UNVEILING THE REALITY OF SOLID TEXTILE WASTE IN CATALONIA: A RISING OPPORTUNITY FOR THE LAUNDRY INDUSTRY

Trabajo de grado

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Final Project

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Declaramos, bajo la gravedad de juramento, que hemos escrito el documento de título "Unveiling the reality of solid textile waste in Catalonia: a rising opportunity for the laundry industry" en la opción de grado de Doble Titulación en convenio con EADA Business School y que, por lo tanto, su contenido es original.

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Abstract

Our project supports Girbau, a global leader in laundry solutions based in Catalonia, in exploring new opportunities to address textile waste as part of their sustainability efforts. Through GirbauLAB, the company has successfully implemented circular solutions for dry and humid waste but is now focused on the growing issue of textile waste. This presents an opportunity to enhance both sustainability and economic gains. The goal of our report is to understand the current landscape of end-of-life textiles in the laundry industry and identify circular practices that could be applied, driven by upcoming EU legislation and the known negative environmental and social impacts of textile waste.

To assess the scale of the problem, we estimated that half a million kg of hotel towels and bedsheets are wasted annually in Barcelona. We conducted interviews with laundries and hotels in Catalonia to gather data and carried out a literature review of the environmental externalities associated with cotton textile waste. We found significant negative impacts from both virgin and recycled cotton in terms of CO2 emissions, freshwater use, and land occupation. For example, the production and transportation of virgin cotton results in over 9.5 million kg of CO2 emissions and the consumption of 34.7 million m^3 of freshwater.

Our scenario analysis outlined the key success factors Girbau must consider to lead the industry towards circularity. These include promoting compliance with new regulations, investing in recycling technologies, and fostering a paradigm shift in material management. Challenges such as limited interview samples, difficulty accessing industry data, and financial

constraints on obtaining proprietary information limited the scope of our research. However, the project highlighted the need for industry transformation to reduce the environmental footprint of textiles in the laundry industry.

Keywords:

Sustainability, Circularity, Textile waste, Environmental impact, Regulatory Compliance, Recycling innovation, CO2 emissions, Water use, Land occupation, Scenario analysis

Resumen

Nuestro proyecto apoya a Girbau, un líder global en soluciones de lavandería con sede en Cataluña, en la exploración de nuevas oportunidades para abordar los residuos textiles como parte de sus esfuerzos de sostenibilidad. A través de GirbauLAB, la empresa ha implementado con éxito soluciones circulares para los residuos secos y húmedos, pero ahora se está centrando en el creciente problema de los residuos textiles. Esto presenta una oportunidad para mejorar tanto la sostenibilidad como los beneficios económicos. El objetivo de nuestro informe es comprender el panorama actual de los textiles al final de su vida útil en la industria de lavandería e identificar prácticas circulares que se puedan aplicar, impulsadas por la próxima legislación de la UE y los conocidos impactos ambientales y sociales negativos de los residuos textiles.

Para evaluar la magnitud del problema, estimamos que se desperdician anualmente medio millón de kilogramos de toallas y sábanas de hotel en Barcelona. Realizamos entrevistas con lavanderías y hoteles en Cataluña para recopilar datos y llevamos a cabo una revisión bibliográfica de las externalidades ambientales asociadas a los residuos textiles de algodón. Encontramos impactos negativos significativos tanto del algodón virgen como del reciclado en términos de emisiones de CO_2, uso de agua y ocupación de tierras. Por ejemplo, la producción y transporte de algodón virgen genera más de 9.5 millones de kg de emisiones de CO_2 y el consumo de 34.7 millones de m^3 de agua dulce.

Nuestro análisis de escenarios delineó los factores clave de éxito que Girbau debe considerar para liderar la industria hacia la circularidad. Estos incluyen promover el cumplimiento de las nuevas normativas, invertir en tecnologías de reciclaje y fomentar un

cambio de paradigma en la gestión de materiales. Desafíos como las muestras limitadas de entrevistas, la dificultad para acceder a datos de la industria y las restricciones financieras para obtener información propietaria limitaron el alcance de nuestra investigación. Sin embargo, el proyecto destacó la necesidad de una transformación industrial para reducir la huella ambiental de los textiles en la industria de lavandería.

Palabras clave:

Sostenibilidad, Circularidad, Residuos textiles, Impacto ambiental, Cumplimiento normativo, Innovación en reciclaje, Emisiones de CO_2, Uso de agua, Ocupación de tierra, Análisis de escenarios

Abbreviations

CAGR - Compound annual growth rate

CO2 - Carbon Dioxide

EU - European Union

EPR - Extended Producer Responsibility

EoL - End-of-Life

FU - Functional unit

GWP - Global Warming Potential

GHG - Greenhouse Gas emissions

ICAC - International Cotton Advisory Committee

Kg - Kilogram

L - Liter

LCA - Life Cycle Assessment

LCIA - Life Cycle Impact Assessment

MJ - Megajoule

Mt - Million Tonne

M3 - Cubic meters

PET - Polyethylene terephthalate

TEUs - Twenty-foot Equivalent Units

TW - Textile Waste

SMTW - Separated municipal textile waste

UMTW - Unseparated municipal textile waste

WULCA - Water Use in LCA

1. Introduction

1.1. About Girbau

Girbau is a global company specializing in both laundry solutions and equipment manufacturing. Founded in 1960 in Vic, Spain, Girbau is a family business that has grown into a leading player in the laundry industry, offering a wide range of commercial and industrial laundry equipment, including washers, dryers, ironers, and finishing equipment. The company is known for its innovation and commitment to sustainability, developing energy-efficient and eco-friendly laundry solutions. Girbau serves various sectors, including hotels, hospitals, laundromats, and commercial laundries, with a strong presence in Europe, the Americas, and Asia. Their mission is to design and provide complete, sustainable and innovative solutions for textile treatments, while enabling profitable growth for their company and its stakeholders. With a focus on quality, reliability, and customer satisfaction, Girbau continues to expand its product offerings and global reach, staying at the forefront of the laundry industry while also contributing to make a positive impact on people and the planet.

One of the ways in which Girbau proves its innovative spirit and care for the planet is through the creation of GirbauLAB. GirbauLAB is a division of Girbau Group dedicated to research, innovation, and the development of advanced laundry solutions. The goal of GirbauLAB is to transform the laundry industry into a regenerative industry that gives back more than it takes, while promoting circularity. It focuses on leveraging technology to enhance efficiency, sustainability, and user experience in the laundry industry. GirbauLAB works on projects ranging from digitization and automation to the integration of artificial intelligence and data analytics into laundry equipment. By pushing the boundaries of innovation, GirbauLAB aims to redefine the future of laundry technology, provide cutting-edge solutions to its customers worldwide, and to contribute to Girbau's overall strategic goals.

Previously, GirbauLAB has utilized their innovation and technology to find ways in which they can reuse the waste generated from the textile/garment washing process. They have already determined sustainable and circular solutions that can be applied to dry waste created from dryers, and humid waste related to microplastics and fibers. Now, they are looking for a circular and applicable solution for end-of-life textile waste that is being produced within the province of Catalonia.

1.2. Problem Definition

Girbau has recently noted new legislation from the European Commission that mandates changes in the textile industry, promoting circularity and requiring companies to reduce, reuse, and recycle textile waste in the coming years. This upcoming legislation signals to enterprises the need to adapt their business models. For Girbau, it presents an opportunity to align with their core values and continue transforming the laundry industry, building on previous projects developed by GirbauLAB.

As mentioned before, GirbauLAB has already done research into circular solutions regarding the dry and humid waste generated from their machinery; however, the end-of-life textiles (solid textile waste) is a waste form that they have not dug into quite yet. Hence, our project aims to track and understand the current solid textile waste generation and management done by the laundry industry in Catalonia.

To understand the context of this waste, we first examined the different types of clienteles Girbau serves: industrial, commercial, on-premise, and vending. The project focused on the industrial sector due to its direct connection to the generation of end-of-life textiles. Industrial laundries primarily serve the hospitality sector (e.g., hotels, residences, and hospitals) by offering rental services for bedsheets and towels, which include laundry services and the facilitation of operational costs and logistics. These bedsheets and towels, however, have a finite lifespan due to constant washing, and therefore are an interesting subject to study and understand where they end up at the end of their lives.

Given that most towels and bedsheets are made with cotton and are white (meaning they are more easily recycled), our project scope is defined as understanding the waste generation of 100% cotton bed linens and towels produced by laundries servicing hotels in the Catalonia.

The project has established and met specific objectives, which will be briefly explained in the following points:

- Estimating the annual volume of bed linens and towels generated as waste by the hotel industry in the province of Barcelona.
- Understanding the negative environmental externalities of the current production of bed linen and towels. The social externalities will be acknowledged and mentioned but are not the focus for Girbau to address now.
- Conducting a scenario analysis that considers various key stakeholders to explore different outcomes that could influence the industry's shift towards circularity.

2. Existing Research

This chapter is divided in two sections: i) an explorative literature review to acquire knowledge about the textile waste, compositions, technologies and best practices, and then ii) a more quantitative and structured literature review to provide a detailed overview of the topics in terms of publication and research trends.

2.1. Explorative Literature Review

2.1.1. Textile Waste

Textile Waste (TW) can be described as “the discarded or unwanted material from the production and use of fiber, textile and clothing” (Juanga-Labayen et al., 2022).

The textile industry has increasingly come under scrutiny due to its rapid growth and significant environmental and social footprint. It is estimated that this sector contributes to 10% of global carbon emissions, exceeding the combined emissions from international flights and maritime shipping (European Environment Agency, 2023). Approximately, 70% of these emissions stem from upstream activities, such as energy-intensive raw material production, preparation, and processing. The remaining 30% is attributed to downstream activities, including transportation, packaging, retail operations, usage, and end-of-use (EoL), with EoL accounting for 3% (McKinsey & Company and Global Fashion Agenda, 2020, p.5). The linear nature of textile production and consumption exacerbates this issue, leading to the accumulation of non-biodegradable waste in landfills and ecosystems (Fletcher & Tham, 2019). The textile industry also faces significant societal issues driven by the pressure for shorter lead times and lower pricing. This leads to poor working conditions, long hours, and low pay for garment workers, with instances of modern slavery and child labor. Efforts to improve these conditions are hindered by restrictions on establishing trade unions. Workers also face hazardous environments due to unsafe buildings and harmful substances used in production. Additionally, local communities, while many benefit from employment opportunities, suffer from poor environmental practices such as factories discharging untreated wastewater, polluting local rivers and impacting their living conditions (Ellen MacArthur Foundation, 2017).

2.1.1.1 Where it comed from and where it ends up

As TW is generated at different life-cycle stages across the value chain of textiles, Wojnowska-Barył et al. (2024) suggest a categorization into three types: pre-consumer, post-consumer, and industrial textile waste.

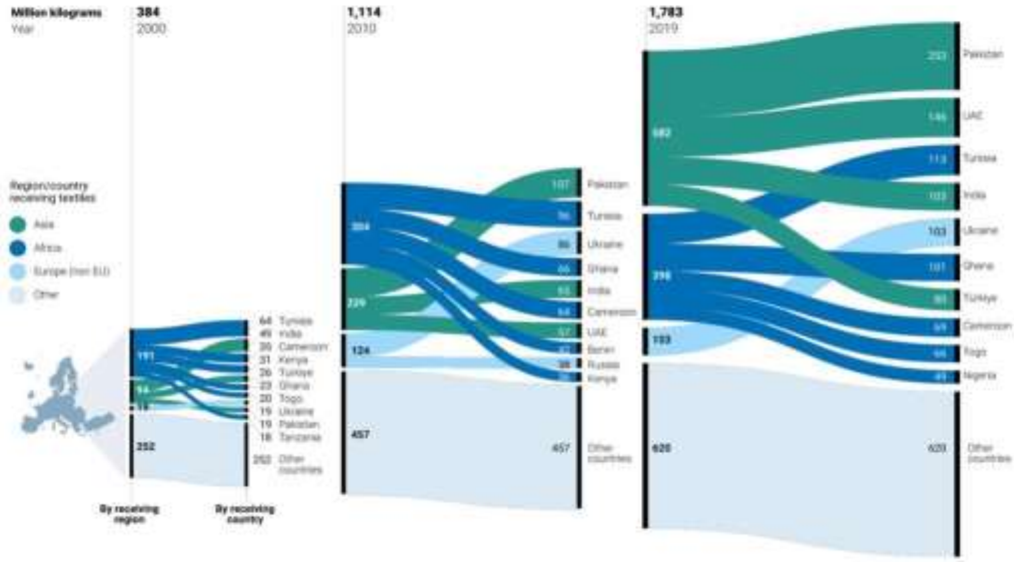
Pre-production textile waste, often termed "clean waste", comprises both fabric scraps, fiber fluff, fiber waste, and yarn waste (which are biodegradable) but also unsold inventory and returns from sales. These materials are predominantly biodegradable or readily recyclable back into the production cycle. On the other hand, post-consumer textile waste encompasses discarded apparel and household textiles (e.g., linens, towels, pillowcases) that have reached the end of their usable lifespan, typically due to wear and tear or irreparable damage. Additionally, industrial textile waste constitutes a broader spectrum of waste originating from textile manufacturing processes, categorized as "dirty waste" due to potential contamination with chemicals, pollutants, and other contaminants inherent to the production process. The authors also identify some examples of industrial textile waste as being wastewater, solid waste, emissions, and by-productions from activities such as fiber extraction, chemical processing, dying, finishing, and garment assembly.

Every year, the world produces around 90 billion kilograms (kg) of textile waste (Tang, 2023), which is the equivalent of a rubbish truck loaded with clothes being incinerated or buried in landfills every second (Ellen Macarthur Foundation, 2021).

In the European Union in 2019, the total textile waste - accounting for pre-consumer, post- consumer, and industrial - reached 12.6 billion kg (Wojnowska-Barył et al., 2024). This increasing amount of waste, made the European exportations of textile waste to triple over the last two decades from slightly over 550 million kg in 2000 to almost 1.7 billion kg in 2019, as identified in Figure 1. A shift is seen not only in which countries make up the top 10 receiving countries, but also in the size of their shares. In 2000, the top 10 receiving countries (see Figure 1) imported 54.6% of all EU used textiles, whereas in 2019, they imported 64%. This suggests that specialization in importing textiles is taking place (European Environment Agency, 2023). Worldwide, Pakistan is now the country that receives the most European textile waste (15%).

Figure 1

EU Exports of used textiles, by receiving country, in 2000, 2010 and 2019, in million kg.



Source: European Environment Agency. (2021). European Maritime Transport Environmental Report 2021. https://www.eea.europa.eu/publications/maritime-transport/

Africa and Asia also receive a relevant share of the material. In Africa the imported textiles are mainly meant for local reuse, due to the demand for cheap used clothes, which are preferred to new items. The textiles imported that are not fit for reuse mostly end up in open landfills and informal waste streams, in countries that are less able to handle the waste efficiently (European Environment Agency, 2023).

In Asia, however, most of the used textiles are imported to so-called "economic zones" where they are sorted and processed. They seem to be recycled locally, mostly downcycled into industrial rags, or re-exported either for recycling in other Asian countries or reuse in Africa. Textiles that cannot be recycled or re-exported are likely to end up in landfills (European Environment Agency, 2023).

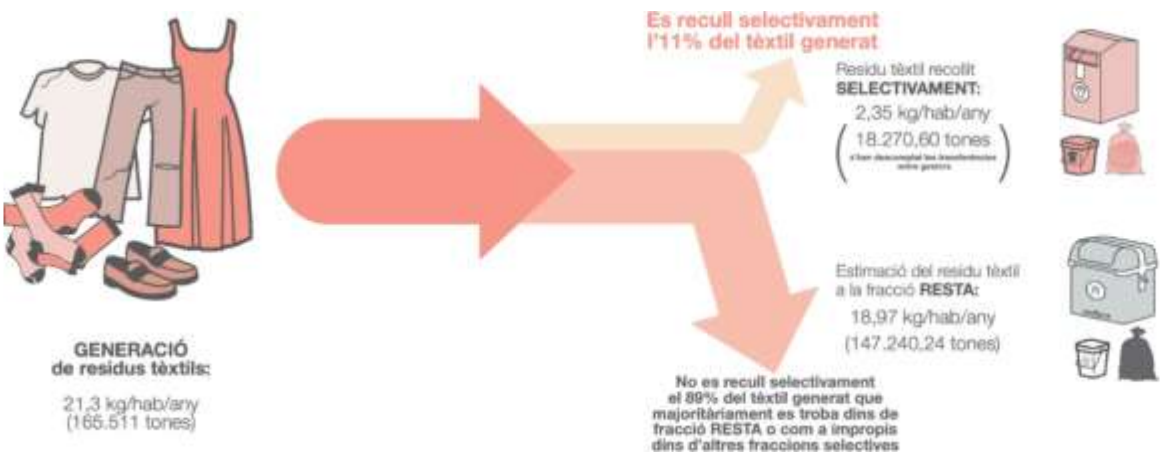
2.1.1.2 Textile Waste in Catalonia

In Catalonia, 166 million kg of textile waste are estimated to be generated each year, which is an annual average of 21 kg per inhabitant (Agència de Residus de Catalunya, 2022). This represents almost twice the European average of 12 kg textiles wasted annually (European Commission, 2023).

As Figure 2 suggests, out of these 21kg, 89% of the textiles are sent to landfills or are incinerated. Only 11% are collected via separate municipal TW (SMTW) collection systems, in one of the eight authorized organizations (Humana, Cartaes, Ecosol, Emaús, Engrunes, Formació I Treball and Roba Amiga and Solidança).

Figure 2

Management flows of the municipal textile fraction in Catalonia, 2021.



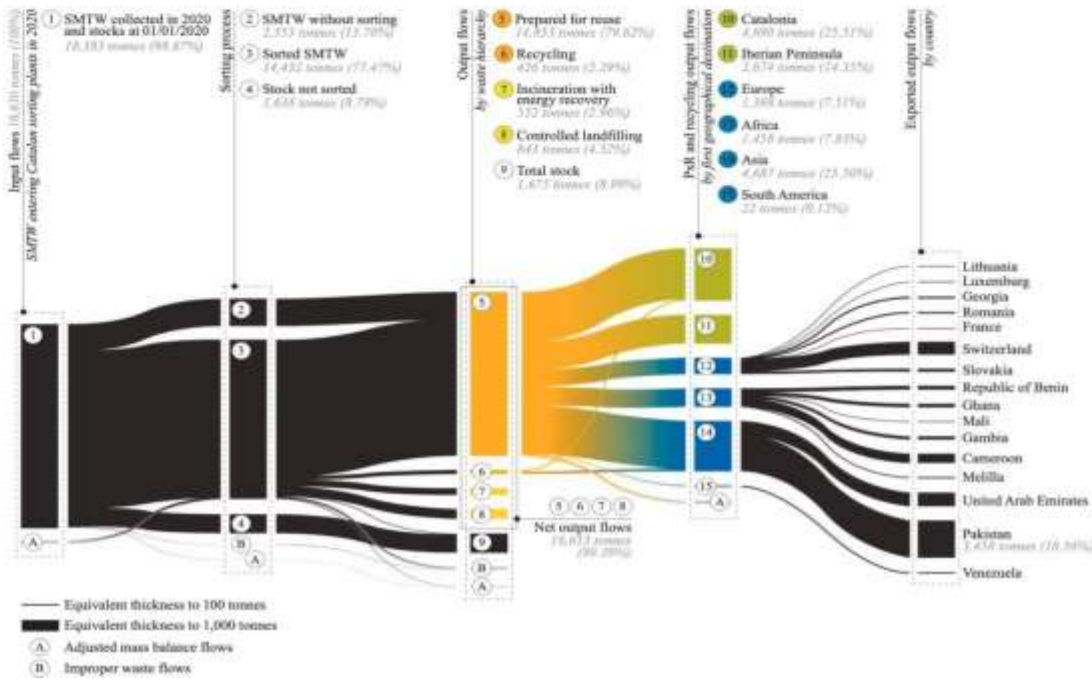
Source: Agència de Residus de Catalunya. (2021). Guia per a la prevenció de residus tèxtils

These records are very far from those established by the Waste Directive 2018/851 which states that all Member States must ensure a separate collection of textiles by 2025 (European Parliament and Council of the European Union, 2018), particularly considering that, according to Nohales (2021), Catalonia's objective by 2025 is (only) to collect 30% of the total textiles generated.

A study conducted by Morell-Delgado et al. (2023) elaborated a comprehensive material flow diagram for the separate municipal textile waste management, in Catalonia (Figure 3).

Figure 3

SMTW flows for Catalonia in 2020.



Source: Morell-Delgado, G., Peiró, L. T., & Toboso-Chavero, S. (2024). Revealing the management of municipal textile waste and citizen practices: The case of Catalonia. Science of the Total Environment, 907, 168093. https://doi.org/10.1016/j.scitotenv.2023.168093

The analysis focuses on the previously mentioned 11% of textile waste that is collected via SMTW collection systems. From those, only 77% is sorted. Most of these, together with the unseparated MTW, referred to as UMTW, are prepared for reuse, as recycling only accounts for 2%, incineration 3% and 5% is landfilled. Both the reuse and recycling processes happen mostly in Catalonia and Asia (Pakistan and UAE), each accounting for 26%.

UMTW is estimated to cost up to 30 million euros to local authorities (Nohales, 2021) and the pandemic proved the need for increasing investment in this area: an increase in the discarding of clothes highly increased during this period. As a result, the amount of MTW collected in 2020 (8.99 %) tripled in comparison to 2019 figures. Due to limitations in terms of physical space, logistics, and financial problems, a significant amount of SMTW was directly sold without any prior sorting (13.70 %). Investments to increase the current collection and treatment capacities of existing MTW sorting plants shall be made, as MTW is predicted to increase considerably in the coming years (Morell-Delgado et al., 2023).

2.1.2. The Laundry Industry

According to research done by Research and Markets Ltd. (2022), the global dry-cleaning and laundry services markets were worth $104.2 million in 2021, having grown at a compound annual growth rate (CAGR) of 2% since 2016. By 2026, it is expected to grow at a rate of 4.1% and from then until 2031 at a rate of 2.8%.

The growth in this industry has been mostly due to the strong economic growth in emerging markets, rapid urbanization, a rise in the number of single person households and growth in the healthcare services sector.

The linen and uniform supply segment was the largest segment of the dry-cleaning and laundry services market segmented by type of service, accounting for 55.4% of the total in 2021 and it is expected to be the fastest-growing segment going forward at a CAGR of 4.9% during 2021-2026.

The linen and uniform supply market is further segmented into linen and industrial launderers. The industrial launderers segment was the largest segment accounting for 53.4% of the total in 2021

Additionally, the dry-cleaning and laundry services market is highly fragmented, with many regional and small players. The top ten competitors in the market made up to 17.37% of the total market in 2021. Among them is the European leader Elis SA, who, in 2018, inaugurated an industrial dry-cleaning center in Barcelona, after having noted a potent growth in the hotel sector in the region (Catalan News, 2018).

2.1.3. Textile Fiber Overview: Cotton

Over the past two decades, global fiber production has shown considerable growth, nearly doubling from 58 million tons in 2000 to 113 million tons (Mt) in 2021. This trend is expected to continue, forecasting an increase to 149 Mt by 2030 if the current rate of production is maintained (Textile Exchange, 2022). Simultaneously, the demand for textile fibers has also increased exponentially, from 75,5 million tons in 2010 to a projected 133,5 Mt by 2030, indicating an annual growth rate of 3,1% (Hummel et al., 2015). This increase in demand and production has also increased the use of significant natural resources, including large amounts of water and chemicals, which are needed from the production of raw materials, (like cotton) to final manufacturing processes, such as spinning and dyeing of fabrics.

Cotton is the most widely used natural fiber as it occupies the second position in global use in the textile industry but generates approximately 11,6 Mt of waste annually worldwide (Alcantara, et.al., 2024). However, research suggests a significant increase in demand for synthetic fibers, which constitute 64% of the market, with polyester accounting for 54% of this segment. This scenario underscores the need for sustainable strategies to manage both the growth in the production of synthetic fibers and waste management in the textile industry, especially considering the high volume of waste generated by virgin fibers like cotton.

On the other hand, because of sustainable development trends in the textile industry, the market share of recycled fibers has seen a slight increase from 8,4% in 2020 to 8,9% in 2021. This increase is mainly attributed to the increase in polyester fiber based on recycled PET bottles. However, despite this growth, less than 1% of the global fiber market comes from pre- and post-consumer recycled textiles (Textile Exchange, 2022). This data highlights the challenges facing the industry to more effectively integrate recycled materials that originate from its own supply chain rather than incorporating waste that comes from outside of it.

2.1.3.1 Cotton production and market trends

Cotton constitutes approximately 90% of all natural fibers used, being the most used fiber in the manufacture of clothing, home furnishings and industrial products. It is the main natural fiber crop and plays a crucial role in the textile industry (Felgueiras, et.al., 2021). In addition, the use of cellulosic fibers, such as cotton, is expected to grow from a current level of 3.7 kg per capita to 5,4 kg by 2030, reflecting a trend towards more sustainable and renewable materials in the textile sector (Häemmerle, 2011). Although total cotton production has remained relatively stable in recent years, with a volume of 26,2 million tons in 2020 (2019/20 crop year according to ICAC), a significant increase has been observed in the market share of “preferred” cotton, which increased from 24% in 2018/19 to 30% in 2019/20. A “preferred” fiber is a type of fiber that is being promoted by the Textile Exchange in order to diminish the textile industry’s environmental footprint and is defined as "a raw fiber or material that delivers ongoing beneficial outcomes and impacts for climate, nature, and people through a holistic approach to transforming raw fiber and material production systems” (Textile Exchange, 2022). However, to achieve a 50% market target by 2025, there is a need to further accelerate the preferred cotton market and continuously improve the environmental impacts of all cotton production.

Furthermore, recycled cotton only accounted for around 0,96% of total cotton production in 2020, with an estimated production of approximately 255 thousand tons, its market share is expected to grow significantly in the coming years. This increase has the potential to contribute greatly to the reduction of greenhouse gas (GHG) emissions, highlighting the importance of developing capabilities and technologies to more efficiently recycle cotton and leverage its post-consumer value.

2.1.4. Externalities

2.1.4.1 Social Externalities of Textile Industry

The textile industry, though it contributes immensely to global employment, faces severe social externalities that require urgent attention. Suarez-Visbal et al. (2022) emphasizes a critical gap in the comprehensive understanding of the industry's social impacts beyond job creation. This limited perspective fails to address significant issues such as human rights violations, hazardous working conditions, and unsustainable wages. Most studies stress the need for deeper analysis and more conclusive findings to address these persistent issues effectively.

In addition to these broader concerns, Bick et al. (2018) provide a detailed account of the labor conditions in the garment assembly sector, which employs approximately 40 million workers worldwide. They highlight the lack of enforcement of occupational and safety standards, leading to numerous health hazards. Workers are exposed to cotton dust and synthetic air particulates, resulting in severe respiratory issues and other debilitating conditions, including lung disease, cancer, and adverse reproductive outcomes. High-profile disasters like the Rana Plaza collapse in Bangladesh, which killed 1.134 workers, underscore the severe consequences of inadequate safety standards in textile factories.

The research done by Muñoz-Torres et al. (2023) points out the scarcity of publications specifically addressing social sustainability in the textile industry. They argue for the necessity of developing a science-based social foundation that would aid companies in effectively identifying and managing their social impacts. This foundation would also assist other stakeholders, including consumers and regulators, in making informed decisions that support socially sustainable development. However, they acknowledge the theoretical and practical challenges that must be overcome to achieve this goal. Despite these challenges, there is a consensus on the need for more in-depth analysis and comprehensive conclusions to foster a more socially sustainable textile industry.

2.1.4.2 Environmental Externalities: Cotton

Cotton, though a staple in the textile industry, is not without its environmental costs. One of the most glaring issues is its staggering water footprint. Research by (Papamichael, et. al., 2023), highlights that an astonishing 10.000 liters of water are required to produce just one kg of cotton, which translates to approximately 2.700 liters for a single cotton t-shirt. The enormity of water consumption becomes even more apparent when considering the global scale, with the textile and clothing industry utilizing a staggering 93 billion cubic meters (m3) of water annually (Bailey, et. al., 2022).

While cotton holds the advantage of being biodegradable, its environmental impact extends beyond just extreme water usage. It is reported that an average global water footprint of 5730 m3/ton for cotton production, encompassing both cultivation of the crop and required water for processing (Felgueiras et. al., 2021). Furthermore, despite consuming approximately 40% less energy than polyester during production, cotton cultivation still relies on fossil fuels for various processes, such as irrigation (Kalliala et al., 1999). Even organic cotton production, though a more sustainable alternative, demonstrates similar energy consumption levels to conventional methods, emphasizing the complex nature of mitigating cotton's environmental externalities.

In summary, the production of cotton textiles exacts a significant toll on natural resources and ecosystems, encompassing water scarcity, waste generation, and energy consumption. Addressing these externalities calls for the need of holistic approaches that prioritize sustainable practices throughout the cotton supply chain.

2.1.5. Textile Waste Management Methods

The textile industry is currently at a critical state where it must reconcile economic expansion with environmental conservation. This calls for a comprehensive reassessment of both production methodologies and waste management protocols. In the past few years, many waste management strategies have been implemented globally, facilitating the establishment of numerous closed-loop systems. These initiatives are instrumental in promoting sustainable practices that not only mitigate environmental impact but also enhance economic viability within the industry. As shown in Figure 4, there are many possible routes for repurposing waste textiles, which could significantly diminish the need for virgin textile fiber production.

Figure 4

A classification of textile reuse and recycling routes.

Source: Sandin, 2018

The subsequent chapter will delve into the prevalent methodologies employed in this process, examining their implications and effectiveness.

2.1.5.1 Textile Reuse

Textile reuse is an environmentally conscious practice that emphasizes the extension of a textile lifecycle through its transition from one owner to another. This sustainable approach significantly diminishes the consumption of water, chemicals, and the generation of waste, thereby mitigating the environmental footprint associated with textile production (Sandin et al., 2018). Various practices of textile reuse mentioned by Belk (2014) include: renting, trading, swapping, borrowing, and inheriting; facilitating this process. These activities can be conducted through diverse platforms, including second-hand stores, garage sales, flea markets, and charitable organizations.

2.1.5.1.1 Challenges of textile reuse

By adopting such measures, consumers and businesses alike can play a pivotal role in fostering a circular economy, where the value of products, materials, and resources is maintained for as long as possible, yielding benefits for both the economy and the environment. However, there has been increasing criticism and concerns towards the reuse model since it could directly impact on the economic performance of local textile businesses; moreover, the hygienic state of textiles represents a formidable obstacle that must be addressed to ensure the successful application of circular economy practices (Baloyi et al., 2023).

2.1.5.1.2 Innovations in textile reuse

Companies such as H&M, Humana or even The Salvation Army are great examples of how different companies among the textile industry have come up with programs and alternatives for the customers to give their clothes and create a channel where consumers can access to used textiles and reuse them. However, since it's been a well-known practice for many years, there isn’t much room for innovations since trust and collaboration among the consumers is the main reason behind its success (Baloyi et al., 2023).

2.1.5.2 Incineration

Incineration stands as a predominant method for the management of textile waste. This process involves utilizing textiles as the primary fuel within a muffle or electric incinerator, where they are subjected to high temperatures ranging from 500°C to 800°C, over a duration of four to five hours (Baloyi et al., 2023). The principal advantage of this method lies in its operational simplicity, as it takes away the need for textile separation, thereby streamlining the process and diminishing the associated time, costs, and procedural intricacies (Youhanan, 2013).

2.1.5.2.1 Challenges of incineration

However, according to Youhanan (2013), a study made to assist the environmental impact from different waste management techniques, there are countless negative externalities generated through the incineration of textiles. For each Ton (1 t) of mixed household wasted textile, the following outcomes are produced:

- 15,800 MJ of energy
- 758 kg of CO2 emissions
- 27 kg of ash
- 650 L of water used for the process

Therefore, it is key to consider the environmental implications of this method, such as the emission of greenhouse gasses and potential air pollutants. Continuous advancements in incineration technology are essential to enhance efficiency and mitigate environmental impacts, ensuring a sustainable approach to textile waste management.

2.1.5.2.2 Innovations of incineration

In 2024, the Croatian company DOK-ING, in partnership with the enterprise Humana Nova, has pioneered a pilot project that marks a significant advancement in waste management technology. This collaborative effort has led to the development of a novel process that transforms traditional textile incineration methods into a more sustainable practice by generating hydrogen. The innovative approach not only aims to mitigate the detrimental environmental effects traditionally associated with textile incineration but also seeks to repurpose the resultant by-products into useful materials such as hydrogen, ash, and soot. This groundbreaking initiative represents a substantial step forward in the pursuit of eco- friendly industrial processes, potentially setting a new standard for waste-to-energy conversion and signaling a shift towards more sustainable manufacturing practices (Chemical Monitors WorldWide, 2024).

2.1.5.3 Mechanical Recycling

Mechanical recycling is a well-established technique within the waste management industry, boasting a significant presence for several decades. This technology is renowned for its robust production capacities, which range from 5,000 to 36,000 tonnes annually (Stubbe et. al., 2024). The nature of mechanical recycling encompasses a series of complex activities, including the collection, identification, and sorting of materials, followed by meticulous processes such as grinding, carding, and blending (Baloyi et al., 2023). However, the core of this technique lies in two primary processes: shredding and spinning, with the goal of creating a closed-loop system.

The initial phase of the recycling process is the accurate categorization of fiber types, as the caliber of the resultant product relies on the quality of the starting materials. Recycling post-industrial waste produces the most significant volume (Baloyi et al., 2023). On the other hand, post-consumer waste recycling requires a more labor-intensive process due to the mixture of composition and color in waste (Stubbe, 2024).

2.1.5.3.1 Challenges of mechanical recycling

One main challenge of this method is the task of recycling blended garments or textiles, which is extremely common, most often being a blend of cotton and polyester fibers. Haule (2017) emphasizes the critical need to segregate fibers according to their original types, due to the commonly blended textiles and varied thread materials used in garment production. This sorting process becomes crucial as the size of the garment pieces fed into the shredder can significantly impact the spinnability of the fibers, with too small of pieces leading to fiber breakage and overly large pieces hindering the shredding process. Also, Haule (2017) discusses that to then separate and classify these fibers post-shredding, then requiring a separate time and energy consuming process.

Once the textiles are sorted according to their composition, they undergo shredding, a mechanical tearing process that breaks them down into fibers (Haule, 2017). This crucial step transforms textiles into their fibrous state, which then allows for them to be converted into other products of value, including stuffing, carpet underlay, insulation, roofing felt, and lower-grade blankets (Beton et. al., 2006). However, this step gradually decreases the quality of the fibers due to the friction generated, inevitably shortening the length and reducing the performance and resistance of the product (Baloyi et al., 2023).

As a response to the loss of quality due to the damage made during the shredded process, recycled fibers are usually mixed with virgin to ensure the quality of the yarn (Baloyi et al., 2023). A recent study, done by Arafat & Udden, (2022) revealed the following results:

- Incorporating up to 25% of recycled cotton fibers with virgin materials does not compromise the yarn's quality, maintaining its thickness and durability.
- The study highlighted how the fiber's origin can have a large influence on the yarn's final quality. Yarns produced using post-consumer recycled fibers had more imperfections when compared to those made with pre-consumer recycled fibers.
- Though quality is lost when substituting virgin fibers with recycled ones, the study makes known the environmental advantages of this practice. Using recycled fibers presents an alternative that aligns with sustainable development goals while reducing waste and resource consumption.

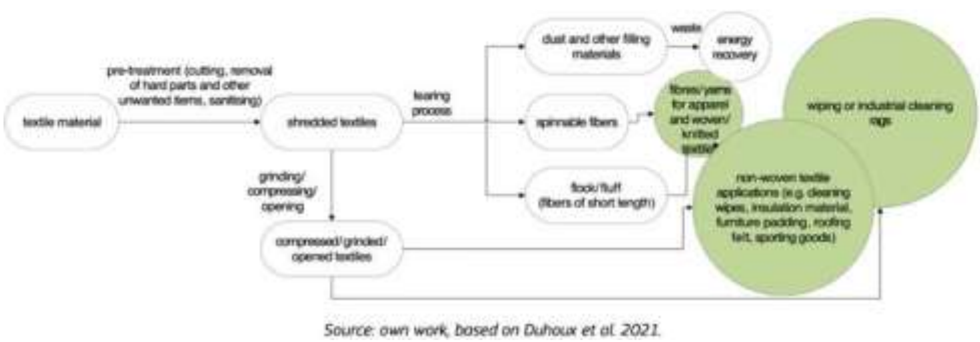
Additionally, fiber length emerges as a crucial determinant for further processing and yarn quality, as emphasized by Parsi et. al., (2016). The shredding process itself can be harsh on textiles, often leading to fiber damage and fiber shortening, thus causing difficulties in the desired next step of spinning. To address this, Haule, (2017) suggests classifying fibers post-shredding to optimize the adjustment of tearing machines and mitigate potential challenges in subsequent spinning processes.

To complete the loop in this recycling method, following shredding, the fibers undergo spinning, where specialized machines weave them back together into continuous yarn strands (Sinclair, 2015). Incorporating these recycled fibers into the spinning process reduces the demand for new virgin fibers, thus promoting sustainability.

As seen in Figure 5 below, Huygens et. al., (2023), creates this map which gives an overview of the mechanical recycling processes and the applications of the resulting end-materials. It is important to note that the green circles pertain to an end-material, and the larger the circle, the more shares are being used to generate that specific end-material.

Figure 5

Mechanical recycling processes and applications (size of green circles represent the shares currently being used).



Source: Huygens, D., Foschi, J., Caro, D., Caldeira, C., Faraca, G., Foster, G., Solis, M., Marschinski, R., Napolano, L., Fruergaard, Astrup, T. and Tonini, D. (2023). Techno-scientific assessment of the management options for used and waste textiles in the European Union. Publications Office of the European Union. doi:10.2760/6292, JRC134586.

By looking at this figure, most of the shredded textiles being generated from the mechanical recycling method are used directly to generate wiping or industrial cleaning rags, followed by non-woven textiles, and finally to generate recycled fibers and yarns. This can be explained due to the complexity of each process given that the method to produce yarns and fibers requires a more detailed sorting and virgin material to ensure the quality of the product.

2.1.5.3.2 Innovations in Mechanical Recycling

Fortunately, recent advancements and innovations in the field of mechanical recycling have significantly enhanced the efficiency of the recycling processes. These improvements have not only led to the production of higher quality recycled materials but have also reduced the reliance on virgin fibers. This shift towards more sustainable practices is particularly important as it contributes to the conservation of natural resources and the reduction of environmental impact. These developments are a promising step forward in the pursuit of more eco-friendly manufacturing and consumption patterns.

In recent studies, one innovative approach to enhance the quality of fibers during the shredding process is the application of lubricants. This method aims to reduce the friction generated, thereby yielding fibers of superior quality. An investigation done by Lindström et al., (2019), employed an aqueous solution of polyethylene glycol 4000 as the lubricating agent. The findings of this study indicate that the utilization of this lubricant significantly increased the efficiency of the shredding operation and resulted in the production of longer fibers when benchmarked against conventional processes.

On the other hand, Hilaturas Ferre, a Spanish family-owned company, has carved a niche in the textile manufacturing sector with its innovative approach to recycling textiles for the fashion industry (About Us | Ferre Yarns, 2023). The company has achieved to use both pre-consumer and post-consumer waste, integrating it as the cornerstone of their material sourcing, thereby achieving an exceptional level of circularity in their production process, having a total of 80,8% of raw material coming from recycled fibers in 2022 (Ferre Yarns, 2021).

This commitment to sustainability is further exemplified by their strategic partnership with Recover, through which Hilaturas Ferre has established a robust system for textile waste recovery and recycling. The collaboration enables the production of high-quality recycled cotton fiber, which is subsequently blended with other recycled materials such as PET, wool, or nylon. It not only enhances the fiber's quality but also diversifies the product range to meet various consumer needs, reflecting the company's dedication to environmental stewardship without compromising on the versatility and quality demanded by the contemporary fashion market (Ferre Yarns, 2021).

In their most recent sustainability report (Ferre Yarns, 2021), the company has employed the LCA methodology, collaborating closely with esteemed third-party evaluators including AITEX, Universitat de Valencia, and UNESCO to measure their environmental footprint during 2022 obtaining the following results as seen in Figure 6 below:

Figure 6

Environmental Savings 2022.

Source: About us | Ferre Yarns. (2024, May 27). Ferre. https://ferreyarns.com/about-us/Ferre Yarns. (2021). Ferre Sustainability Report 2021. https://ferreyarns.com/wp-content/uploads/SUSTAINABILITY_REPORT_2021_FERRE-1.pdf

Upon reviewing the current research, successful case studies, and practical applications by pioneering companies, it becomes evident that existing technologies and processes can facilitate the creation of closed-loop systems within the textile industry. This shift towards a circular economy model enables the utilization of waste as a resource, allowing companies to significantly reduce their environmental footprint. Such advancements underscore the potential for sustainable industry practices that align with environmental conservation efforts.

2.1.6. Catalonia's Influence in The Textile Industry

In Catalonia, the textile and clothing industry has long held a significant role in the region's production landscape, employing around 94.400 individuals, constituting 12% of all industrial employment. Despite its importance, the sector is primarily composed of small or medium-sized enterprises, totaling around 2.600 companies (Gascón, et.al., 2005). The textile sector within Catalonia, although modest in size compared to other industries, wields considerable influence both regionally and nationally. Despite contributing only 2,3% of industrial VAT and 2,0% of turnover within Catalonia, it surpasses the averages for Spain and the EU (Francolí & Teixidor, 2023).

The spinning process remains a pivotal activity within Catalonia's textile landscape, boasting the highest percentage of exports, with 56% of sales directed abroad. However, the process of fabric finishing is predominantly focused on domestic sales, with 81% of products sold within the state. It is reported that companies in Catalonia account for a striking 41,4% of Spanish textile exports (Francolí & Teixidor, 2023).

2.1.6.1 Prevalence of Cotton in Catalonia

Cotton production is a cornerstone of Catalonia's textile industry, representing 30% of the sector and serving as the hub for Spain's cotton production, accounting for 70% of the national output. Despite ongoing modernization efforts, labor costs remain modest, comprising less than 15% of total product costs (Gascón, et.al., 2005).

Catalonia's textile industry demonstrates a commitment to innovation and sustainability. An example of this innovation and these sustainable practices can be illustrated by Garrotxa County, a county located in the Northeast region of Catalonia. Garrotxa County stands out for its contributions to Spain's recycled-cotton exports, and its contribution to the textile industry can be visualized in Figure 7 below:

Figure 7

Recycled Cotton Spinning in Garrotxa County.

Location: Garrotxa County	
Number of establishments:	22
Number of employees:	738
Turnover (estimated):	€ 100 million
Exports/production (%):	80
Specialization index:	9.99
Weight in its sector in Catalonia (%):	18.00
Weight in all Catalan Industry (%):	0.05

Main companies in the local industrial production system

Name of company	City or town
S Vilarrasa, SA	Besalú
Hilaturas Victoriano Puigdemont, SA	Sant Esteve d'en Bas
Hilados Dusol, SA	Les Planes d'Hostoles
José Valeri Homs, SA	Olot
Francisco Pagès Valentí, SA	Sant Jaume de Llierca
Filatura Vera, SA	Olot
Hilados Olotenses, SA	Olot
Hilaturas de Castellfullit, SA	Besalú
Triturados Textiles, SA	Besalú
Fontfilva, SA	Olot

Source: Gascón, J. M. H., Francolí, J. F., & Pezzi, A. (2005). Map of local industrial production systems in Catalonia. Gencat. Ministry of Employment and Industry of the Autonomous Government of Catalonia Department of Industry. https://empresa.gencat.cat/web/.content/001-departament/04-serveis/01-publicacions/Empresa_Industria/papers_d_economia_industrial/documents/arxius/2 1_angles.pdf

Leveraging a specialized industrial production system established in the early 20th century, Garrotxa County produces thick yarn from recycled-cotton fibers. These products can be utilized in various applications, such as household furnishings, sports textiles, and cleaning materials (Gascón, et.al., 2005). According to the Catalan recycled-cotton company HILOSA, they carry out their entire yarn production process in Garrotxa county close to the Garrotxa Volcanic Area Nature Park. In this context, production adheres to the quality standards and procedural requirements stipulated by various certifications, validating the company's manufacturing system as sustainable and ecologically sound (Hilosa - Recycled Cotton Yarns for Weaving, Knitting, Blankets, Ecologic, n.d.). The labeling of products made from recycled yarn underscores the region's dedication to environmental responsibility and resource efficiency.

2.2.Quantitative literature review

2.2.1. Justification And Methodology

As a result of preliminary research related to the central topic of our project, a notorious disconnect was identified between the concepts of laundry and the textile industry, specifically concerning post-industrial solid waste, and its environmental implications. This observation enhances the need for further exploration to clarify the interactions and ecological consequences of this relationship. Therefore, it is proposed to carry out a review of the state of the art, employing a bibliometric analysis using R and RStudio tools. This analysis will be based on data extracted from the Scopus database, which is the main source of bibliographic information selected by our team, among others. The purpose of this methodology is to acquire a broad understanding of the context of the project in the last 10 years and to assess the potential impact that our research may have on the field of study.

The analysis revolves around the following search equations and filters:

1. Search 1: Textile AND waste AND (laundry OR laundering)

a. Filtered by years to ensure relevance (2014-2024).

2. Search 2: Cotton AND polyester

a. Filtered by years to ensure relevance (2014-2024).

b. Taken as exclusions are those referring to areas of medicine and physics in terms of particle movements.

In addition, the analysis is performed in 3 main categories to identify the growth of the subject within academia and to map the current trends regarding it. These categories are:

1. Main information: number of documents (overall around 3.300 documents were considered), annual growth rate, annual scientific production

2. Documents: most frequent words, word cloud, trend topics

3. Conceptual structure: co-occurrence network (density graph analysis), thematic map

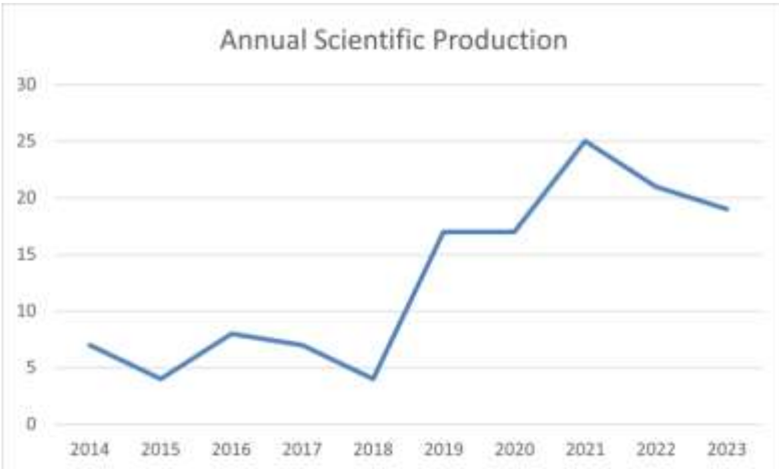
2.2.2. Results

2.2.2.1 Search 1: Textile AND waste AND (laundry or laundering)

We selected this initial search equation with the objective of exploring the level of study achieved in the specific field in which we work, as well as the connections identified between these two industries. The use of this search allowed us to identify 141 articles published between 2014 and 2024. As shown in the graph of Figure 8, there is a notable increase in annual scientific production, with an average growth of 5,54% since 2018. This shows a growing interest in this subject and underlines the need we have pointed out to deepen the study of the interactions between these industries.

Figure 8

Annual Scientific Production for the equation "Textile AND waste AND (laundry or laundering)" between 2014 and 2024.

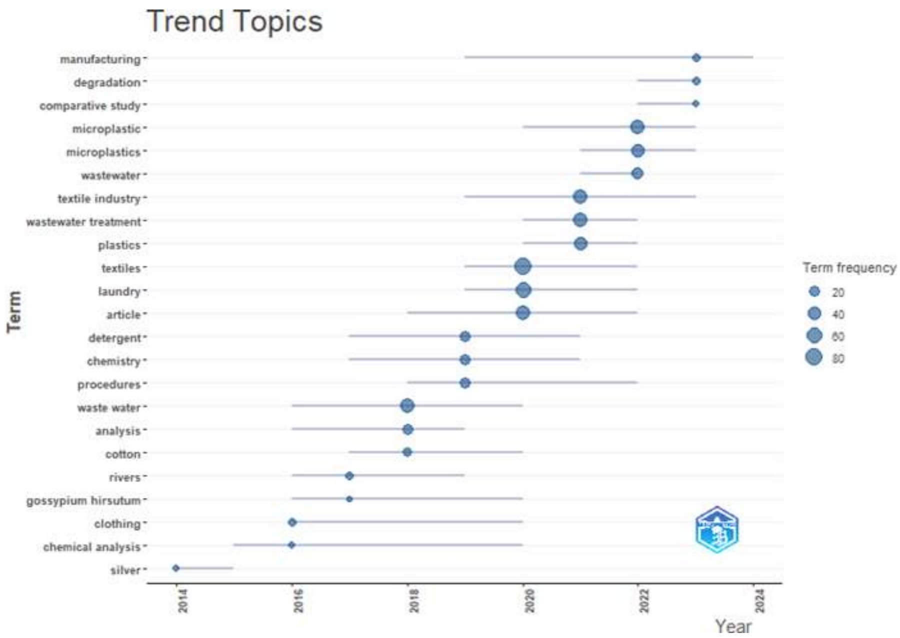


Source: R studio bibliometric analysis.

We also conducted a content analysis focused on the trends of the topics addressed by various authors. The trend evolution mapping presented in Figure 9 shows how the topics have evolved from initial focuses on chemical analysis, with terms such as "chemistry" and "detergent", and their respective environmental impacts, represented by words such as "wastewater" and "treatment". Starting around 2018, terms of our interest such as "textiles" began to emerge, as well as terms related to their composition, such as "plastics", "microplastics" and "cotton". This finding points to the growing importance of the connection between these two industries, although its precise nature is not yet entirely clear.

Figure 9+

Trend topics appearance from 2014 to 2024 and term frequency for "Textile AND waste AND (laundry or laundering)".



Source: R studio bibliometric analysis.

Based on the trends and keywords identified above, we proceed to perform an analysis using a heat map that illustrates the existing connections between the previously mentioned topics. As can be seen in the map named Figure 10, two main areas of co-occurrence emerge: (1) everything concerning water and wastewater treatment, and (2) components derived from the textile industry, highlighting research focused on plastics and polyester, while cotton is still considered as an area with potential for further study (blue area). This approach allows us to clearly visualize the distribution and interrelationship of key topics within the research field, providing a structured understanding of the areas that require further academic attention.

Figure 10

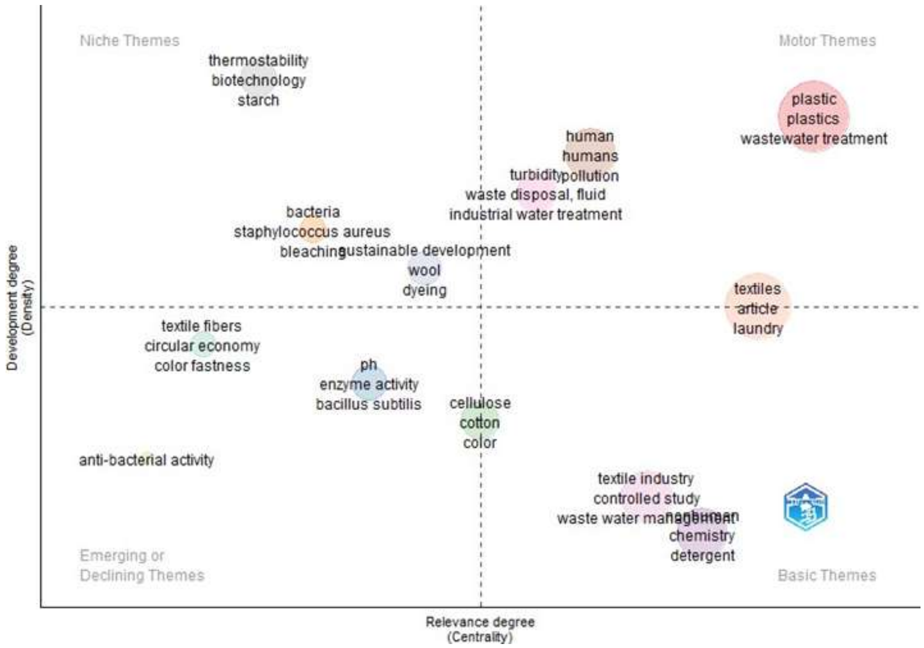
Heat map illustration of existing connections of the trend topics.

Source: R studio bibliometric analysis.

Finally, we proceeded to analyze the thematic map to discern the relevance of our project within the thematic spectrum studied. As presented in Figure 11, we can affirm that the use and treatment of water constitute the central axis of research in this area. In addition, it is observed that the textile industry appears as a "Basic Theme", which can also be interpreted as a cross-cutting theme among the scientific community. On the other hand, we have identified that the circular economy and textile fibers form the same emerging cluster and have a potential for studying. This finding gives a clear purpose to our project and offers us the opportunity to enter a yet to be exploited academic field, which is highly relevant for our research colleagues.

Figure 11

Thematic relevance map for "Textile AND waste AND (laundry or laundering)".



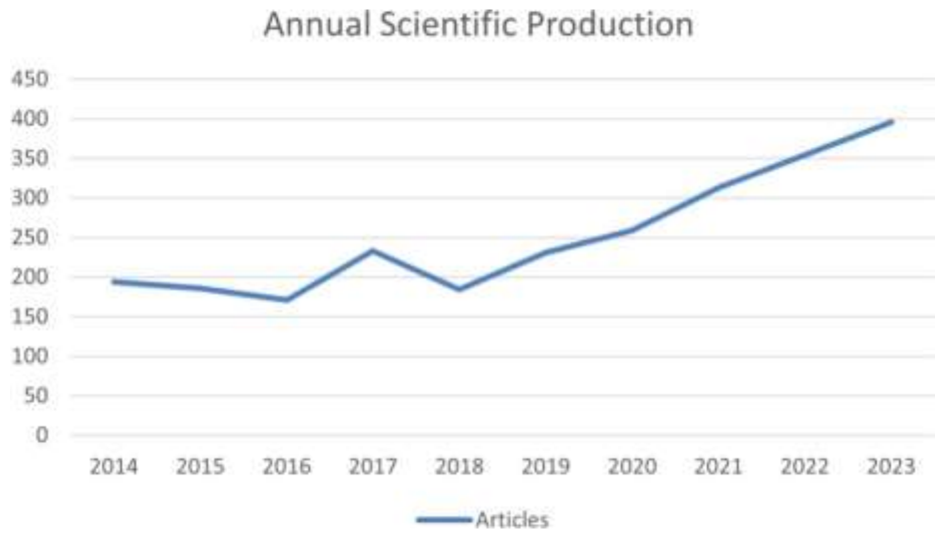
Source: R studio bibliometric analysis.

2.2.2.2 Search 2: Cotton AND Polyester

Adopting an alternative perspective, we decided to conduct a state-of-the-art review focused on the two textile composition materials that are the subject of our study: cotton and polyester. The search conducted yielded a total of 2.640 articles published between 2014 and 2024. Analysis of the annual written output graph, named Figure 12, reveals a steady increase in the number of publications from 2018 onwards, suggesting a growing interest by the academic community in the textile sector. This increase can be interpreted as a reflection of the increased attention towards the implications and developments in the use of these materials in the industry that was also evident in the previous analysis.

Figure 12

Annual Scientific Production for the equation "Cotton AND Polyester" between 2014 and 2024.

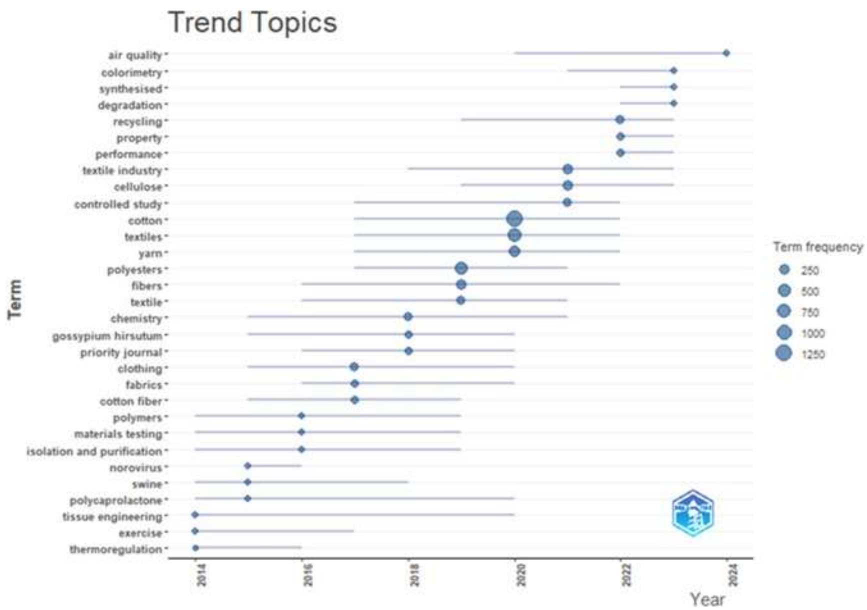


Source: R studio bibliometric analysis.

On the other hand, the content analysis, illustrated in Figure 13, reveals that these two textile components have been predominantly studied from a chemical perspective. Recently, however, terms such as "recycling" and "degradation" have also begun to be identified, indicating a growing interest in sustainability. This trend is evidenced by the Life Cycle Assessment (LCA) of textile products, suggesting a deeper focus on sustainability within the field.

Figure 13

Trend topics appearance from 2014 to 2024 and term frequency for "Cotton AND Polyester"

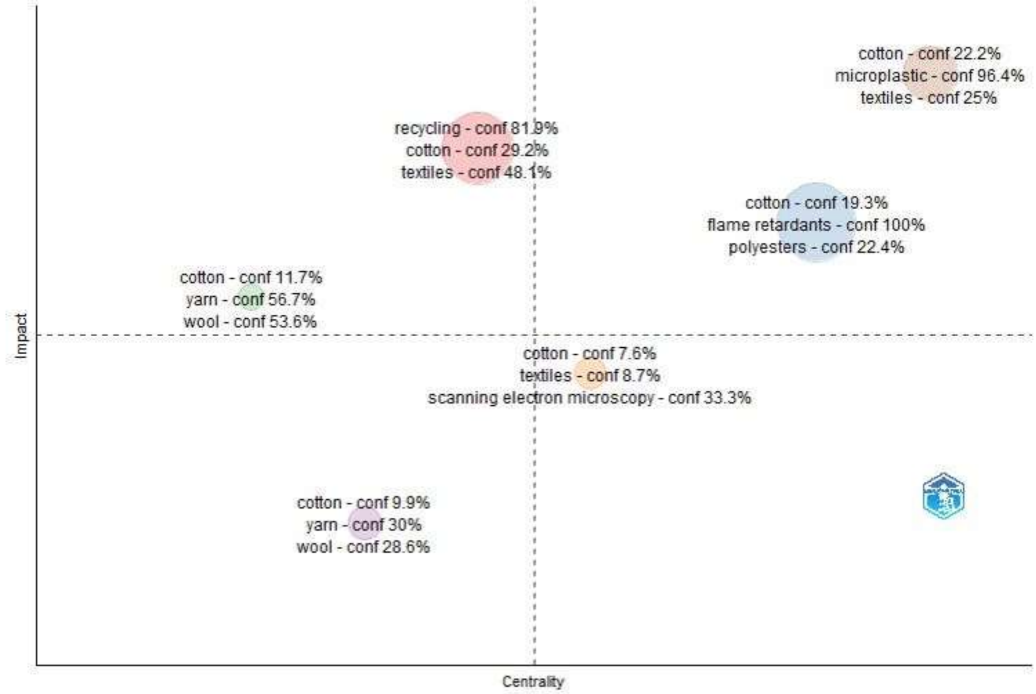


Source: R studio bibliometric analysis.

Finally, upon careful review of the thematic map as illustrated in Figure 14, we wish to highlight that the microplastics cluster has established itself as a central axis of research in the related articles, evidencing an intensive focus on this topic. In parallel, cotton is consolidated as a predominant object of study in this field, reflecting its continued relevance in textile research. In addition, it is important to note that the cluster encompassing recycling and textiles has undergone a remarkable transition, evolving from being a highly specialized topic to becoming an emerging focus of interest in the field of sustainability. This thematic migration illustrates an expansion in the scope and depth of sustainability-related studies, marking a significant shift towards exploring more sustainable practices within the textile industry and giving rise to the relevance that our project could have.

Figure 14

Thematic relevance map for "Cotton AND Polyester".



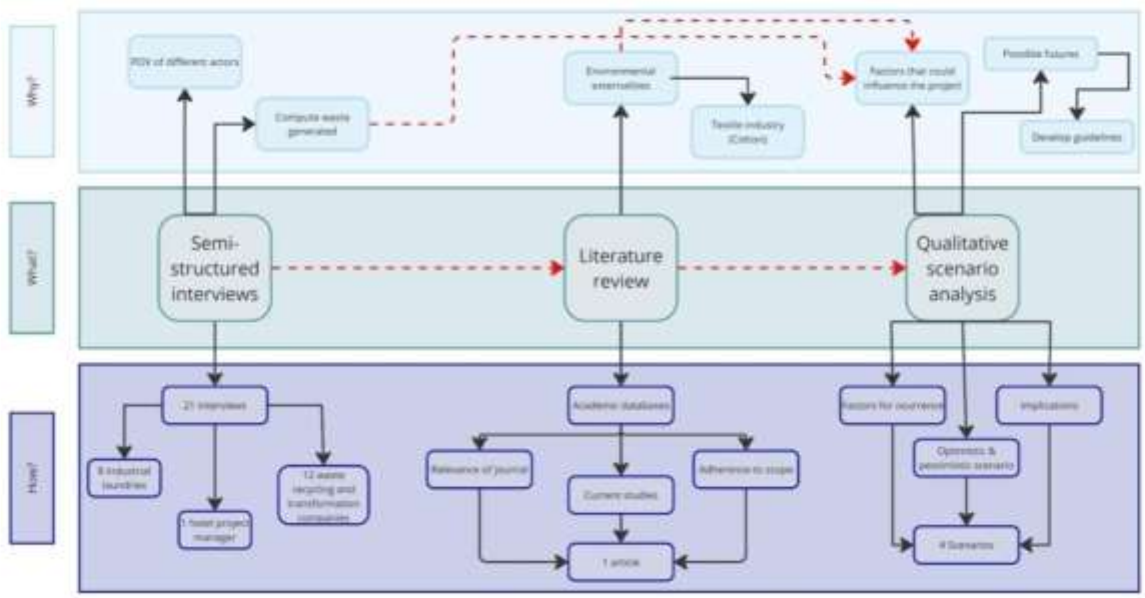
Source: R studio bibliometric analysis.

3. Methodology

In this project we adopted a mixed methodological approach, combining both qualitative and quantitative procedures to achieve the scope of this project. The research starts with a series of semi-structured interviews with relevant actors in the laundry, hospitality and waste management sector, followed by a comprehensive literature review to establish a solid theoretical framework. Finally, this data was complemented by a qualitative scenario analysis that sought to examine possible futures and factors influencing the project moving forward. The use of all three methods allowed us to validate our assumptions using multiple sources and provided us with a broader picture of understanding. The methodology adopted is illustrated in Figure 15, where the interviews, the literature review and the qualitative scenario analysis are shown in an integral and complementary way.

Figure 15

Methodology



Source: Our own work

3.1. Interviews

It was decided to conduct interviews to get the perspective of the different actors in determining factors of the project and to compute the total waste generated by their daily practices as an industry. A total of 21 number of semi-structured interviews were conducted with three different groups: 8 with industrial laundries with operations in Catalonia which were led by

Girbau (Appendix A & F); 1 interview with a Project Manager at a hotel group (Appendix C & D), responsible for 4 different hotels with different ratings and 12 with companies in charge of waste recycling and transformation (Appendix B & G). The interviews were conducted using telephone calls, video conferences and e-mails. Overall, the questions focused on exploring the perception and level of participation of the actors in circularity practices within and outside their industries. For the case of the questions asked to the hotels' Project Manager, they were mostly focused on understanding the establishments' practices in terms of room compositions and textiles' washing processes. Subsequently, the results of the interviews were analyzed for significant patterns of behavior that would help us locate opportunities for improvement and implementation of the project.

3.2. Literature Review

The literature review is conducted with the objective of delimiting and computing the externalities derived from the textile production process for 100% cotton textiles. Based on that, the systematic review is focused on the environmental externalities deriving from the textile industry supply chain. We consulted academic databases Scopus, Google Scholar, and ProQuest. In our search, we employed a combination of terms associated with environmental externalities and cotton, and we searched for journals, or reviewed articles published in English. The search resulted in 57 articles; we then applied the following filters to identify potential articles that can be used to calculate the externalities of cotton textile waste:

- Relevance of the journal (such as ABS Journal Ranking 2021)

- Current studies
- Adherence of the study to our scope

Only one study met the criteria, and it was then used to quantify the environmental externalities of the cotton textiles waste.

3.3. Qualitative Scenario Analysis

Finally, the last part of the project employed a qualitative scenario analysis to understand the future trends of the sector and develop guidelines for several stakeholders who want to engage in the circular transformation of the textile sector. Four possible scenarios were developed based on trends identified in the literature review and interviews: (1) Technological barrier, (2) Industry cooperation, (3) European Union legislation and (4) Raw material prices. Each scenario was analyzed by discussing the factors that determine its occurrence, the implications and consequences in case of finding an optimistic or a pessimistic scenario. Together with a member of GirbauLAB and Professor Melissa Demartini (tutor), a review and feedback of the scenarios was carried out, evaluating the admissibility of each one. Subsequently, recommendations were made that dictate the best practices with which Girbau can ensure a good implementation of the project.

4. Results

4.1. Waste Estimation

The starting point of this project was the estimation of the waste of bed sheets and towels generated by hotels in Catalonia.

As there were many approaches to estimating this value, we decided to bring together the information found on the latest Tourism Activity Report from Observatori del Turisme a Barcelona (2022) along with Girbau's shared knowledge on the industry and the insights collected from the interviews conducted. These interviews were carried out with Girbau's partner laundries that provide rental services, a critical factor that enables these laundries to have precise knowledge on the end-of-life status of these textiles.

4.1.1. Geographic Scope

Although preferably the geographic scope would be Catalonia, in practice there was not enough information on this region. The Tourism Activity Report only accounts for three territorial levels of data analysis (the city of Barcelona, the region of Barcelona, and the province of Barcelona), and no other report provides information on the entire region of Catalonia. As the province of Barcelona is the largest geographic region with available data and most of the laundries and hotels interviewed are in this region, it was decided together with Girbau that this would be the scope of our waste estimation.

Figure 16

The three territorial levels of data analysis considered in the Tourism Activity Report.

Source: Observatori Turisme de Barcelona. (2022). Informe anual 2022 [Annual report 2022]. https://www.observatoriturisme.barcelona/sites/default/files/2022_IAT_OTB_0.pdf

4.1.2. Assumptions

During this estimation, some information had to be assumed, due to the unavailability of specific data, or for the sake of simplicity. Many of these assumptions were based on the information provided during an interview to a Project Manager at Grape Hospitality on the practices of four hotels with different ratings (i.e., stars) located in Barcelona.

The assumptions are listed below:

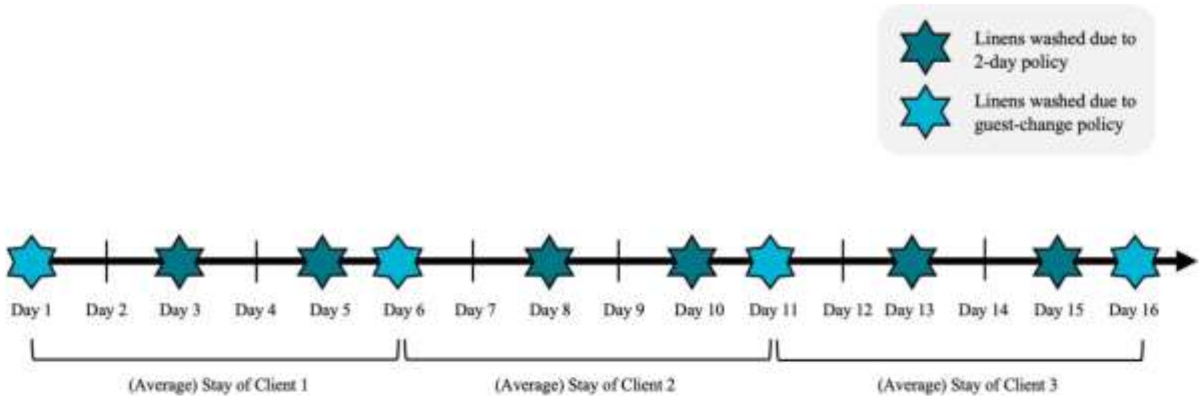
- The insights provided in the report regarding the year of 2022 were kept the same (e.g.: as of today, there are still the same number of beds in this region).
- Based on the outputs of the interviews (Appendix F) we assumed an average of 1,2(3) % of textile waste, out of which 40% are bed sheets and 60% towels.
- We do not differentiate between 1–5-star hotels. Instead, we make average assumptions on their current practices.

- Hotels are open 365 days a year.

- The textiles are changed based on 2 criteria (Figure 16):
    - Every 2 days
    - Every time a client checks out (according to the report the average stay is 4,9 days)

Figure 17

Example of the frequency of linen washing, for a 16-days scenario.



Source: Our own work.

- The textiles are thus washed 228 times a year (if they are washed 10 times in 16 days according to the assumed criteria, then they are washed 228 times in 365 days).
- Each room can either have:
    - 1 double bed
    - 2 single beds
- Single beds account for 20% of the total number of beds, whereas double beds account for 80%.

- According to the information provided by Girbau, each double-bed is equipped with four fitted sheets (sabana bajera), two flat sheets (sabana encimera) and four pillowcases (funda almohada) - see Table 1.
- On single beds, there are the same amount of fitted and flat sheets, but only two pillow covers - see Table 1.
- Also, the towels are assumed to be 1 of each kind (bath, hand, face) per guest, i.e., in a double bed there are two sets of each towel, while in a single bed there is only one- see Table 1.

Table 1

Beds'composition per bed type and towel sets per bed type.

Set of Bedsheets	Quantity
Per Double Bed	
Fitted Sheet	4
Flat Sheet	2
Pillow Case	4
Per Single Bed	
Fitted Sheet	4
Flat Sheet	2
Pillow Case	2

Set of Towels	Quantity
Per Double Bed	
Bath	2
Hand	2
Face	2
Per Single Bed	
Bath	1
Hand	1
Face	1

Source: Our own work, adapted and translated from information shared by Girbau.

4.1.3. Estimation of waste

4.1.3.1 Bed sheets

According to the Tourism Activity Report (2022), there are 142.804 hotel beds in the province of Barcelona and their occupancy rate is 60,7%, such that, on average, only 86.682 beds are in fact used. Based on the assumption that bed sheets are changed every 2 days and every time a customer checks-out, then they are changed 228 times a year. This means that all the bed sheets used are washed, in total, 19.763.496 times a year.

As our aim was to get the amount wasted in kg, we needed to understand how many kg were in fact being washed. For this, Girbau provided us the following information, summarized on Table 2, with the composition of each type of bed, and the weight of its respective textiles.

Table 2

Composition of each type of bed and weight of its respective textiles.

	Weight (per textile; in kg)	Quantity (per bed; in uni)	Total Weight (per textile per bed; in kg)	Total Weight (per bed; in kg)
Per Double Bed				
Fitted Sheet	0,432	4	1,728	3,83
Flat Sheet	0,966	2	1,932	
Pillow Case	0,042	4	0,168	
Per Single Bed				
Fitted Sheet	0,216	4	0,864	2,05
Flat Sheet	0,552	2	1,104	
Pillow Case	0,043	2	0,086	

Source: Our own work, adapted and translated from the information shared by Girbau.

As we are assuming that 20% are single beds and 80% are double beds, then out of the 19.763.496 washes, 3.952.699 concern single beds and 15.810.797 concern double beds

As the total weight of the set of each single bed is 2,05 kg, then, per year, 8.103.032,95 kg of single bed sheets are washed. Using the same rationale for double beds, whose sets weigh 3,83 kg, we get 60.555.352,51 kg. In total, 68.658.385,46 kg of bed sheets are washed per year.

Finally, the interviews conducted by Girbau allowed us to understand that laundries have an average of 1,2(3) % of wasted textiles, out of which 40% concern bed sheets and 60% towels.

So, the wasted bed sheets account for 0,49(3) % of 68.658.385,46 kg, which sums up to a total of 338.714,70 kg of hotel bed sheets wasted yearly in the province of Barcelona.

4.1.3.2 Towels

As already determined, out of the 19.763.496 washes, 3.952.699 concern single beds and 15.810.797 concern double beds. Although these numbers were previously calculated for the case of bed sheets, they can also be applied to towels, as every time the bed sheets are changed, the towels are changed as well.

As summarized below, in Table 3, each double bed has two sets of bath, hand and face towels, while each single bed has one. As each double-bed set weighs 1,52 kg and our estimation suggests that double-bed sets are washed 15.810.797 times, then the total weight of these washed towels is 24.032.411,44 kg. Using the same reasoning for the single-bed ones (where each set weights 0,76 kg) we get 3.004.051,24 kg. In total, 27.036.462,68 kg of hotel towels are washed every year.

Table 3

Composition of each type of towel set per bed and its respective weight

	Weight (per towel; in kg)	Quantity (per bed; in uni)	Total Weight (per towel per bed; in kg)	Total Weight (per bed; in kg)
Per Double Bed				
Bath	0,49	2	0,98	1,52
Hand	0,225	2	0,45	
Face	0,045	2	0,09	
Per Single Bed				
Bath	0,49	1	0,49	0,76
Hand	0,225	1	0,225	
Face	0,045	1	0,045	

Source: Adapted and translated from the information shared by Girbau

Finally, the interviews conducted by Girbau allowed us to understand that laundries have an average of 1,2(3) % of wasted textiles but, out of which 40% concern bed sheets and 60% towels. So, the wasted towels account for 0,74% of 27.036.462,68 kg, which is then 200.069,82 kg, which represents the total amount of wasted towels per year in the province of Barcelona.

4.2. Externalities

4.2.1. Research Methodology

Our analysis of the externalities deriving from the production of cotton started with a systematic literature review methodology to understand the extent to which this problem has already been studied and whether those conclusions can be applied to the case of the textiles used in the province of Barcelona.

The first dataset (now called “dataset 1”) was constructed from Scopus and was populated by identifying scientific articles containing the keywords “LCA” AND “cotton” AND “fiber”. The second dataset (“dataset 2”) was also constructed from Scopus and included the keywords “externalities” AND “cotton”.

Both datasets were subjected to an initial selection that used the following criteria:

- Journal or review articles published in English, between 2018 and 2024

Dataset 1 resulted in a set of 14 papers that were downloaded. Dataset 2 did not provide any result. For this reason, only the abstracts of dataset 1 were carefully read. Additional filters were applied to improve the quality and significance of the dataset:

- Research focused on environmental externalities (e.g.: climate change, water acidification, land use, etc), ii) not having too specific of a geographic scope (e.g. not focusing only on a city, but rather on a country, such as Brazil or China), and iii) providing clear results, ideally organized in the form of a table

After applying the above-mentioned criteria, dataset 1 (now termed the “Scopus relevant dataset”) included 2 papers.

To complement the small population of Scopus relevant dataset, a parallel systematic literature review was conducted on Google Scholar, with the keywords “LCA” AND “cotton” AND “fiber” (“dataset 3”). Similarly to the literature review conducted on Scopus, dataset 3 was also further reviewed according to the following criteria:

- Journal or review articles published in English, between 2020 and 2024 (this time frame was shorter than the one used on Scopus, due to the wide range of papers available)

This search originated 4060 results. As the results were ordered by relevance, while analyzing their abstracts, we concluded that only the first 41 papers were sufficiently relevant to proceed to the next scanning stage. Using the same criteria as the one used for Scopus (i.e., focused on environmental externalities, wide geographic scope and results organized on a table), the final relevant dataset (termed “Scholar relevant dataset”) included 3 papers.

4.2.1.1 Other sources

The sampling was complemented by a snowball search which allows us to detect 2 additional articles. Indeed, as reported by several studies, snowball search can replace the search in several different databases, hence being an alternative search strategy to use when performing literature review (Warasthe et al., 2022; Wohlin et al., 2022). Based on this approach we identified 2 other relevant papers

4.2.2. Content Analysis

The following is a qualitative overview of each article. Roy et al. (2023) assessed the contribution of mechanically recycled cotton to reducing environmental impacts of fabric production by blending the recycled cotton with 100% virgin cotton of different types, using a “cradle-to-gate” approach for producing 1 kg of fabric. La Rosa and Grammatikos (2019) conducted a LCA to evaluate the environmental impacts of cotton cultivation and fibers production for textiles, comparing traditional to organic cropping, and other natural fibers as well (e.g.: jute, hemp and kenaf). Chen et al. (2019) collated published results on the environmental performance of cotton clothing based on different environmental impact assessment methods, i.e., life cycle assessment, carbon footprint, and water footprint. Fidan et al. (2023) compiled various research focused on LCA. Out of these, the article “Life Cycle Assessment of Textile Fibres in Brazil: A Literature Review” (Picoli et al., 2023), stood out for its extensive literature review of LCA of the three most used fibers in the textile industry: polyester, cotton, and viscose. For the case of Felgueiras et al. (2021), although the focus of their research was not to conduct a LCA, they discussed the LCA of Cotton and Viscose Fibres for Textile Productions elaborated by Dibdiakova, J., and Timmermann, V. (2014). Kalliala and Nousiainen (2000) conducted a LCA for the textiles used by hotels. Although this study could be a good proxy, we determined it as being very outdated. Kazan et al. (2020) conducted a LCA of cotton woven shirt production, from cotton cultivation to the final product.

See Appendix H, which summarizes in a table each of the articles under the Scopus relevant dataset and Scholar relevant dataset, including their year of publication and journal in which they were published, as well as the metrics used in their LCAs.

Despite their relevance, all these articles were found to use different methodologies and have varying geographic scopes. For this reason, we were unable to join their results together and allow the research to complement each other. Therefore, we decided to focus our analysis on the paper written by Roy et al. (2023), as it is the most recent and comprehensive analysis, published in a prominent journal.

In the LCA conducted by Roy et al. (2023) a "cradle-to-gate" approach was used to analyze the environmental impacts of producing fabric from various types of virgin cotton (sourced from the U.S., the Better Cotton Initiative in Brazil, China, and from global averages) and recycled cotton. The "cradle-to-gate" approach encompasses all processes; from the initial production of raw virgin cotton to the completion of the fabric as a garment prepared to leave the factory gate. The functional unit (F.U.) of this study is defined as 1 kg of fabric produced, incorporating a blend of virgin cotton from different sources and mechanically recycled cotton.

Given the scope of this project, we will be focusing solely on the virgin and recycled cotton produced in China, as this is the most relevant supplier of textiles used in the hotel industry in the province of Barcelona.

The results of the LCIA (Life Cycle Impact Assessment) are presented in Table 4.

Table 4

LCIA results of 1kg fabric produced in China at the gate using virgin, recycled cotton.

Impact Category	Unit	Impacts (per 1kg)	
		Virgin	Recycled
GHG Emission	kg CO2 eq	17.40	12.41
Water Footprint	m3 eq	64.46	11.84
Land Use	m2a crop eq	2.02	1.816

Source: Adapted from Roy, S., Chu, Y. Y. J., & Chopra, S. S. (2023). Life cycle environmental impact assessment of cotton recycling and the benefits of a Take-Back system. Resources, Conservation & Recycling Advances, 19, 200177. https://doi.org/10.1016/j.rcradv.2023.200177

In this research, the primary data, regarding the inputs of raw materials, energy, electricity, transportation, and chemicals, was collected from New Focus Textiles Limited, a circular woven fabric supplier with mechanical fabric recycling facilities in China.

The required generic data for the processes that reflect materials and energy flow were obtained from the SimaPro v8.5 (LCA software) database libraries (e.g., Ecoinvent v3.8, Agri-footprint, USLCI) and literature (e.g., Zhang et al., 2021), using the cut-off approach, way of simplifying the LCA by excluding certain flows or impacts deemed to have minimal significance or relevance to the study's goals.

The impacts of selected categories were assessed using various impact assessment methods. For instance, GHG emissions (in kg CO2 eq) were estimated using the Global Warming Potential (GWP) for a 100-year time horizon (IPCC, 2013). Water footprint analysis (in m3 eq) utilized the AWARE Method developed by WULCA. The land use impacts (in m2 area crop eq) were analyzed using the ReCiPe Midpoint (H) v1.02 method.

For the LCI analysis, datasets from the SimaPro specific to China were utilized and complemented with global average data, as the local datasets were limited, except for electricity production specific to China and water consumption. It should be mentioned that data on cotton lint production for China were sourced from the Chinese context (Zhang et al., 2021) and standardized based on the F.U. defined in this study.

In the following sections we will examine the applicability of these impact estimations for the case of textiles commonly used in the province of Barcelona. Though not perfect, these estimates are a good starting point as, according to the surveys conducted by Girbau, the bedsheets and towels produced in China are the most widely used among hotels in this region.

Though we determine these estimates are helpful for the impacts happening in the production stage of the cotton, it is still necessary to understand the impacts that need to be accounted for additionally, in the transportation phase. Clearly, if the production is occurring in China, and we are discussing the case of Barcelona textiles, we need to understand how these textiles are being transported to Barcelona. We determined that in most cases, textiles are coming via maritime shipping, and therefore did a short literature review specifically on maritime shipping and its environmental impacts.

4.2.2.1 Maritime Transportation

Maritime transportation, the method by which goods and people are transported by sea, has significantly contributed to economic development across various industries and countries by enabling large-scale trading. While ships typically consume less fuel than airplanes, making maritime transport a seemingly greener and more cost-effective mode of transportation, its environmental impact is substantial and cannot be overlooked.

The most discussed environmental effects of maritime transport include the emission of exhaust gases such as carbon dioxide (CO2), sulfur dioxide (SO2), nitrogen oxides (NO2 and NO3), and particulate matter (PM) (Fuentes & Adland, 2023). In terms of these gases, most of the world is looking closely at CO2 emissions at the moment. In the case of maritime transport, it is cited as generating approximately 1 gigatonne of CO2 emissions annually, accounting for about 3% of global anthropogenic greenhouse gas emissions (International Maritime Organization, 2020).

In addition to the environmental impacts, the emissions from ships have direct consequences on human health, particularly in port areas where cargo handling operations are concentrated. The pollutants released contribute to air quality degradation, which can lead to respiratory and cardiovascular diseases among local populations (UNDRR, 2023). Furthermore, oil spills and marine habitat destruction caused by shipping activities pose serious threats to marine biodiversity and ecosystems (NOAA, 2020).

While maritime transportation is essential for global trade and economic growth, it is crucial to measure, monitor, and mitigate its environmental and human health impacts. Sustainable practices and advancements in cleaner technologies are imperative to reduce the negative effects associated with this vital industry.

4.2.3. Cotton externalities for the case of the province of Barcelona

4.2.3.1 Greenhouse Gas Emissions

The analysis conducted on the Greenhouse Gas (GHG) emissions involved in the production of virgin cotton is a good proxy for the case of the textiles used in the Barcelona province. Despite this, it is important to note that, although the paper reveals that the emission contributions from transportation ranged from 0,7% to 6%, (thus being much lower than activities such as electricity production (46,3%), cotton production (28,9%), and chemicals (12,4%)) the “cradle-to-gate” approach used does not account for nor encompass the environmental costs associated with transporting these textiles to Barcelona, which could be significant.

Due to the complexity of this exercise, we had to make some assumptions, namely that the ship (1) is coming from the Shanghai port to the Barcelona port, (2) is a container ship, (3) is only transporting textiles, and that it is completely full.

For each of these assumptions, we found the corresponding estimations, such as (1) the distance between the two ports is 18.596 kilometers (Ports.com, 2023), (2) each container ship transports on average 4.500 TEUs (BBC, 2022) and because each TEU typically loads up to 24.000 kg (Marine Insight, 2022), it sums up to a total capacity of 108.000 tonnes, (3) a ship in these conditions would emit an average of 16 grams of CO_2 per tonne-kilometer (g CO_2/tkm) (Sinay, 2023).

Considering the above-mentioned proxies, the total emissions of one container ship can be estimated as: 16*18.596*108.000 = 32.133.888.000 g CO_2 = 32.133.888 kg CO_2

The <u>total emission per 1kg of textile during maritime transportation</u> is then 32.133.888/108.000.000 ≈ *0,298 kg CO_2.*

Despite this result, it is important to keep in mind that these emissions vary according to factors such as the type of ship, operational profiles, cargo carried, fuels consumed, materials used, arrangements and control systems (European Maritime Transport Environmental Report, 2021).

4.2.3.2 Water Footprint

The estimation of the water footprint considers all the various water usage across the life cycle, from the cotton cultivation phase to the spinning and fabric creation.

We believe the current estimation for the case of China can be a good proxy for the externalities of the textiles in Barcelona, as the water footprint should only take into account the volume of freshwater used throughout the process. During the maritime transportation of the products from China to Barcelona province, there is no freshwater being additionally used in this process - as Figure 17 suggests. Therefore, we accept the current impact amounts as they are given in the article, and we can apply them to our own study.

Figure 18

Pollutant emissions to the water body from a generic ship.

Source: EMSA/EEA (2021)

4.2.3.3 Land Use

The article highlights that although the land usage in the case of the virgin cotton produced in China is much lower than other sources studied and available in their study, this has to do with the fact that only raw materials (cotton seeds, water, fertilizers, pesticides, etc.), fuel (diesel), electricity/ heat, and road transportation were considered in the LCIA of Chinese virgin cotton production, and no ship transportation from other continents or regions to China and road transportation (transport of raw material to the factory) was required, which makes this low impact for the case of China reasonable.

4.2.3.3.1 What does this mean?

After conducting this in-depth analysis, we have drawn several conclusions regarding the externalities cotton is generating. Firstly, maritime transportation, while vital for many industries, significantly contributes to environmental degradation through greenhouse gas emissions, pollutants, oil spills, and marine habitat destruction. The heavy reliance on fuel oils exacerbates air and water pollution, affecting both marine life and human health.

Secondly, the transportation of fabrics from China to the province of Barcelona specifically impacts the greenhouse gas (GHG) emissions category. The other categories, such as water footprint and land use, are primarily affected during the production phase and thus were not reassessed in this analysis. By adding the maritime transportation impact of 0,298 kg CO2 eq to the previous calculations, we observed an increase in the overall environmental impact. For virgin cotton fabric, the GHG emissions per kg rose from 17,40 kg CO2 eq to 17,70 kg CO2 eq, and for recycled cotton fabric, from 12,41 kg CO2 eq to 12,71 kg CO2 eq.

Table 5 summarizes all the findings of the impact of producing and transporting the textiles from China to Catalonia.

Table 5

LCIA results of 1kg fabric produced in China at the gate using virgin, recycled cotton, the corresponding impact of the maritime transport on GHG emissions, and the total impact of both activities.

Impact Category	Unit	Impacts (per 1kg)				
		Production		Maritime Transport	Production + Maritime Transport	
		Virgin	Recycled		Virgin	Recycled
GHG Emission	kg CO2 eq	17,40	12,41	0,298	17,70	12,71
Water Footprint	m^3 eq	64,46	11,84	N/A	**64,46**	**11,84**
Land Use	m2a crop eq	2,02	1,82	N/A	**2,02**	**1,82**

Source: Our own creation

Overall, it is clear that maritime transportation increases GHG emissions, and it can also be concluded that the production and transportation of recycled cotton creates a lesser negative impact.

4.3.Scenario Analysis

4.3.1. Scenario 1: Technology Barrier

4.3.1.1 Who has the technology now?

In the current landscape, there exists a limited number of businesses equipped with the technology to process textile waste through mechanical recycling. For example, we discovered through interview responses from companies that belong to different type of industries, "Triturats La Canya", a specialized shredding company, has gained the trust and currently holds a predominant position in the Catalonia region since the responses either shared that their current recycling operations are made by them, or they referred us to them to gain more information about the complete process.

The results from the interviews suggest that the costs associated with this technology may be very expensive, thereby posing significant challenges for other textile-related enterprises to adopt it. Such financial barriers could impede these companies from establishing sustainable cycles that would enable them to repurpose waste produced within their own operations. Consequently, this could delay the progress towards more sustainable industry practices.

4.3.1.2 What business model do they have with this?

The current business model adopted by most of the recycling textile companies involves a service-based fee structure. Under this model, recycling entities do not purchase wasted textiles as raw materials for their operations; rather, it is the clients who initiate contact with recycling facilities to process their waste. This waste is then converted into new materials that can be reintegrated into the production cycle. Therefore, the recycling facilities' revenue is derived only from the service given, which will be determined by the nature, quality, and volume of the material provided, as well as the desired characteristics of the future textile product.

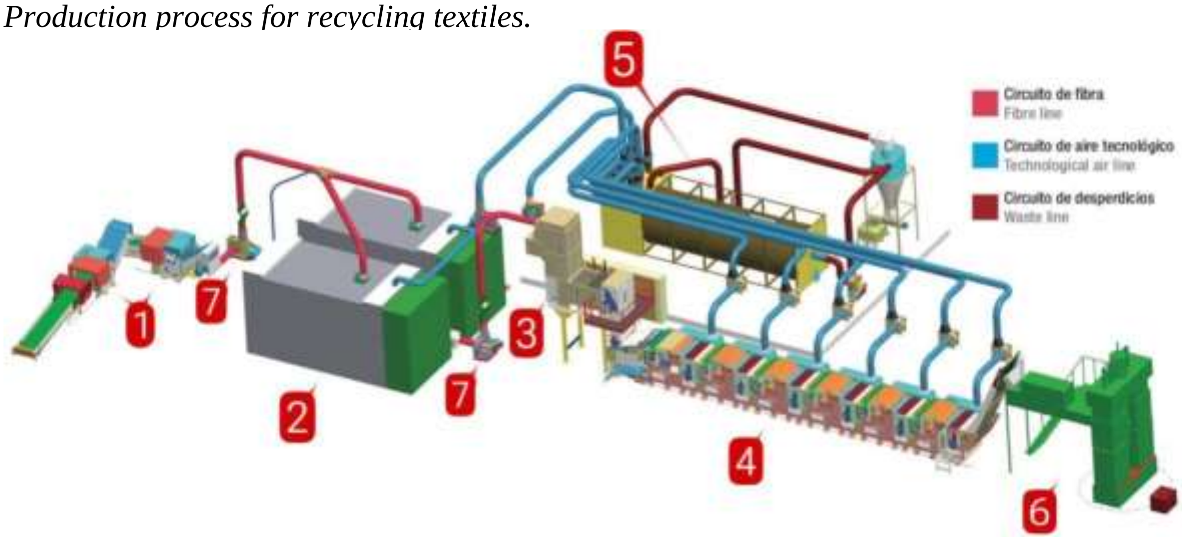
This model is predominantly tailored to accommodate large-scale industries that generate substantial waste volumes, since insights from the interviews show that most of the recycling facilities often require a minimum of 1.000 kg of waste per transaction to utilize the services offered, thereby presenting challenges for smaller enterprises seeking to engage with these facilities.

4.3.1.3 Which is the technology?

Our research has identified a range of machinery currently utilized within the industry. An infographic, seen in Figure 19, shows the assortment of equipment employed during the mechanical recycling process.

Figure 19

Production process for recycling textiles.



Source: Margasa Reciclaje Textil (n.d.)

Legend:

1. A rotary cutter for textile waste, that can be featured with an optional metal detector, will tear apart the textile into smaller pieces.
2. An automatic blending system designed to handle textile waste and fibers to mix them and accommodate them into specific volumes of scrap stacked.
3. A loader device that will pick fibers autonomously to load and distribute the material across the working space.

4. Shredding machine with multiple cylinders that will define the total capacity and will recycle textile such as yarn scraps, fabric cuttings, clothing (both pre- and post-consumer), non-woven materials, and more.
5. Rotating Filter that will treat the air used during the process; moreover, it will also collect dust and microfibers that are conveyed into a compactor.
6. Hydraulic Press that will exert enormous amounts of force to the resultant material.

Figure 19 serves as an example of the complex array of machinery necessary for the effective recycling of textile waste. Although various machines from different manufacturers are available on the market, this example demonstrates the challenges involved in the implementation of such systems by companies. The difficulty of this process relies from the necessity for textile waste to undergo multiple stages, including shredding and filtration, to adequately separate the diverse fiber types before they can be re-spun into new yarns. Finally, the process must be conducted with great care to maintain material quality, as the mechanical recycling procedures can be quite rigorous and potentially damage the integrity of the final product.

4.3.1.4 Optimistic Scenario:

Boost of the accessibility of current technologies.

The impacts of this scenario include:

- Recognition: companies would recognize the investment potential and the long-term opportunities this technology has.
- Reduction of costs: The new technologies developed could imply the reduction of costs or simplifying machinery and processes. As seen in the literature

review, there are currently new innovations happening in the industry towards mechanical recycling, with new methodologies or even with chemical recycling, companies are testing new innovative ways to recycle textile fibers without compromising the quality.

- Circular Business Models: By reducing the current barriers, companies can adopt their business models, making a shift from their existing systems to closed-loop models.

4.3.1.5 Pessimistic Scenario:

The current technology may not evolve to become more cost-effective.

The impacts of this scenario include:

- Maintaining the status quo: the current barriers would continue preventing the industry's shift toward sustainable business practices.
- Exclusivity: The current processes would only allow those robust companies that generate a significant volume of textile the access to do business with recycling facilities, leaving behind small enterprises across the region.
- Lack of specialized knowledge: The few recycling facilities that had the financial resources to invest in the technology would keep the knowledge concentrated, reducing the number of options available in the market.

4.3.2. Scenario 2: Cooperation

4.3.2.1 What cooperation are we seeing currently?

While conducting interviews among various spinning and shredding companies in Catalonia, a particularly telling statement emerged, from the company "Hilaturas Arnau," that encapsulates the current level of trust within the market: "Nobody wants the waste from another." This sentiment shows the absence of a proper mechanism to verify the quality of waste, which complicates its utilization as a raw material.

This issue shows the reasoning behind why the current business model favors a service-oriented approach. The lack of trust among companies prevents the establishment of a symbiotic relationship within the industry, one in which the waste generated by one company could serve as a resource for another. Establishing such a symbiosis would initiate a paradigm shift towards transparency and quality assurance in waste management, fostering a more collaborative and sustainable industry ecosystem.

4.3.2.2 Optimistic Scenario:

A business model based around trust and cooperation is created and instilled among businesses, then spreading into the industry.

Impacts of this scenario include:

- A new collaborative framework: New business models would be developed to facilitate the viability of sharing resources.
- Mechanisms established: To verify the quality of waste, new mechanisms in hand with data technologies would emerge, allowing companies to foster mutual trust.
- Prolonging the life cycle of textile resources and diminishing the reliance on virgin raw materials. This interdependence would therefore facilitate the sharing of resources, thereby stimulating a sustainable loop. This loop would be instrumental in

4.3.2.3 Pessimistic Scenario:

Lack of collaboration among the industry.

Impacts of this scenario include:

- Struggle to establish circular models: since collaboration is the key pillar for companies to be able to share resources, knowledge, and make the possibility where the textile resources flow through a circular way.
- Lack of Interest: Without the proper incentives, companies would not be able to create a paradigm shift, since they would be interested or wouldn't perceive the benefits.

4.3.3. Scenario 3: Legislation

4.3.3.1 Which laws could affect the industry? What do they entail?

There are three big proposals that are directed towards the management of textile waste in the European Union and are expected to be implemented in the next six years, however there are gradual adoption plans and objectives that must be met in the approaching years leading up to 2030. These proposals are:

1. Extended Producer Responsibility (EPR) Schemes: [proposed on July 5th, 2023] oblige all producers to take responsibility for the entire life cycle of their textile production including, and emphasizing, the management of the waste (collection, recycling and disposal) their products generate (European Commission, 2023). Manufacturers must pay a tax based on a calculation by "eco-modulation" (The EU's Proposal for Extended Producer Responsibility for Textiles, n.d.) where costs of the taxes vary based on the environmental performance of products, their level of circularity, and their weight. Each country will be free to regulate these schemes, and some of the EU members are already in an implementation phase, even before this has become official for the whole European

Union. Members must implement these schemes within 30 months of the directive’s enactment.

2. Waste Framework Directive Revision: [proposed on July 5th, 2023] the EU proposed to conduct a revision on the directive, specifically on topics of waste management. The revision aims to make updates to improve circular and sustainable management of the residues of textile products. It obliges EU members to set up separate collection systems for said textile products before January of 2025, and to further combine strategies for sorting, re-using and recycling (European Commission, 2023).
3. EU Strategy for Sustainable and Circular Textiles: this strategy (not law) outlines the EU's vision for the textile industry through 2030, enhancing aspects like durability, recyclability and elimination of toxic components in textile products (European Commission, n.d.). The strategy establishes design requirements, disclosure of certain information and promotes new alternatives for unsold or returned textiles.

4.3.3.2 Optimistic scenario:

The legislation presented is enforced in the established timelines and gradual implementation works effectively.

Impacts of this scenario include:

- An increase in the demand for circular solutions: Since manufacturers are now held accountable for the life cycle of their products, especially in the waste management processes, they will need initiatives or companies that enhance recycling, reusing and redesigning processes. This results as being beneficial for our project because of the uniqueness and current lack of similar solutions.

- Innovation fostering: the urgency in finding solutions to avoid incurring in the eco-modulation taxes encourages an increase of solution design or search.
- Economic opportunities: a demand increase opens the market for businesses that offer these types of solutions, which could be capitalized on and seen not only as compliance, but also as a new strategic advantage.
- Environmental and social benefits: the original motivation will be addressed, and it will result in the increase of the general well-being of both the planet and society.

4.3.3.3 Pessimistic Scenario:

The legislation presented faces delays in approval and the enforcement is not effective neither at EU nor at country levels.

Impacts of this scenario include:

- No incentive: the delay implies that companies will not perceive the immediate need to insert a circularity strategy in their supply chains, since there is no risk of taxation for any of their processes. This is negative for our project, as the lack of this need decreases the demand and willingness of cooperation that we require to advance.
- Uncertainty and distrust: hesitation to invest in these strategies would increase as the uncertainty for the enforcement of the law does.
- No innovative environment: the lack of urgency also does not foster any creativity boost towards alternatives.
- Environmental and social setbacks: the damages will continue to worsen if action is not taken towards the many problems textile waste produces.

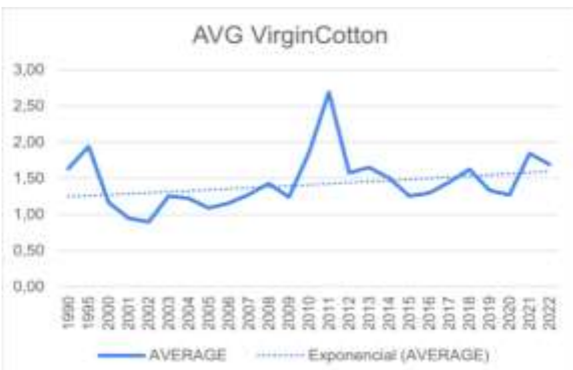
4.3.4. Scenario 4: Raw Materials

4.3.4.1 Price trends of raw materials (Virgin Cotton)

The following graph, Figure 20, was created using statistics found in Appendix E and shows the remarkable variations in virgin cotton prices between 1990 and 2022. Around 2011, it can be observed that there was a significant peak. Despite the many fluctuations, the smoothed trend line shows a slightly increasing overall trend throughout the years.

Figure 20

Average price per year of virgin cotton from 1990 to 2022.



Source: Our own work, adapted from information sourced from Statista.

The peak in 2011 could have been caused by specific market or production events that had an impact on supply and demand. The general upward trend could indicate a gradual increase in virgin cotton prices (possibly because of inflation), changes in global demand, or increases in production costs. Based on this exponential trend, prices could continue to increase slowly under stable market conditions such as the current ones.

4.3.4.2 Previous causes of peaks in price

As seen in the price comparative analysis (Appendix E) there have been some noteworthy spikes in prices over the past years. We will focus on the causes of the three biggest peaks:

4.3.4.2.1 Virgin cotton rise in 2011

Badkar (2012) establishes that due to the supply disruptions that started in 2010, the price of a cotton bale more than doubled starting in 2011, rising from an average of $0.70 to $ 2.25 per pound. These supply disruptions included severe flooding in important producer countries, such as Pakistan and Australia, which significantly reduced the supply. At the same time there was an accelerated increase of demand from countries with a fast-developing textile industry, like China and India (Linghe & Masato, 2012). Farmers started having disputes over supplies, which resulted in further problems in their clientele since they were not able to uphold the agreements signed when the prices were still low. This led to several lawsuits, arbitration claims, the creation of a cotton integrity reporting line and a general disconnection between price and physical markets.

Cotton trading was highly volatile at the beginning of 2011 and the vicious cycle of hoarding and banning exports worsen the environment even more resulting in an overall rise of prices (Walker, 2011)

4.3.4.2.2 Consequences of the Covid-19 pandemic

The Covid-19 pandemic was highly characterized by the temporal closing and working restrictions across all industries. The textile industry was affected mainly due to the production rate plummeting in key producer countries such as China, India and Bangladesh (Textile and Garment Supply Chains in Times of COVID-19: Challenges for Developing Countries, 2020). However, production was not the only supply chain factor that contributed to the rise in prices, maritime transportation also had a large impact according to Himes (2023), that was included in the overall price of the yarns and bales, and since most textiles were imported, this meant a high import cost.

4.3.4.2.3 2022 war-related problems

Like the Covid-19 disruptions, the Ukrainian war caused a reduction in production rates and an increase in energy and transportation costs. According to Husband (2022), the World Bank even announced a 40% rise in the commodity markets mainly due to energy prices and the direct effect on petroleum that the war had. The latest also generated intense pressure on polyester production and prices since its main material had a rise of 570% (McKeegan, 2022).

4.3.4.2.4 Recycled materials trends

The global market for recycled polyester and cotton is growing due to consumer demand for more sustainable products and regulatory pressure on companies to reduce their environmental impact. According to a Textile Exchange survey (2017), “the circular economy is already part of the business strategy of 24% of fashion companies while 57% are working along these lines.” In addition, 7% of the polyester that the sector used in 2016 was recycled and 15% of the cotton already came from sustainable sources, according to the Preferred Fiber Materials Market Report 2017 (Modaes, 2017). The prices of these materials can vary significantly depending on several factors, including quality, availability of the input for their creation, processing costs and the technology required. The typical fluctuations of any raw material, influenced by changes in global supply and demand, affect the market. However, due to the additional costs of recycling and sustainability certification, products made from recycled materials are often more expensive than those made from virgin materials but close enough to remain competitive.

4.3.4.3 Optimistic Scenario:

Prices for both materials keep rising because of supply chain disruptions, demand shifts and taxation on externalities due to legislation implementation in the EU.

Impacts of this scenario include:

- Increases the cost-effectiveness of our proposal: recycled alternatives become more attractive financially.
- Brand image: enhances brand image and provides a new competitive scope not only empirically but also in terms of new certifications, grants and other incentives for sustainability.
- Consumer demand: consumer niches that are inclined towards sustainability will be adopted by the different companies.
- Technological advances in recycling processes: seeking to mitigate the risks of disruptions and volatility of supply chains, companies may invest into R&D of recycling technologies making them more accessible for customers and addressing the technological barrier mentioned above.

4.3.4.4 Pessimistic Scenario:

Prices for both materials decrease due to possible efficiencies in technology, or sustainable strategies focused on other areas of the supply chain, or a reduction in global demand because of economic downturns.

Impacts of this scenario include:

- No financial incentive: with already higher prices of recycled fibers, a reduction in virgin materials eliminates the urgency to invest in alternatives.
- Market resistance: the lack of urgency could imply that companies do not foster changes in their production processes, especially if cost benefits can't be proved.
- Consumer indifference: seeing a setback in sustainability efforts due to a lack of commitment from companies can make customers give up on their pressures or would make this niche even smaller than it is.

5. Discussion

The initial phase of this project involved estimating the solid textile waste generated in the province of Barcelona (though it was initially planned to be Catalonia, we soon came to the realization that there was not enough data available for this region). The findings indicate that approximately 338.714,70 kg of hotel bed sheets and 200.069,82 kg of towels are discarded in this region, annually, amounting to a total of 538.784,52 kg.

Even though this estimation derives from a theoretical exercise, we believe it uncovers a reality that has been hidden due to the lack of studies conducted in this field and region (a limitation further elaborated in chapter 6). During our research, we also came to the realization that most laundries and hotels do not track the end-of-life of their textiles, although many new directives and regulations will come into force starting next year, which will constitute a challenge for them in the very short term.

Additionally, our extensive analysis on the social and environmental externalities unveils many negative consequences that derive from the production of these textiles, typically 100% made from virgin or recycled cotton, that every year turn into waste. We estimate, firstly looking at production and transportation of virgin cotton, that around 9.535.408,43 kg CO2 is emitted, 34.730.050,16 m3 of freshwater is used, and 1.088.344,73 m2 area of land is used. Doing the same analysis for the case of recycled cotton, the impacts are as follows: 6.846.873,68 kg CO2 is emitted, 6.379.208,72 m3 of freshwater is used, and 978.432,69 m2 area of land is used. Conducting this analysis allows us to go beyond merely estimating the waste, but rather unearthing the true impact of the existence of this waste, that extends far beyond their EoL, and which has significant implications.

Overall, these first stages of our analysis allow us to understand that although this is a pressing subject with detrimental consequences, both the laundry and hotel industries appear to show limited engagement as agents of change. As we move into discussing the best practices for circularity in the sector, it is critical to integrate the insights to our proposed keys, which looks to address each scenario directly from Girbau´s action capacity.

5.1. Four Keys to Unlock Circularity in the Laundry Industry, Led by GirbauLab

5.1.1. Key #1: Become an advocate for compliance

The upcoming legislation is going to stress the importance of reporting and transparency for companies in the textile industry, however, most of them do not have the sense of urgency needed to change their business model towards compliance with these directives. This is an opportunity for Girbau to be noted as a key player in the subject. With this initiative, Girbau could become the essential solution for laundries and hotels towards this objective and lobbying efforts could be used for future partnerships or business opportunities.

In this aspect it is important that Girbau actively advocates for the benefits of joining the initiative using as leverage the possible tax implementation to externalities and a detailed explanation of consequences of non-compliance with the Waste Framework Directive. Also, for the project to succeed, it is important to motivate the prioritization of transparency in waste management in a way that it ensures its accessibility to all stakeholders in the initiative.

5.1.2. Key #2: Venture into new recycling technologies

Technology plays an important role in the transformation of the industry by shifting it into a more responsible, sustainable and circular environment. The extensive influence Girbau has in the industry, and their resources available gives them the opportunity to step up by investing in the research, development and implementation of recycling technologies. Either by bringing awareness to their customers to collaborate and share resources that could be scaled up, or by supporting startups interested in becoming pioneers in the transformation of the laundry industry in Catalonia.

5.1.3. Key #3: Provide expertise in managing recycled materials

Girbau is sitting in an advantageous position in terms of know-how due to the fact that they have already launched circularity projects that recover waste and repurpose it into recycled raw materials for new products. They have worked with humid waste, which included microplastics and fibers; to create polypropylene used in 3D printers and, they have used dry waste (lint obtained from dryers) to create recycled paper.

The aforementioned, coupled with the analysis provided on raw material price volatility and supply chain disruption, showed it is imperative that the industry starts considering the usage of recycled raw materials, strengthens Girbau´s potential role as an advisor on business opportunities involving recycled raw materials.

5.1.4. Key #4: Foster a new vision in the laundry industry

The preceding keys emphasize the great importance of collaboration and transparency to shift the current individualistic mental models that govern today's enterprises. Nevertheless, GirbauLAB has a clear vision and values that support the transformation of the industry along with their resources, experience and data found from this project they require to use these tools wisely fostering a circular culture. Firstly, to transform the current mental models, Girbau needs to build a shared vision among their current customers and the rest of the industry. With the new legislation approaching and the estimation of the current waste that hasn't been utilized, they can create a vision among the companies where circularity becomes the solution. Once a common vision is settled, partnerships among the industry are required, with the proper incentives Girbau different businesses from the laundry industry can start collaborating and with a transparent channel flow of sharing information, resources and technology, a symbiotic ecosystem can evolve organically in which companies can share resources in a way where circularity becomes the main pillar by creating closed loops that minimize the waste produced and maximize the value of the current natural resources.

6. Conclusion

This project on solid textile waste generated from industrial laundries with rental services in Catalonia revealed significant insights into the current situation of textile waste management within the region's laundry and hotel industry.

Our findings show the magnitude of hotel towels and bed sheets wasted at approximately half a million kg a year in the province of Barcelona. This number highlights the current challenge companies have when engaging with waste management but also showcases an opportunity for boosting circular economy practices in it.

The analysis also reviewed the environmental impacts associated with the production and transportation of these textiles to Catalonia. It was shown that the process has significant contributions to emitting harmful greenhouse gases and an extremely large water footprint, though using recycled cotton can greatly reduce these impacts created.

The gap added to external challenges like technology barriers, pending legislation, raw material price volatility and individualistic practices calls upon a collaborative and dynamic change in the business models of the possible actors in our circular loop. Girbau's position as a leader in the laundry industry provides a strategic advantage to influence and implement sustainable practices. By advocating for compliance, venturing into new recycling technologies, providing expertise in managing recycled materials, and motivating a paradigm shift in the industry, Girbau can drive significant change in both reducing the amount of waste generated and reducing the externalities associated with it.

Throughout the project, we encountered several challenges that restricted our access to information and impacted the desired outputs of our project. Some limitations include the narrow interview scope, which diminished our interview sample size, as well as the informal measurement and management of textile waste within Catalonia's laundry industry. Access to information was challenging and contacting laundries and other companies involved in the industry proved difficult due to our team being comprised of students. Financial constraints also

Figure 21

Scope definition of interviewed laundries

prevented us from accessing certain data, as it required substantial payment, limiting our ability to obtain relevant information. Furthermore, our literature reviews and general research revealed that these fields of textile waste and its negative externalities are largely unexplored.

Source: Our own work

Finally, to complement and further develop this research we recommend cooperating with other companies along the country that are also interested in this type of initiative to be able to expand the scope and have a bigger response rate that translates in a more accurate prediction. Also, we emphasize the need to have financial support for this research to access potentially relevant data in material reports and LCA software as well as the support from experts in the field that could guide the quantitative mathematical output calculation.

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