

Quais as principais matérias prima utilizadas pela empresa?

6 respostas

Resíduos têxteis de confecções

Resíduos textêis

resíduo textil

sobras de corte de outras confecções

Pré e pós consumo, vindos de cooperativas que fazem a coleta.

Resíduos de confecção

A empresa utiliza resíduos como matéria prima? Se sim, quais?

6 respostas

Sim. Resíduos de tecido de uniformes, uniformes usados.

Textêis

aparas de algodão

poliéster, polipropileno, algodão e viscose

Reciclamos apenas poliéster

Todo tipo de fibra natural e sintética

Quais métodos de reciclagem são adotados pela empresa?

6 respostas

Separação por cor e venda. Recebemos resíduos de mais de 25 confecções, em torno de 30t mensais

Mecânica

apenas mecanico

separação por tipo de fibra, desfibragem e transformação em novos fios

Utilizamos a reciclagem mecânica

Desfribrar e usar como enchimento

Quais ações a empresa adota para diminuir a descarte de resíduos?

6 respostas

Sempre buscamos parceiros para dar destino aos resíduos e destinarmos o mínimo possível para incineração

Programas internos

toda fibra é reciclada

não sobra resíduos

Não possuímos um método para isso, mas o processo gera pouco descarte.

O que sobra da empresa ou não é usado aqui é vendido para outros parceiros

Como você vê o futuro da sustentabilidade na indústria da têxtil?

5 respostas

Está crescendo porém há necessidade de políticas públicas para aumentar o engajamento de pequenas confecções e oficinas de corte

Estamos caminhando para melhorar , mas ainda tem muito pela frente.

falta divulgação do quão benefico é a reciclagem e uso desse tipo de tecido

É preciso uma mobilização de indústrias e um grande investimento nessa área para que possa inovar e crescer

Falta conhecimento das pessoas sobre sustentabilidade e sobre reciclagem também