LUISS

Department
of Economics and Business - Major in Management

Course of Management

Circular Economy and LCA in the Fashion Industry: Manteco SpA Case Study

Prof. Francesca Vicentini

SUPERVISOR

Chiara Corradini - 274571

CANDIDATE

Academic Year 2023/2024

Table of Contents

Abstract

The fashion industry is one of the most resource-intensive and environmentally damaging sectors. This thesis explores the integration of Circular Economy (CE) principles and Life Cycle Assessment (LCA) in the fashion industry, focusing on Manteco SpA as a case study. Manteco, a pioneer in sustainable textiles, has successfully implemented innovative recycling and upcycling techniques, particularly with its MWool® recycled wool. This study examines Manteco's sustainability initiatives, the comparative analysis of circular practices among leading fashion brands, and the role of LCA in assessing environmental impacts. The findings underscore the potential of CE and LCA to transform the fashion industry into a more sustainable and ethical model, aligning with global sustainability goals.

List of Figures

List of Tables

List of Abbreviations

- CE: Circular Economy
- CSR: Corporate Social Responsibility
- EPD: Environmental Product Declaration
- GRS: Global Recycled Standard
- LCA: Life Cycle Assessment
- MWool®: Manteco Wool
- UNCTAD: United Nations Conference on Trade and Development

Introduction

The fashion industry is renowned for its rapid production cycles and significant environmental footprint, exerting immense pressure on natural resources such as water, energy, and land. This sector is a major contributor to environmental issues including greenhouse gas emissions, chemical pollution, and textile waste. These challenges underscore the urgent need for sustainable transformation within the industry.

A promising solution to these environmental concerns is the Circular Economy (CE) model. Unlike the conventional linear approach of 'take-make-dispose', the CE model focuses on a sustainable framework where resources are continuously reused, remanufactured, and recycled. This approach seeks to extend product lifespans, minimize waste, and create closed-loop systems that significantly reduce environmental impact.

Life Cycle Assessment (LCA) plays a pivotal role in the practical application of CE principles. It offers a detailed analysis of the environmental impacts associated with all stages of a product's life, from initial raw material extraction through to final disposal. By thoroughly assessing these impacts, LCA helps identify areas where resource use can be optimized and sustainability can be improved.

Manteco SpA, a leading textile manufacturer based in Italy, exemplifies the effective application of CE and LCA within the fashion industry. The company's innovative practices, particularly in the realm of recycling and creating recycled wool fibers like MWool®, showcase the practical benefits of integrating sustainability principles.

This thesis delves into the ways CE and LCA are applied within the fashion industry, focusing on Manteco's pioneering efforts. It explores how the company has successfully utilized these frameworks to mitigate environmental impacts, improve resource efficiency, and promote sustainable practices. Additionally, the study provides a comparative analysis of circular economy initiatives across various fashion brands, evaluating the success and impact of their sustainability efforts.

As consumer demand for environmentally friendly products grows, the adoption of CE and LCA is becoming increasingly vital for the fashion industry. Manteco's experience illustrates the potential for innovation and leadership in fostering a sustainable fashion ecosystem, setting a high standard for the industry to follow.

Chapter 1: Circular Economy and the Fashion Industry

The fashion industry currently stands as one of the most environmentally harmful and resource-intensive sectors worldwide. Its operations exert considerable strain on natural resources such as water, energy, and land, while simultaneously contributing significantly to greenhouse gas emissions, the release of toxic chemicals, and the generation of textile waste.

This historical pattern of waste output and resource depletion within the fashion industry underscores the pressing need for a transition to a circular economy (CE). The CE concept has emerged in response to the linear economy's adverse environmental impacts, offering a pathway to reshape the fashion system into a more sustainable, ethical, and innovative model.

By advocating for resource regeneration and circular value flows, the CE presents an opportunity to address the industry's unsustainable practices. Remarkably, according to the Ellen MacArthur Foundation, less than 1% of materials used in clothing production are recycled into new garments, with over half of all clothing ending up in landfills or being burned within a year.[1]

Beyond environmental concerns, the linear fashion model perpetuates unfavorable working conditions, low wages, and human rights violations for industry workers. The urgent need for reform has garnered international attention, particularly regarding the issue of textile waste.

Embracing eco-friendly methods throughout the garment supply chain holds promise for significantly enhancing the sustainability of the fashion and textile industries. Businesses are increasingly recognizing the potential value in efficiently utilizing waste, with the capacity to recycle up to 95% of discarded textiles annually. This shift aligns with growing consumer concerns about the social and environmental impacts of their purchases and unlocks untapped economic opportunities.

The adoption of CE principles has the potential to catalyze a sustainable revolution in the fashion industry, fostering a future where style and sustainability coexist harmoniously. Its overarching goal is to establish a closed-loop system in fashion, extending the wear-life of clothing and preserving material and product values for as long as possible.

[1] Ellen MacArthur Foundation. (2017). *A New Textiles Economy: Redesigning Fashion's Future*.

1.1 Concept of Circular Economy

The concept of the circular economy is defined by the European Parliament, as:
"a model of production and consumption that involves sharing, lending, reusing, repairing, refurbishing, and recycling existing materials and products for as long as possible. This extends the lifespan of products, contributing to minimizing waste. Once the product has fulfilled its function, the materials it is composed of are reintroduced, where possible, into the economic cycle. This allows them to be reused within the production cycle, generating additional value"[2]

The goal of this model is to establish a regenerative system where resources are used more efficiently, waste is minimized, and economic growth is decoupled from resource consumption and environmental harm. The circular economy emphasizes a shift away from the linear "take-make-dispose" model towards a more sustainable approach.

In this conventional linear model, materials are extracted, transformed into products through manufacturing processes involving labor and energy, and then delivered to end-users who eventually dispose of them once their intended purpose is served. The issue with the linear economy is that products quickly become obsolete to encourage consumers to purchase new items. However, this entails a series of consequences that are not considered, such as the limit of natural resources tapped into for production and the environmental impact.

A shift towards the circular economy is thus essential for several reasons (see Figure 1.1). The circular economy offers a holistic approach to the linear model, aimed at addressing these issues comprehensively. Regardless of a product's life cycle, the linear economy prioritizes profitability whereas the circular economy focuses on sustainability. As defined by the Ellen MacArthur Foundation (2018): *"Circular economy is looking beyond the current "take, make and dispose" extractive industrial model, the circular economy is restorative and regenerative by design. Relying on system-wide innovation, it aims to redefine products and services to design waste out, while minimizing negative impacts. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital"* [3].

[2] European Parliament. (2023*). Circular Economy: definition, importance, and benefits.*

[3] Ellen MacArthur Foundation. (2018). *Circular Economy.*

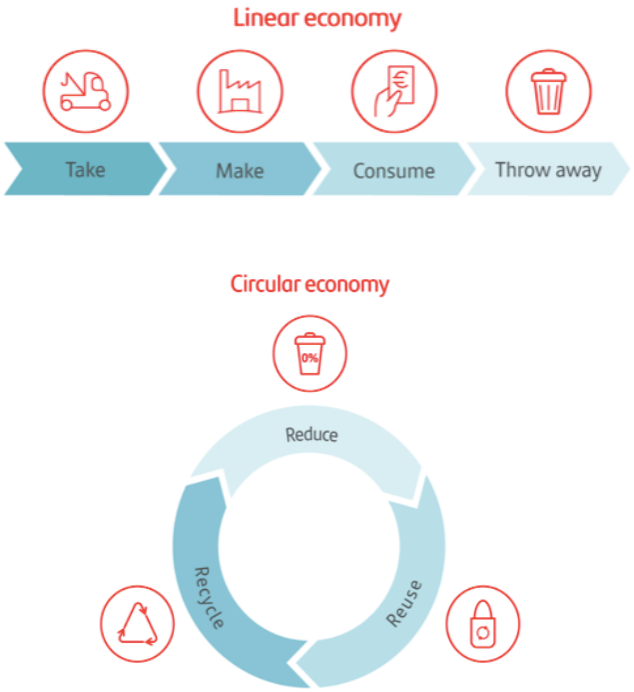

Figure (1.1): Differences between linear and circular economies.

The concept of the circular economy (CE) has a rich history dating back to 1976 when Stahel and Reday-Mulvey introduced the idea of "an economy of loops," emphasizing the extension of product lifespans and associated processes. Since then, CE has become intricately linked with various sustainability principles, such as ecological economics, cleaner production, and industrial symbiosis. This interdisciplinary nature underscores CE's holistic approach to addressing environmental challenges.

Despite its long history, the implementation and adoption of CE remain relatively recent, reflecting ongoing efforts to integrate its principles across different industries and sectors. However, this integration also presents challenges, as the diverse array of stakeholders interpreting and implementing CE may result in its concept becoming blurred.

In this complex landscape, the Ellen MacArthur Foundation has emerged as a key player, providing a comprehensive framework for CE (see Figure 1.2) through its delineation of the biological and technical cycles. This framework highlights the transformative potential of CE significant shift towards sustainable resource management and economic practices.

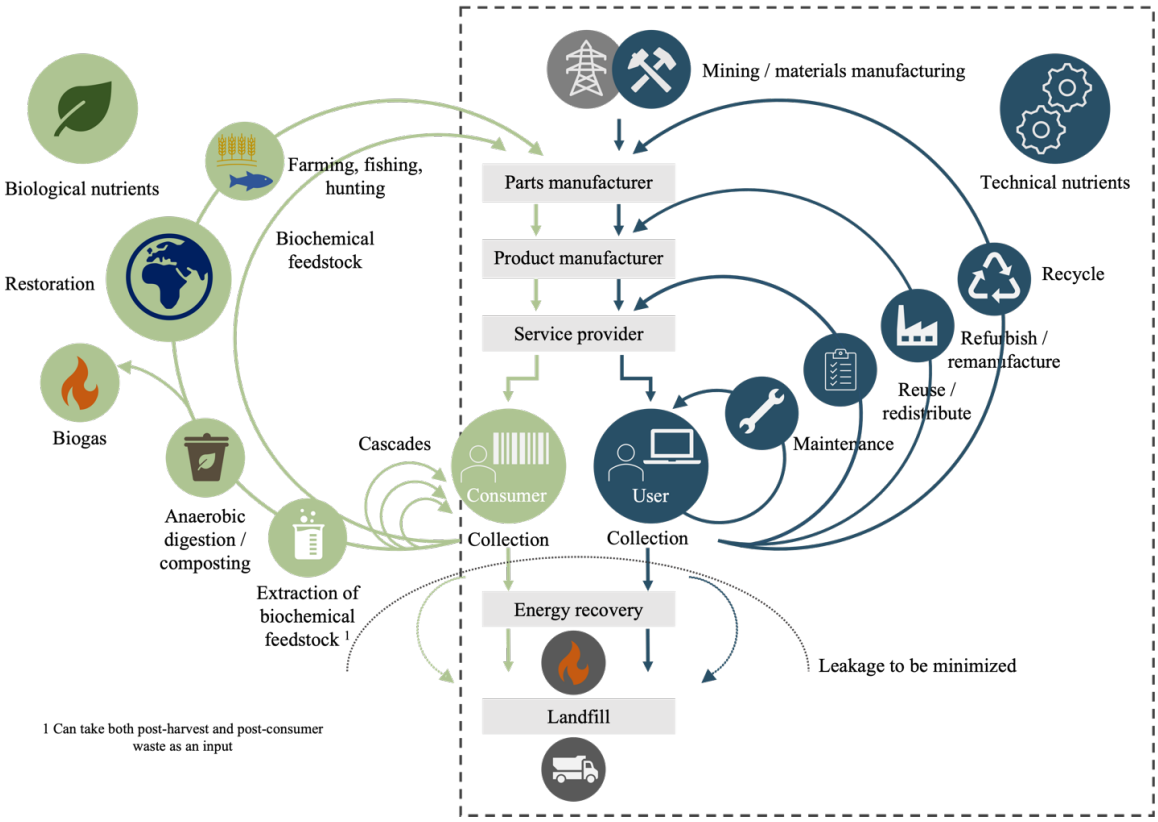

Figure (1.2): A graphical depiction of CE, illustrating both the biological and technical cycles as outlined in *The Ellen MacArthur Foundation's (2013) Butterfly Diagram.*

Incorporating insights from the "*Butterfly Diagram*," the objective of the circular economy is to ensure that all materials, products, and components, whether biological or technical, remain in use at their highest value and for as long as possible, ideally indefinitely. Thus, when referring to a circular economy, we aim to extract the utmost value from our resources while maintaining their peak usefulness and quality. As stated before, this diagram illustrates two integral cycles within the circular economy framework: the technical cycle and the biological cycle. The technical cycle encompasses strategies to extend the lifespan of products and materials through activities like reuse, repair, remanufacturing, and recycling. By keeping materials in circulation and minimizing waste generation, the technical cycle contributes to resource conservation and reduced environmental impact.

Conversely, the biological cycle emphasizes the integration of organic materials back into natural ecosystems. Through processes such as composting, nutrients from biodegradable materials are reintegrated into the Earth, supporting the regeneration of natural ecosystems. This cycle exemplifies the regenerative principles of the circular economy, highlighting the interconnectedness between human activities and the environment.

1.2 Circular Economy Practices in the Fashion Industry

Circular Economy (CE) stands as a promising framework for reshaping business practices, notably within the fashion industry, which is renowned for its considerable environmental and social impacts. This industry ranks among the most significant contributors to global waste, compounded by its environmental and social challenges.

Historically, the fashion industry has treated clothing as "disposable," a trend exacerbated by the global reach of "fast fashion." Over the past 15 years, this trend has been further accentuated due to increasing demand worldwide from a middle class with higher disposable income, leading companies to double their production in the same period.[4]

This rise has amplified the sector's environmental impact, prompting critiques from various stakeholders, including NGOs like the Ellen MacArthur Foundation, pushing the industry towards more sustainable practices.

In response, the fashion sector is actively transitioning towards a circular paradigm that prioritizes the principles of sustainability from the sourcing of raw materials to the end of the product lifecycle. This shift sees companies establishing transparent collaborations with environmentally conscious suppliers and manufacturers, leading to a newfound emphasis on innovative designs and packaging that aim to minimize waste and preserve ecological integrity.

Consequently, organizations have been particularly influential in shaping and promoting the CE practices in the fashion industry, such as (see figure 1.3):

- *Sourcing Sustainable Fibers*: This practice involves obtaining raw materials that are eco-friendly, such as organic cotton, which is grown without harmful pesticides or genetically modified seeds, or recycled polyester, which is made from existing plastic products. The aim is to reduce the environmental impact from the very start of the production process.
- *Textile Production and Design*: At this stage, consideration is given to how textiles are made and garments are designed. Emphasis is placed on designing for longevity, which means clothes are made to last longer and potentially be updated or altered instead of discarded. It also incorporates the use of sustainable materials and eco-friendly manufacturing processes.

[4] Ellen Macarthur Foundation. 2017. *A New Textiles Economy: Redesigning Fashion's Future.*

- *Manufacturing and Other Production Processes*: This focuses on how clothing is produced. It seeks to make the production process more sustainable through the use of renewable energy, reducing water consumption, and minimizing waste. Techniques might include closed-loop systems where waste products are reused.
- *Distribution*: Once the garments are made, they need to be distributed to retailers and customers. Sustainable distribution tries to minimize the carbon footprint of these logistics, perhaps by using transportation methods that produce lower emissions, like rail or ship, instead of trucks or airplanes.
- *Consumption (Leasing/Buying)*: This segment looks at how consumers acquire clothing. New business models such as leasing or renting clothes can reduce the amount of clothing that needs to be produced. Buying sustainable fashion supports brands that are mindful of their environmental impact.
- *Wearing the Garments*: The focus here is on the use phase of the garment's life. It involves consumers taking actions that extend the life of their clothes, such as better care, repair, and adjustments, rather than buying new items.
- *Repairing and Upcycling*: When garments are damaged or no longer wanted, they can often be repaired or repurposed instead of thrown away. Upcycling involves creatively transforming clothing into new items, thereby extending their useful life.
- *Recycling*: At the end of a garment's life, recycling involves breaking down the materials to create new fibers that can be reused in new textile products, thus keeping the materials in use and out of landfills.

Figure (1.3): Circular Fashion Economy, Retail Consulting & Advisory. (n.d.)

By adopting these practices, the fashion industry can create a more sustainable lifecycle for clothing, which reduces waste and lessens the industry's overall environmental impact. These practices could significantly enhance the sustainability of the fashion industry, potentially enabling up to 95% recycling of textiles currently destined for landfills.[5]

As more brands rethink their business models in terms of sustainability and circularity, they redesign their strategies, supply chains, and procedures to align with these principles, marking a crucial step towards reducing the industry's environmental footprint, particularly in light of its classification by the UN Conference on Trade and Development (UNCTAD) as the world's second most polluting sector.

1.3 Importance of Circular Economy in Sustainable Fashion

"Sustainability" when used in reference to the fashion business, primarily refers to mitigating negative environmental effects throughout the lifecycle of clothing, its production, usage, and eventual disposal. The sector's pivot toward the Circular Economy (CE) represents a crucial response to these sustainability challenges, moving away from the disposable culture prevalent in today's "fast fashion" environment.

In particular, a set of guidelines that businesses can adhere to integrate CE principles effectively, known as the "ReSOLVE approach" [6] have been recently adopted:

- *Regenerate*: Revitalize and replenish natural resources by preserving and enhancing the health of ecosystems and by returning organic nutrients to the environment and natural cycles following their separation from technical components.
- *Share*: Seeks to extend the lifespan of products by promoting asset sharing through collaborative models or exchange platforms, and by reusing assets until they hold value, facilitated by reselling channels.
- *Optimize*: Enhance the efficiency of logistics systems and optimize their performance to maximize the duration of product usage. This involves prioritizing maintenance, improving quality, and designing products for longevity. Additionally, it entails reducing resource consumption through increased efficiency and waste reduction.

---

[5] Moorhouse & Moorhouse. (2017). *Sustainable Design: Circular Economy in Fashion and Textiles. The Design Journal 20: 1948–59.*
[6] Ellen MacArthur Foundation, *Growth within: A circular economy vision for a competitive Europe (2015).*

- *Loop*: Maintain the utilization of products and materials through the establishment of closed loops, the remanufacturing and refurbishment of products and components, and recycling efforts.
- *Virtualize*: Entails digitizing products and providing their utility virtually. This involves transitioning from physical products to service-based offerings and replacing brick-and-mortar stores with online platforms to enable remote service provision.
- *Exchange*: Utilize renewable resources and technologies, opting for sustainable materials and energy sources, and adopting innovative technologies that prioritize service delivery over traditional product-centric approaches.

In an era marked by rapid digital innovation, technology acts as a cornerstone in transitioning towards a circular economy. Various technologies, such as new materials, cloud computing, 3D printing, among others, are instrumental in supporting the principles and implementation of the Circular Economy and the ReSOLVE approach.

The trend of *sustainable fashion* is on the steady rise, particularly among Generation Z (ages 10-25), who are increasingly cognizant of the detrimental effects on the environment. This rising consumer consciousness is compelling various industries to reevaluate and revamp their manufacturing practices. Indeed, sustainability has emerged as a mega trend in the fashion industry, as businesses strive to meet this demographic's expectations.

Moreover, some macro trends are reshaping consumer demand and underpinning the need for sustainable and innovative business models as alternatives to the fast fashion paradigm[7]:

1. *Consumer Awareness:* Growing demand for eco-friendly products and the proliferation of sharing and exchange platforms. Social media plays a crucial role in facilitating social interactions and supporting online product and service transactions. Notably, the surge in e-commerce development stands out as a significant trend in the fashion sector.

[7] Todeschini, B. V., Cortimiglia, M. N., Callegaro-de-Menezes, D., & Ghezzi, A. (2017). *Innovative and sustainable business models in the fashion industry: Entrepreneurial drivers, opportunities, and challenges. Business horizons, 60(6), 759-770.*

2. *Circular Economy Trend:* The rise of the circular economy trend, recognized as a strategic area of innovation for the textile and clothing sector's future development. It aims to *prolong the lifespan of textile and clothing products through recycling and reuse.8*
3. *Corporate Social Responsibility (CSR):* Voluntary integration of social and environmental concerns into business operations and stakeholder relations.[9]
4. *Sharing Economy:* transition from ownership to access, as seen in collaborative and access-based consumption approaches. Collaborative consumption offers an efficient means to align individual needs with available resources.
5. *Technological Advancements:* The fashion sector increasingly intersects with the digital realm, with new applications of AI enhancing transparency and traceability throughout the supply chain.

Transitioning towards a circular system not only signifies a more economically viable production method but also presents an opportunity for brands to innovate in fabric design and deepen their commitment to sustainability. It's a shift that promises to reshape the fashion landscape, creating a harmonious balance between industry ambitions and environmental stewardship.

To fully grasp the importance of the Circular Economy (CE) in sustainable fashion, it is vital to revisit the most widely accepted definition of sustainable development as outlined in the 1987 Brundtland Report by the World Commission on Environment and Development:
"*Sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs.*" [10] This concept of sustainable development is at the core of the circular economy, especially within the fashion industry, emphasizing the necessity for production and consumption processes that respect the principle of solidarity—not only among contemporaneous stakeholders but extending to future generations as well. The circular economy in fashion is an embodiment of this, seeking to balance economic viability with environmental integrity and social equity.

---

[8] ETP Fibre Textiles Clothing. (2016). *Towards a 4th Industrial Revolution of Textiles and Clothing -Strategic Innovation and Research Agenda for the European Textile and Clothing Industry.*
[9] European Commission. (2010). *Corporate Social Responsibility (CSR).*
[10] Brundtland Report. (1987). *World Commission on Environment and Development.*

A landmark in this field was the publication of the "Energy Analysis" [11] manual by Boustead and Hancock in 1979, which laid down a systematic method for performing Life Cycle Assessment (LCA). This methodology aims to objectively evaluate the environmental impact of a product, process, or activity by tracking the energy and materials consumed and the waste generated.

Throughout the 1980s, LCA evolved as an essential tool, enhancing various productive activities, and adopting several names, including Life Cycle Analysis, Cradle to Grave Analysis, and Eco Balance. The official term "Life Cycle Assessment" was established in 1990 at a SETAC[12] conference in Vermont, USA, defining LCA as a comprehensive process that includes every stage of a product's lifecycle from raw material extraction to final disposal.

This same conference also introduced a structured methodology for LCA that involves three main cyclic phases, setting a standard framework still used today. Subsequently, a range of manuals, texts, tools, and databases were developed to aid the practical application of LCA in the industry. This led to the formulation of the first ISO standards for LCA in 1997, which were later updated in 2006 (ISO 14040, ISO 14044).[13]

Since 2003, the European Union has actively promoted LCA to lessen environmental impacts and enhance product and industrial performance. This support was emphasized in the European Commission's 2003 Communication on Integrated Product Policy, which highlighted LCA's importance for helping small and medium-sized enterprises create sustainable products. Moreover, the 2008 European Commission[14] communication on "Sustainable Consumption and Production" reinforced LCA's role as a crucial tool for promoting sustainable development.

---

[11] Boustead, I., & Hancock, G. F. (1979). *Energy Analysis.* This seminal text first introduced a systematic procedure for conducting Life Cycle Assessment (LCA), which remains foundational in the field.

[12] Society of Environmental Toxicity and Chemistry (SETAC). (1991). *Definition and history of Life Cycle Assessment.*

[13] International Organization for Standardization (ISO). (2006). *ISO 14040: Environmental management - Life cycle assessment - Principles and framework* and *ISO 14044: Environmental management - Life cycle assessment - Requirements and guidelines.*

[14] European Commission. (2008). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan.*

This policy aimed to improve product life cycles, encourage better products and technologies, and ensure consumers have access to clear product information.

Today, LCA remains a vital and reliable tool for measuring the environmental performance of production processes, essential for making informed decisions in sustainability.

2.1 Understanding Life Cycle Assessment

LCA is a powerful, methodical, and objective tool, capable of assessing environmental incidence of products, processes or activities including all stages of its life cycle and all its possible impacts without geographical, functional, or temporal limits. ("Life cycle assessment of MSF, MED and RO desalination technologies") The LCA methodology adopts a "Cradle-to-Grave" perspective, recognizing that every stage in a product's or activity's life cycle bears responsibility for its environmental impact. In particular, LCA aids researchers in analyzing potential environmental interactions across diverse activities, from raw material extraction and energy production to product manufacturing, usage, recycling, and disposal. (see Figure 2.1).

This comprehensive approach broadens the scope of LCA to encompass diverse processes, activities, and services, enabling a thorough comprehension of environmental factors. By evaluating impacts across the entire life cycle, LCA enables a more precise assessment of environmental trade-offs when comparing different products and processes. This comprehensive scope proves invaluable in preventing the transfer of problems, such as from one phase of the life cycle to another, from one geographic region to another, or from one environmental issue to another.

The Life Cycle Assessment (LCA) examines a product's journey through four interconnected stages, each integral to understanding its environmental impact. It begins with raw material acquisition, where resources are extracted or harvested from nature, potentially leading to habitat destruction, pollution, and resource depletion. The production stage follows, involving the processing of raw materials into final products through various manufacturing processes, energy consumption, and transportation. Here, environmental impacts such as air and water pollution, energy use, and waste generation may occur. As the product reaches consumers, the use phase begins, encompassing its operation, maintenance, and eventual disposal. During this period, energy consumption, emissions, and waste management play significant roles in the product's overall environmental footprint. Finally, the product reaches its end-of-life stage, where disposal methods like landfilling, recycling, or incineration are employed, each carrying

its own set of environmental consequences, including pollution, greenhouse gas emissions, and resource recovery. By examining these stages holistically, LCA offers valuable insights into a product's environmental impacts, informing decision-making processes and facilitating the adoption of more sustainable practices across its entire life cycle.

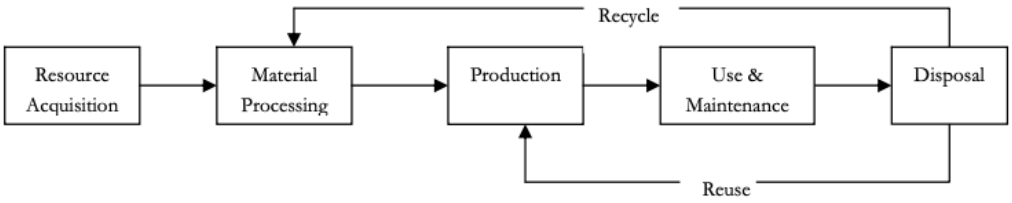

Figure 2.1 Generic life cycle stages (arrows represent transportation) from Cradle to Grave.

2.2 Application of LCA in Sustainability Studies

The application of Life Cycle Assessment (LCA), as defined by ISO 14040, involves *"compiling and evaluating the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle".* [15] This process is structured into four distinct phases (see Figure 2.2):

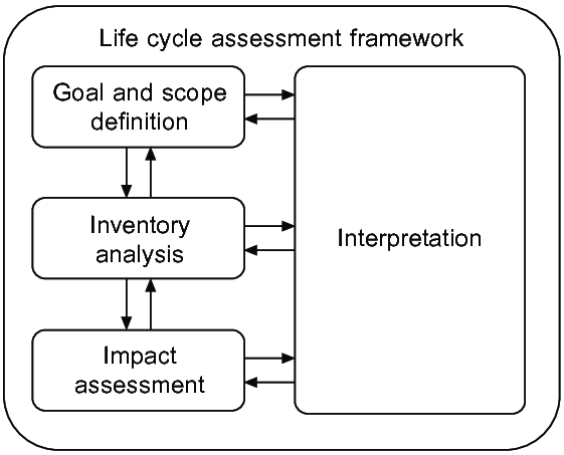

Figure (2.2.) Stages of an LCA according EN ISO 14040.

a) *Goal and Scope Definition Phase:* This initial phase establishes the objectives and boundaries of the LCA study. It determines the specific goals to be achieved and the scope of the analysis, including the system boundaries and level of detail. The depth and breadth of the LCA can vary significantly depending on the study's purpose.

[15] International Organization for Standardization (ISO). (2006). *ISO 14040: Environmental management - Life cycle assessment - Principles and framework*

b) *Inventory Analysis Phase:* Also known as the life cycle inventory (LCI) phase, this stage involves compiling comprehensive input and output data related to the system under study. Data collection is essential to meeting the defined study goals and providing a basis for subsequent analysis.

c) *Impact Assessment Phase:* In this phase, known as the life cycle impact assessment (LCIA), additional information is generated to assess the environmental significance of the LCI results. Various impact categories, such as greenhouse gas emissions, water pollution, and resource depletion, are evaluated to better understand the overall environmental footprint of the product system.

d) *Interpretation Phase:* The final phase of the LCA procedure involves summarizing and discussing the results obtained from the LCI and LCIA phases. This information serves as the basis for drawing conclusions, making recommendations, and informing decision-making processes in alignment with the goals and scope defined at the outset of the study.Therefore, Figure 2.2 illustrates the sequential flow of these phases in an LCA study, highlighting the structured approach followed to comprehensively assess the environmental impacts of a product system throughout its life cycle.

2.3 Significance of LCA in Assessing Environmental Impacts

What are the environmental consequences associated with a bicycle, a laptop, or a salad when considering the entirety of their life cycles, from production and usage to eventual disposal?
By exploring this question, we can uncover the significance of Life Cycle Assessment (LCA) in understanding and addressing environmental impacts across a diverse range of products and activities.

Life Cycle Assessment (LCA) stands as a pivotal instrument in evaluating environmental impacts across a spectrum of products, processes, and activities. Through its comprehensive methodology, LCA offers stakeholders a profound understanding of the environmental ramifications associated with every phase of a product's life cycle. This insight empowers decision-makers to steer towards sustainability, supporting initiatives and shaping policies that pave the way for a greener future.

The significance of LCA extends beyond mere assessment; it delves into the meticulous classification and characterization of environmental impact categories, a crucial step in the analysis process. This involves assigning inventory data to specific impact categories like CO2, NOx, SOx, CH4, NH3, PO4, and HCFC. Subsequently, the characterization of this data into impact categories such as eutrophication potential, global warming potential, ozone layer depletion, acidification potential, photochemical oxidation, non-carcinogenic respiratory effects, land use, and water use effects is carried out using specialized software like OpenLCA (ISO, 2006).

These meticulously chosen impact categories are not arbitrary but are based on the recommendations of esteemed environmental authorities like the United States Environmental Protection Agency (USEPA). Recognizing their significance, stakeholders employ LCA to address the most impactful aspects of environmental sustainability, as emphasized by Corporation & Curran (2006).

In essence, the integration of LCA into decision-making processes and policy formulation signifies a commitment to sustainability. It enables stakeholders to navigate complex environmental challenges, identify areas for improvement, and implement targeted measures to mitigate adverse impacts. By leveraging the insights garnered from LCA, stakeholders can chart a course towards a more sustainable and resilient future for generations to come.

Additionally, when examining the environmental consequences associated with commonplace items like bicycles, laptops, or salads, LCA proves to be invaluable. These seemingly disparate products share a common thread—their life cycles encompass production, usage, and eventual disposal, each stage carrying its own set of environmental impacts. LCA offers a robust framework for understanding and addressing these impacts comprehensively. For instance, a bicycle, often heralded as a sustainable mode of transportation, may conceal a web of environmental challenges, from raw material extraction to end-of-life disposal. By conducting an LCA, stakeholders can identify opportunities for optimization, reduce energy consumption, and promote recycling initiatives, thus minimizing the bicycle's overall environmental footprint. Similarly, laptops and salads undergo intricate processes involving resource extraction, manufacturing, distribution, and disposal, each contributing to their environmental footprint. Through LCA, stakeholders can assess trade-offs, optimize design choices, and

implement sustainable practices, ultimately guiding the development of more eco-friendly products and practices.

In conclusion, Life Cycle Assessment (LCA) serves as a powerful tool for assessing environmental impacts across diverse products, processes, and activities. By providing a comprehensive understanding of the environmental consequences associated with each stage of a product's life cycle, LCA enables stakeholders to make informed decisions, support sustainability initiatives, and guide policy development towards a more sustainable future.

Chapter 3: Manteco SpA: A Case Study

3.1 Overview of Manteco SpA

Manteco SpA is an innovative leader in the textile industry, renowned for its dedication to sustainability, circular economy principles and the “Made in Italy” concept. Founded in 1943 and based in Prato, Italy, the company has a long history of producing high-quality wool fabrics. Manteco began its journey in the 1940s by reusing military wool blankets, re-spinning the fibers without any new dye to create heavy blankets. This family-run company, born out of the necessity to utilize scarce resources during the Second World War, has grown into a leader in the sustainable textile industry. Initially, Italy faced a shortage of sheep pastures for textile production, prompting Manteco to innovate by revaluing the high-quality wool from military blankets. This resourcefulness laid the foundation for their commitment to sustainability and circular economy principles.

Today, Manteco is renowned for its dye-free recycled wool and other sustainable textiles. The company's innovative approaches have led to significant environmental achievements; for instance, in 2021 alone, Manteco saved 817,722 wool garments from landfills[16], giving them new life. As demand for their products increased, Manteco scaled up its operations, continuously evolving to meet the growing needs of the market while maintaining a strong focus on sustainability. Through relentless innovation and a deep-rooted commitment to environmental stewardship, Manteco has set new standards in the textile industry, proving that sustainable practices and high-quality products can go hand in hand.

The "Made in Italy" concept is intrinsic to Manteco's identity. This quality mark not only refers to production in Italy but also represents artisanal excellence, attention to detail, and technological innovation. Manteco embodies these values by using traditional techniques combined with modern technologies to create fabrics that are globally appreciated for their quality and sustainability.

---

[16] Circle Economy Foundation. "Manteco - Recycling Textiles Without the Use of Dyes." Knowledge Hub, 29 August 2022, [https://knowledge-hub.circle-economy.com/circleeconomy/article/19711?n=Manteco---Recycling-textiles-without-the-use-of-dyes].

Manteco's product range is diverse, catering to various segments of the textile market, including fashion, interior design, and industrial applications. Notable products include:

- **ReviWool®**: A low-impact virgin wool designed to be environmentally friendly from the outset, using wool that is sourced and processed with a focus on reducing environmental impacts.
- **MWool®**: An innovative recycled wool fiber made from both pre-consumer and post-consumer textile waste. MWool® exemplifies Manteco's commitment to the circular economy by significantly reducing carbon footprint, water usage, and energy consumption compared to conventional virgin wool.
- **Eco-Wool Fabrics**: Wool fabrics produced using environmentally friendly processes and materials, incorporating sustainable practices in every step of their production.
- **Custom Sustainable Textiles**: Manteco offers a range of customizable sustainable textile solutions for fashion brands looking to incorporate eco-friendly materials into their products, helping them meet specific sustainability goals.

Manteco's operations leverage both traditional techniques and modern technologies. A significant aspect of the company's strategy is its focus on recycling and reusing materials, which not only minimizes waste but also reduces the demand for virgin resources, thereby lessening the overall environmental footprint of their products.

In recognition of its sustainability efforts, Manteco received the prestigious Climate Action Award[17] at the CNMI Sustainable Fashion Awards 2023. The company has demonstrated substantial emissions reductions by using recycled content in half of their total fabric production. For instance, more than 1,500 tons of MWool® fibers produced in 2022 led to a reduction of 118,554 tons of CO2-eq emissions.[18] Therefore, these Manteco® fabrics use significantly less water and energy in the production process.

[17] CNMI Sustainable Fashion Awards. (2023). Climate Action Award. Retrieved from CNMI Sustainable Fashion Awards.

[18] Manteco S.p.a. "Manteco is the Winner of 'The Climate Action Award' at Sustainable Fashion Awards 2023." Manteco, 2023, https://manteco.com/manteco-is-the-winner-of-the-climate-action-award-at-sustainable-fashion-awards-2023/.

In this regard, Figure 3.1[19] summarizes the material and resource savings achieved thanks to MWool®, ReviWool®, and the color creation process without the use of chemicals for MWool® (Recype®) in the year 2022.

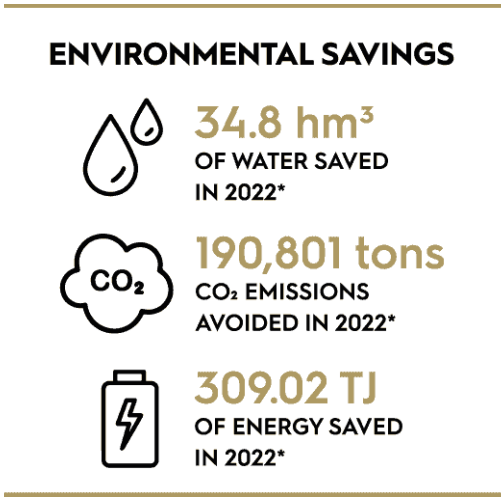

Figure (3.1): Environmental Savings

Through the use of MWool®, Manteco's next-generation recycled wool, the company saved 119,004 tons of CO2-eq, 21.86 hm3 of water, and 191.1 TJ of energy. With Recype®, Manteco's dye-free color creation process for MWool® fabrics, they saved 1,550 tons of CO2-eq, 0.26 hm3 of water, and 22.8 TJ of energy. Through ReviWool®, their low-impact virgin wool, Manteco saved 70,247 tons of CO2-eq, 12.68 hm3 of water, and 95.12 TJ of energy. Thanks to their Zero-Waste, Manteco recovered 215,372 kg of industrial wool waste, with 71.5% of this carefully sorted and reused in the production cycle. Additionally, with Project43[20], they recovered 53,600 kg of garment-making offcuts.

Manteco's sustainability efforts are closely linked to the principles of Life Cycle Assessment (LCA). By applying LCA, Manteco can comprehensively assess the environmental impacts associated with its products and identify opportunities for improvement.

For example, the LCA of MWool® involves evaluating the environmental impacts from the collection of pre- and post-consumer textile waste, through various recycling processes, to the production of the final wool fiber. This assessment covers all stages, including transportation,

[19] Manteco. (2023). Sustainability Report. Retrieved from Manteco Sustainability Report.

[20] Manteco S.p.a. "Project43." *Manteco*, 2024, https://manteco.com/project43/.

energy use, and waste management. The findings from these studies highlight the significant environmental benefits of using recycled wool, with MWool® having less than 1% of the carbon footprint and other related impacts compared to virgin wool.

By integrating LCA into its operational strategy, Manteco ensures that its products are designed and manufactured with a clear understanding of their environmental impacts. This holistic approach not only helps in reducing the overall ecological footprint but also aligns with global sustainability goals. Manteco's proactive use of LCA demonstrates its leadership in promoting transparency and accountability in the textile industry.

Manteco SpA exemplifies how a traditional industry can embrace modern sustainability practices. Through innovative use of recycled materials and the application of Life Cycle Assessment, Manteco not only produces high-quality products but also sets new standards for environmental responsibility. This holistic approach underscores Manteco's position as a pioneer in sustainable textile production.

Manteco's sustainability roadmap[21], aims to achieve continuous growth and improvement through innovative and responsible solutions. The company is dedicated to promoting the 17 Sustainable Development Goals (SDGs) of the United Nations' 2030 Agenda[22]. This commitment is outlined in their Charter of Values for Sustainability, which encompasses various aspects such as policies and objectives, traceability and sustainable supply chains, design and choice of sustainable materials, chemical risk management, climate commitment, and the well-being of people as a core part of their operations.

[21] Manteco. (n.d.). Manteco for Planet. Retrieved from https://manteco.com/manteco-for-planet/.

[22] United Nations. (2020). The 17 Goals. Retrieved from United Nations.

3.2 Sustainability Initiatives at Manteco SpA

Manteco SpA has implemented a comprehensive range of sustainability initiatives aimed at minimizing environmental impact and promoting responsible production practices. Manteco sustainability initiatives are embedded in every aspect of the company's operations, from sourcing raw materials to the final stages of product manufacturing:

- **Recycling and MWool®**
- **Energy Efficiency and Renewable Energy**
- **Water Management**
- **Chemical Management**
- **Waste Reduction and Circular Economy**
- **Social Responsibility**
- **Transparency and Certification**
- **Research and Development**

Recycling and MWool®

A cornerstone of Manteco's sustainability efforts is the extensive use of recycled materials, particularly in the production of MWool®. This initiative not only addresses waste reduction but also embodies the principles of the circular economy by transforming waste into valuable resources.

Manteco collects pre-consumer waste from spinning and garment-making processes, as well as post-consumer discarded clothes. Pre-consumer waste, which accounts for about 15% of the total, comes from tailoring and spinning processes. Tailoring waste is sourced from regions like Eastern Europe, Turkey, Italy, and North Africa, while spinning waste primarily comes from Eastern Europe and Italy.

Post-consumer waste makes up the remaining 85% and involves garments collected from special containers in the USA and Northern Europe. These garments are packed in plastic bags and transported to collection centers where non-textile items are removed. The sorted textiles

are then packed into large bales and shipped to India (85%) or Pakistan (15%). In these countries, the textiles are manually sorted by material type, and accessories like zips, buttons, and labels are removed. The processed textiles are then sent to the industrial area of Prato, Italy. In Prato, the textiles undergo further sorting by treatment type and color. This meticulous manual sorting process, although time-consuming, eliminates the need for dyeing, thereby reducing the environmental impacts associated with the dyeing process.

The textiles are then processed into recycled wool fibers through shredding or fraying. Shredding is a mechanical process that uses a machine with teeth and blades to "open" the fabric. The textiles are wetted to reduce resistance while maintaining fiber elasticity, and then dried. Alternatively, fraying, a dry mechanical process involving cylinders with sharp points, can be used. In 2019, MWool® fibers were produced using shredding (26%), fraying (70.5%), and a small portion (3.5%) came directly from spinning waste and required no additional treatment[23]. The flowchart in Figure 3.2 [24] illustrates the system boundaries of MWool®, encompassing all the processes and steps involved in the assessment. Each stage of the value chain is described in detail below.

[23] Bianco, Isabella, et al. "Life cycle assessment (LCA) of MWool® recycled Wool Fibers." *Resources* 11.5 (2022): 41.

[24] Manteco S.p.A. (2022). Life Cycle Assessment (LCA) of MWool®. Full Study. Retrieved from https://manteco.com/wp-content/uploads/2022/12/LCA-MWOOL-full-study-PDF.pdf

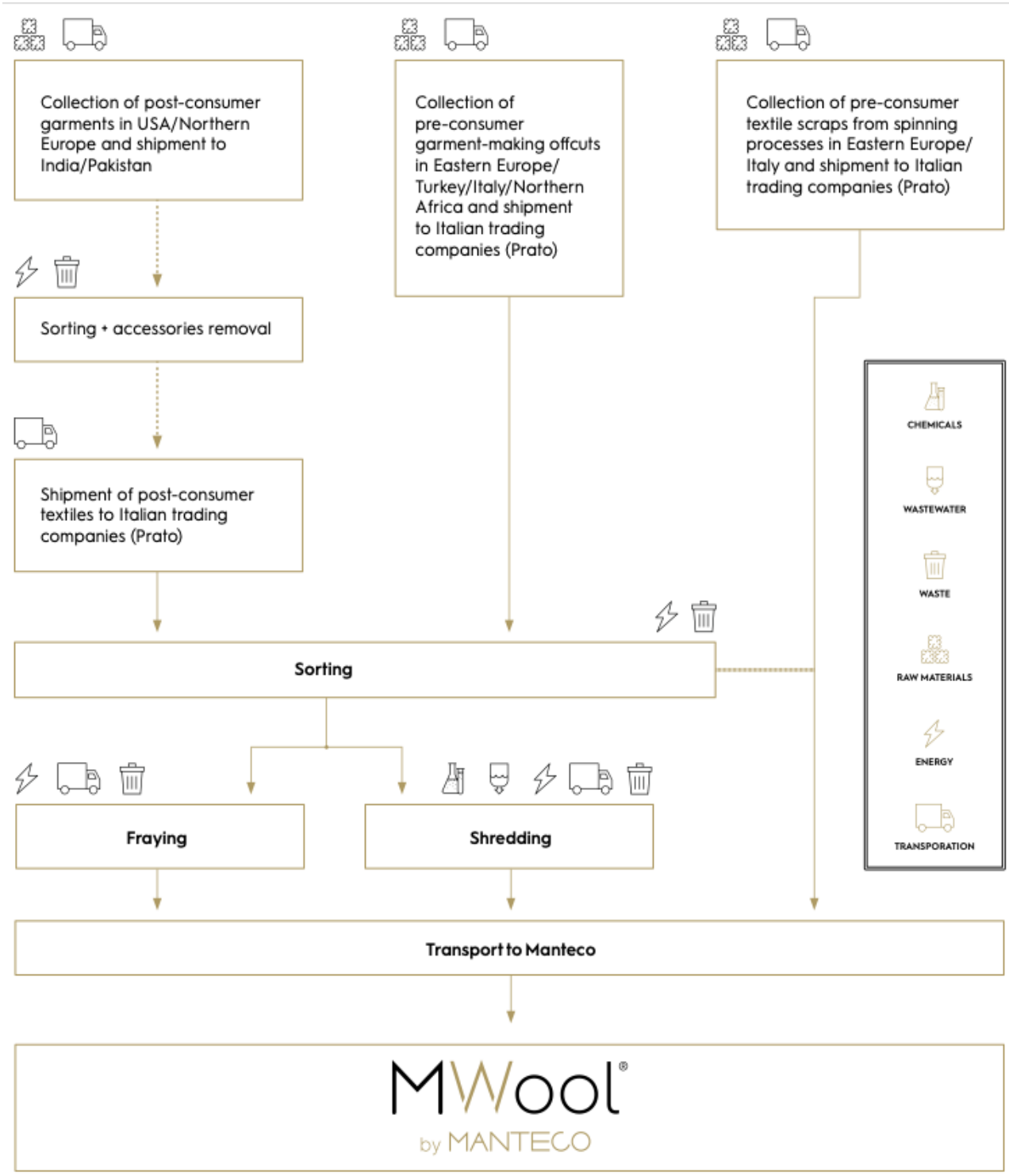

Figure (3.2). Flow chart of recycled wool fibers (MWool) production

In addition, a sensitivity analysis has been conducted on the MWool® fibers to evaluate how stable the results are when operational conditions (such as the source of waste wool and the type of treatment) are pushed toward the upper or lower range. The following scenarios represent circumstances in which Manteco occasionally operates:

- MWool® produced from 100% pre-consumer waste by spinning (not further treated)
- MWool® produced from pre-consumer waste, 100% frayed
- MWool® produced from pre-consumer waste, 100% shredded
- MWool® produced from post-consumer waste, 100% frayed
- MWool® produced from post-consumer waste, 100% shredded

The textile may be subjected to the fraying or shredding processes, depending on its condition . In addition, in some cases, waste from spinning (pre-consumer textile) are already fibers and, as a consequence, do not require any type of treatment.[25] With reference to the year 2019, the Table 1 below shows the total and relative amounts of pre- and post-consumer textiles that have been frayed, shredded, or left untreated.[26]

	QUANTITY (KG)	QUANTITY (%)
Shredded	390176	*26,1%*
Frayed	1055035	*70,5%*
Not treated	52200	*3,5%*
Total	1497411	*100%*

Table 1. Absolute and relative quantities of pre- and post-consumer textiles that have been shredded/ frayed/not treated in 2019.

The environmental benefits of MWool® are substantial. Compared to virgin wool, MWool® generates significantly fewer CO2-eq emissions—99.2% less—and consumes much less water and energy.

[25] International EPD System. (2022). “Environmental Product Declaration Manteco”. Retrieved from https://api.environdec.com/api/v1/EPDLibrary/Files/dec8cd5d-1106-4490-9280-08da3f2d2648/Data

[26] Manteco S.p.a. "LCA MWool Full Study." Manteco, May 2022, https://manteco.com/wp-content/uploads/2022/05/LCA-MWOOL-full-study-PDF.pdf.

Energy Efficiency and Renewable Energy

In addition to recycling, Manteco prioritizes energy efficiency and the use of renewable energy sources. The company's production facilities are equipped with advanced machinery that reduces energy consumption. For instance, Manteco has invested in state-of-the-art spinning and weaving technologies that optimize energy use. Moreover, the company is continuously exploring ways to integrate renewable energy into their operations, further reducing their carbon footprint. Solar panels and other renewable energy sources are being considered to power manufacturing processes, thereby decreasing reliance on fossil fuels.

Water Management

Water management is another critical area where Manteco excels. The textile industry is notoriously water-intensive, but Manteco has implemented measures to mitigate this impact. The company employs state-of-the-art water treatment systems to ensure that wastewater from the production processes is treated and reused wherever possible. This not only conserves water but also reduces pollution and aligns with broader environmental sustainability goals. Manteco's water recycling initiatives ensure that the company minimizes its freshwater usage and mitigates the impact on local water resources.

Chemical Management

Manteco is also committed to reducing the use of harmful chemicals in its production processes. The company has adopted eco-friendly dyes and finishing agents that are less harmful to the environment and human health. These chemicals are carefully selected to meet stringent environmental standards, ensuring that Manteco's products are safe and sustainable. Additionally, Manteco continuously monitors and optimizes its chemical use to minimize any potential adverse effects.

Waste Reduction and Circular Economy

Waste reduction is a fundamental aspect of Manteco's sustainability strategy, reflecting the company’s deep commitment to minimizing its environmental footprint. Beyond the innovative recycling of textile waste into MWool®, Manteco diligently reduces waste at every stage of its production processes. This begins with the optimization of cutting techniques, employing precision technology to maximize fabric utilization and significantly reduce offcuts. The company ensures that any scraps generated are meticulously collected and repurposed into new products, preventing these materials from becoming waste. Manteco's adherence to circular

economy principles is evident in its efforts to establish a closed-loop system, where every material is continuously reused and recycled within their production cycle. This approach not only minimizes waste but also conserves valuable resources, reducing the need for virgin materials and lowering the overall environmental impact. Additionally, Manteco engages in upcycling projects that transform discarded textiles into high-value products, fostering innovation and creativity while promoting sustainability. Through these comprehensive waste reduction initiatives, Manteco not only demonstrates leadership in sustainable textile manufacturing but also sets a high standard for environmental responsibility in the industry.

Social Responsibility

Manteco's sustainability initiatives extend beyond environmental considerations to include social responsibility. The company is committed to ensuring fair labor practices and maintaining high standards of worker safety and well-being. Manteco collaborates with suppliers who share their commitment to ethical practices, ensuring that every step of the supply chain adheres to these principles.

Transparency and Certification

Transparency is a key component of Manteco's approach to sustainability. The company regularly conducts and publishes detailed Life Cycle Assessments (LCAs) of its products, providing stakeholders with a clear understanding of the environmental impacts associated with their production. Additionally, Manteco's sustainability efforts are validated through various certifications, such as the Global Recycled Standard (GRS)[27] and the Environmental Product Declaration (EPD)[28]. These certifications verify that Manteco's products meet high environmental and social standards.

Research and Development

Continuous improvement is a hallmark of Manteco's sustainability journey. The company invests heavily in research and development to find new ways to reduce its environmental footprint. This includes exploring innovative recycling technologies, developing new sustainable materials, and improving production processes. By staying at the forefront of

[27] Global Recycled Standard (GRS). Retrieved from https://textileexchange.org/standards/global-recycled-standard/

[28] Environmental Product Declaration (EPD). Retrieved from https://environdec.com/

sustainability innovation, Manteco ensures that it can adapt to evolving environmental challenges and continue to lead the industry in responsible practices.

Therefore, Manteco SpA's sustainability initiatives demonstrate a deep commitment to environmental stewardship and social responsibility. Through comprehensive recycling programs, energy and water conservation measures, responsible chemical management, waste reduction efforts, and a focus on transparency and continuous improvement, Manteco sets a high standard for sustainability in the textile industry. These initiatives not only reduce the company's environmental impact but also contribute to a more sustainable future for the industry as a whole.

3.3 Circular Economy Strategies at Manteco SpA

Manteco SpA has fully embraced circular economy principles, integrating them into every aspect of its operations to enhance sustainability and reduce environmental impact. The company has implemented several innovative strategies to support a circular economy, transforming the way textiles are produced, used, and disposed of:

1. **Closed-loop recycling**
2. **Eco-design and Innovation**
3. **Resource Efficiency**
4. **Upcycling**
5. **Sustainable Supply Chain Management**
6. **Consumer Engagement and Education**
7. **Innovative Production Techniques**
8. **Collaborations and Partnerships**
9. **Continuous Improvement and Innovation**

1. Closed-loop recycling

Central to Manteco's strategy is its closed-loop recycling system, which ensures that materials are continuously reused in a cycle of production and consumption (Figure 3.3)[29].

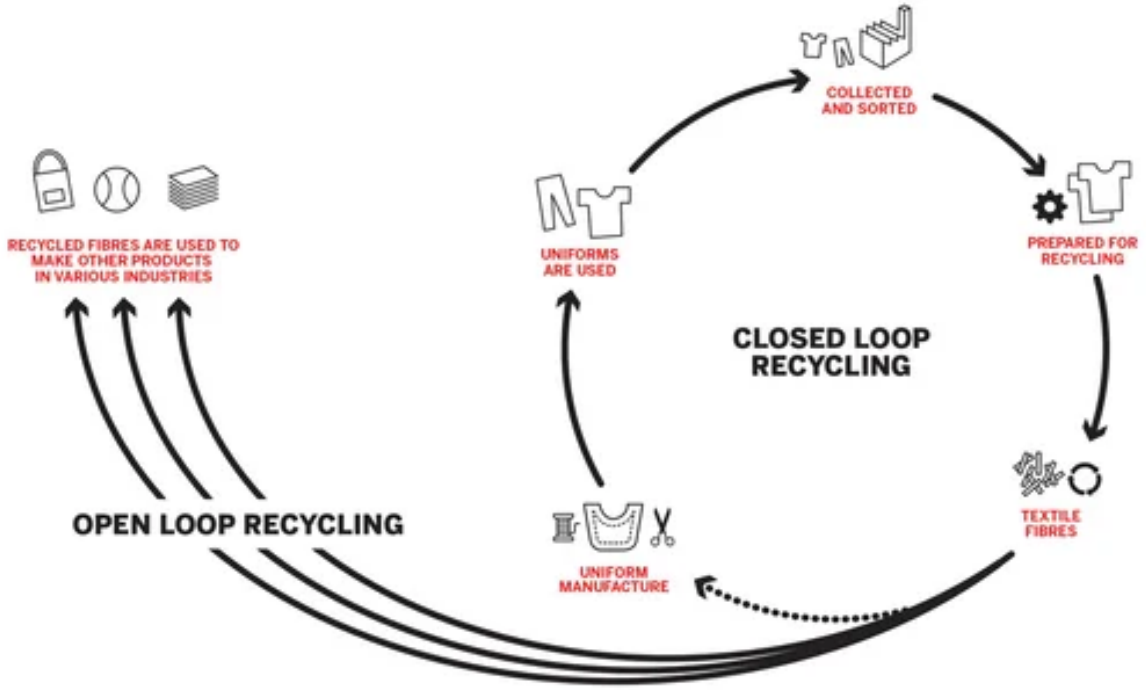

Figure (3.3): Closed Loop textile recycling

This innovative approach begins with the collection of garments, which are meticulously sorted and prepared for recycling. The garments are then processed into pulp, which serves as the raw material for creating new fibers. These fibers are spun into yarn, woven into fabrics, and used to manufacture new garments. Once these garments reach the end of their useful life, they are collected again, sorted, and reintroduced into the recycling process, thereby reducing waste and conserving resources.

A prime example of Manteco's commitment to circular economy strategies is the previously mentioned Project43[30]. This unique, traceable, and revolutionary project aims to optimize existing materials and promote "Zero Waste" practices (see Figure 3.4). Project43 focuses on recovering offcuts from the garment manufacturers that use Manteco's fabrics and regenerating them into new luxury fabrics. By participating in Project43, brands and designers can optimize

[29] Total Uniform Solutions. "The Future Lies in Closed-loop Textile Recycling." Uniform Blog, 15 July 2023, [https://blog.uniform.com.au/the-future-lies-in-closed-loop-textile-recycling].
[30] Manteco S.p.a. (2024). Project43.

existing resources and recycle their garment-making offcuts, contributing to the creation of circular, high-end textiles.

Most of Manteco's wool fabrics, whether virgin or recycled, are designed as mono-fiber or bi-fiber. This design choice allows for easier mechanical recycling into new MWool® fibers, facilitating the production of circular textiles. This approach ensures that the principles of circular fashion are embedded right from the start, enabling brands and designers to participate in sustainable practices by recycling offcuts and optimizing the use of resources.

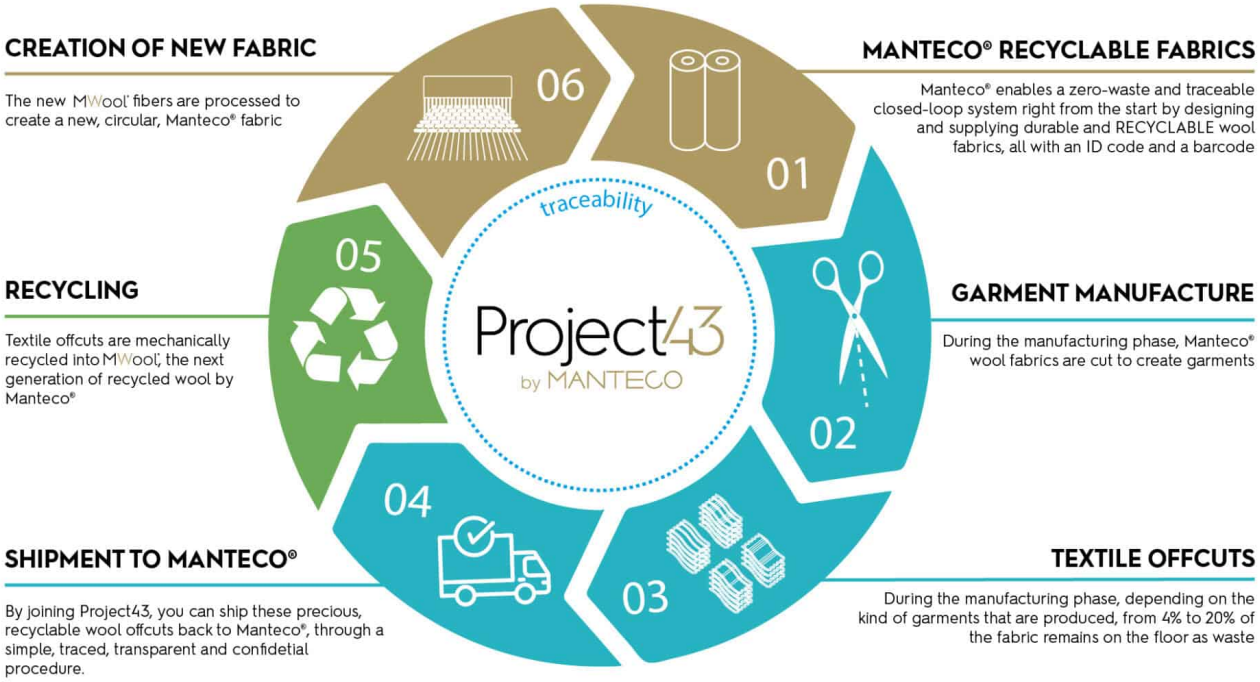

Figure (3.4): The traceable circular economy project for pre-consumer garment making offcuts coming from Manteco® fabrics.

2. Eco-design and Innovation

In addition to recycling, Manteco focuses on extending the lifecycle of its products through robust design and production techniques that ensure durability. By promoting repair and reuse, the company encourages customers to prolong the life of their garments, reducing the need for frequent replacements. Moreover, Manteco integrates circular economy principles into the design phase of its products, emphasizing the creation of durable, high-quality items designed for longevity and ease of recycling at the end of their useful life. By incorporating design-for-disassembly principles, Manteco ensures that products can be easily taken apart and recycled, allowing high-quality materials to be efficiently recovered and reused. This approach maintains

the circular flow of materials, as evidenced by a 2018 survey by the Sustainable Coalition[31], which indicated that products designed with longevity and recyclability in mind can extend their lifecycle by up to 30%, thereby reducing the need for new raw materials and minimizing waste.

3. Resource Efficiency

Resource efficiency is another cornerstone of Manteco's circular economy strategy. The company employs advanced manufacturing technologies and processes to optimize the use of raw materials and minimize waste. For example, precision cutting techniques significantly reduce fabric offcuts, and any leftover materials are repurposed into new products. This efficient use of resources reduces the environmental impact of production and conserves natural resources.

4. Upcycling

Manteco SpA can enhance its circular economy efforts by implementing an upcycling strategy that transforms textile waste into high-quality new products. This involves collecting and sorting textile waste, developing innovative upcycled designs, and collaborating with designers and educational institutions. Consumer engagement through awareness campaigns and workshops, along with marketing the environmental benefits of upcycled products, can boost Manteco's brand value. Rigorous quality control and continuous monitoring will ensure high standards and help increase the volume of upcycled materials. This strategy reduces waste, conserves resources, and strengthens Manteco's reputation as a sustainability leader, attracting eco-conscious consumers and fostering loyalty.

5. Sustainable Supply Chain Management

A key aspect of Manteco's circular economy strategy is sustainable supply chain management. Manteco works closely with its suppliers to ensure that raw materials are sourced sustainably and that production processes are environmentally friendly. This includes setting stringent criteria for supplier selection and regularly auditing suppliers to ensure compliance with Manteco's sustainability standards. Manteco supply chain is called MSystem[32] (3.5), a unique

[31] Sustainable Apparel Coalition. "Sustainable Apparel Coalition." *Higg Product Tools*, 2023, https://product.higg.org/page/sustainable-apparel-coalition.

[32] Manteco S.p.a. "MSystem: The Creation of High-end Fabrics Since 1943." Manteco, 2024, [https://manteco.com/msystem/].

network formed by 50 artisans involved in the creation of Manteco's high-end fabrics, located within an area of 10 miles. The company operates in Europe’s biggest textile district, where thousands of subcontractors specialize in different textile phases. Since 1943, generation after generation, Manteco has created and enhanced its supply chain of highly selected partners by carefully maintaining the fundamental values of the company: quality, transparency, traceability, and sustainability. Each partner leverages its skills, know-how, and machinery to ensure that the final products meet the highest standards and represent the quality and reliability of Made in Italy.

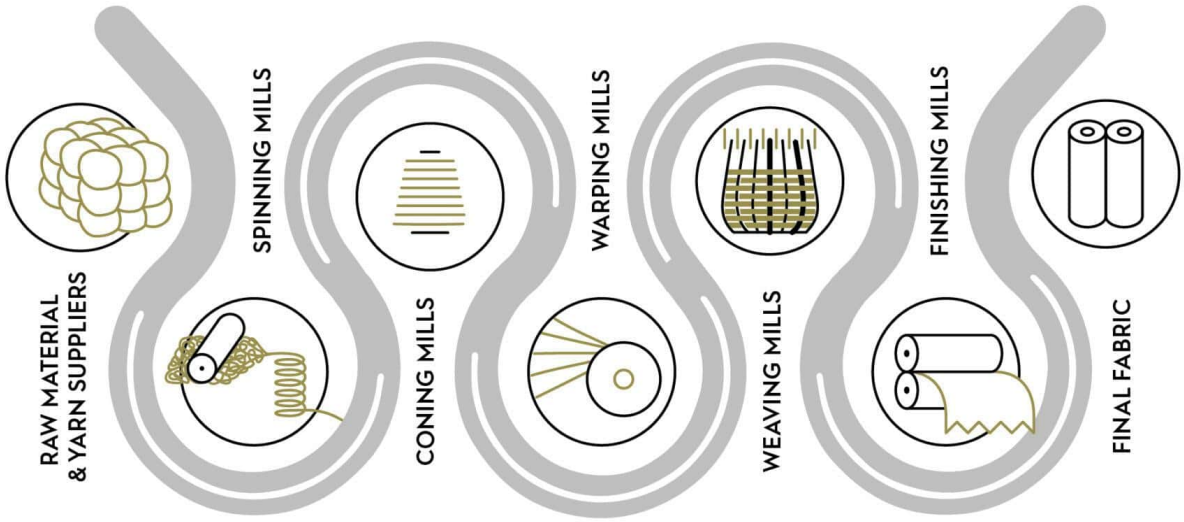

Figure (3.5): Our traceable, transparent, and zero-mile supply chain

6. Consumer Engagement and Education

Consumer engagement and education are also vital components of Manteco's strategy. The company actively promotes circular economy principles and sustainable practices among its customers. By educating consumers on the importance of recycling, repair, and reuse, and offering programs to facilitate the return and recycling of used garments, Manteco fosters a community of environmentally conscious consumers.

7. Innovative Production Techniques

Manteco employs state-of-the-art technologies to ensure that the recycled fibers are processed with minimal environmental impact. The company's production techniques include the use of energy-efficient machinery and renewable energy sources. The company invests heavily in research and development to explore new recycling technologies, sustainable materials, and

innovative production methods. This ongoing commitment ensures that Manteco can adapt to evolving environmental challenges and maintain its leadership in responsible production.

8. Collaborations and Partnerships

Manteco's success in circular economy practices is also attributed to its strategic collaborations with various stakeholders, including suppliers, customers, and industry partners. These collaborations focus on promoting circularity throughout the value chain, from raw material sourcing to end-of-life product management. Manteco works closely with its partners to develop new recycling technologies and improve the sustainability of textile products. A 2021 survey by McKinsey & Company[33] revealed that companies engaging in collaborative efforts along the supply chain are more likely to achieve their sustainability goals. Manteco's partnerships reflect this trend, emphasizing the importance of collective action in driving circular economy initiatives. Manteco SpA has become a benchmark for circular fashion and luxury through strong collaborations and partnerships. As a member of the Ellen MacArthur Foundation and a partner of the SDA Bocconi Monitor for Circular Fashion, Manteco actively engages with leading organizations to promote and implement circular economy principles. These collaborations enable Manteco to uphold and advance its sustainability goals, ensuring high-quality and environmentally responsible textile production.

9. Continuous Improvement and Innovation

Manteco’s commitment to continuous improvement and innovation is exemplified by its innovative approach to colorimetric measurement (Figure 3.6). By adopting advanced colorimetric technologies, Manteco ensures precise color consistency and quality in its textile products. This not only enhances the aesthetic appeal and marketability of their products but also optimizes the dyeing process to reduce waste and resource consumption. The precise measurement and control of color help in minimizing the environmental impact associated with dyeing, as it allows for more efficient use of dyes and chemicals, thereby reducing water and energy usage. This innovative approach underscores Manteco's dedication to integrating cutting-edge solutions to advance sustainability and maintain high production standards.

[33]McKinsey & Company. (2021). McKinsey Global Surveys: 2021 A Year in Review. Retrieved from https://www.mckinsey.com/~/media/mckinsey/featured%20insights/mckinsey%20global%20surveys/mckinsey-global-surveys-2021-a-year-in-review.pdf

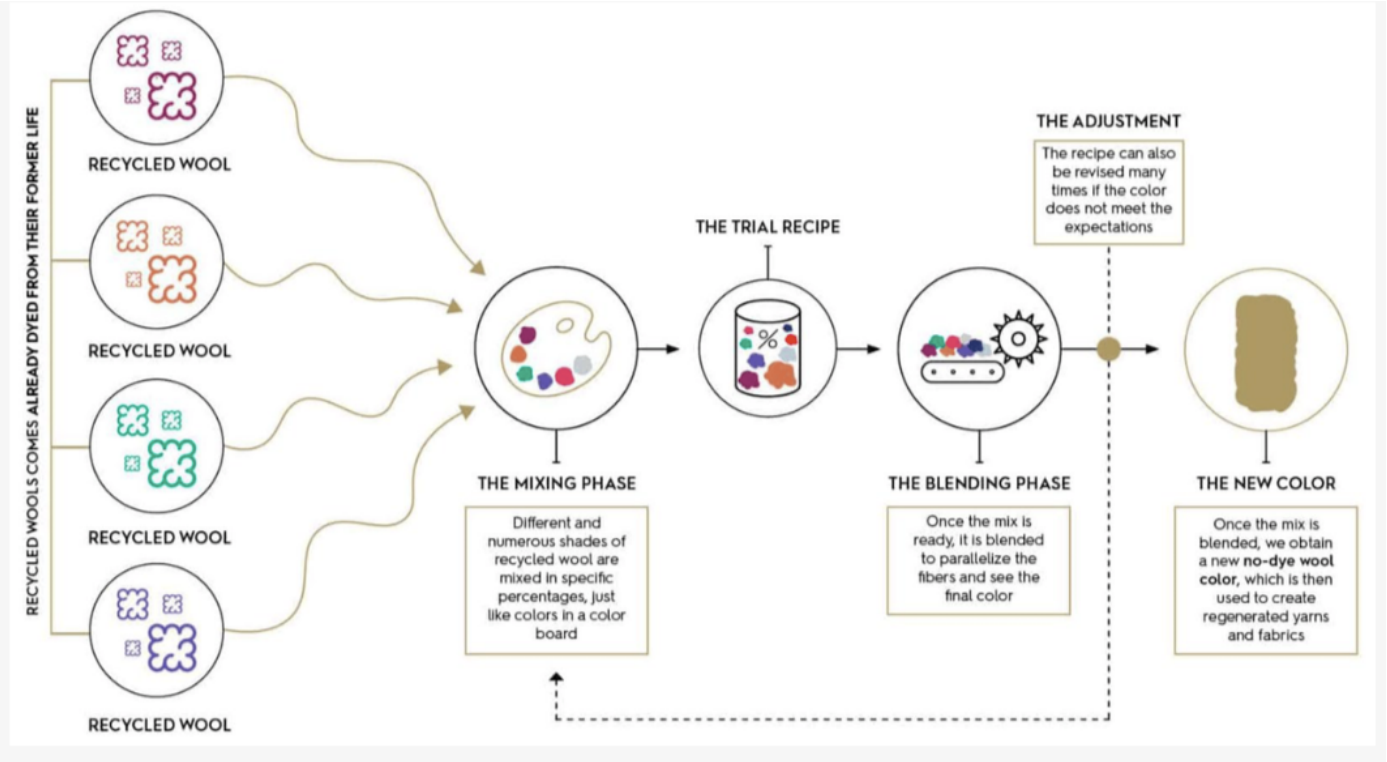

Figure (3.6): The innovative approach to the solution of colorimetric measurement adopted by Manteco S.p.A., Prato, Italy.

In summary, Manteco SpA's circular economy strategies exemplify a holistic approach to sustainability, integrating advanced recycling techniques, strategic collaborations, and innovative product design to create a closed-loop system. Through these efforts, Manteco not only minimizes waste and conserves resources but also sets a high standard for environmental responsibility in the textile industry. The company's commitment to continuous improvement and sustainability innovation underscores its leadership in promoting a circular economy.

Chapter 4: Analysis and Findings

4.1 Comparative Analysis of Circular Economy Practices in the Fashion Industry

In this section, I have conducted a comparative analysis of the circular economy practices implemented by various companies in the fashion industry:

- Manteco SpA
- H&M Group
- Patagonia
- Nike

The aim is to understand how different brands integrate circular economy principles into their operations, the strategies they employ, and the outcomes of these initiatives.

The fashion industry, recognized as one of the most polluting sectors globally, has seen an increasing adoption of circular economy practices aimed at reducing its environmental impact. Circular economy practices involve designing out waste, keeping products and materials in use, and regenerating natural systems. This analysis examines how different fashion companies have implemented these principles, comparing their approaches, successes, and challenges.

Manteco SpA, an Italian textile company, stands out for its innovative approach to recycling and upcycling wool and other fibers. The company has invested heavily in traceability and transparency, ensuring that every step of their production process is documented and environmentally responsible. Their MWool® technology allows them to produce high-quality recycled wool fabrics, which have a significantly lower environmental footprint compared to traditional wool. This commitment to sustainability is reflected in their zero-waste design principles and their policy of maintaining all production within a 10 km radius of their headquarters, which minimizes transportation emissions and supports the local economy. Manteco's products not only meet high-quality standards but also align with the growing consumer demand for sustainable fashion.[34]

In contrast, **H&M Group** has implemented a range of circular economy initiatives, including the Garment Collecting program and the Conscious Collection. The Garment Collecting

[34] Manteco. (2020). Manteco Sustainable Wool. Retrieved from [Manteco](https://manteco.com/sustainability/).

program encourages customers to return old clothes for recycling, which H&M then uses to create new products. This initiative closes the loop on textile waste, reducing the demand for virgin materials. The Conscious Collection features clothing made from sustainable materials such as organic cotton and recycled polyester. H&M's comprehensive sustainability reports provide transparency about their progress and future goals, fostering trust with environmentally conscious consumers.[35]

Patagonia, known for its robust sustainability ethos, operates the Worn Wear program, which promotes the repair, reuse, and recycling of Patagonia products. This program not only extends the lifespan of clothing but also educates consumers about the environmental benefits of reducing waste. Patagonia's commitment to using recycled polyester and organic cotton further underscores their dedication to sustainable practices. Their detailed environmental assessments of their supply chain help them maintain high standards of sustainability, contributing to their reputation as a leader in the industry.[36]

Nike has integrated circular economy principles through its Move to Zero initiative, aiming for zero carbon and zero waste. The Nike Grind program, which recycles worn-out athletic shoes into new products such as playground surfaces and sports fields, exemplifies their commitment to recycling and upcycling. Nike's use of sustainable materials like recycled polyester and Fly leather—a material made from recycled leather fibers—demonstrates their innovative approach to sustainable design. Advanced tracking and transparency systems ensure accountability throughout their production processes, reinforcing their commitment to sustainability.[37]

To illustrate the comparative effectiveness of these strategies, the following Table 2 provides a detailed comparison of the circular economy practices implemented by these companies:

[35] H&M Group. (2020). Sustainability Performance Report 2020. Retrieved from [H&M Group](https://hmgroup.com/sustainability-report/2020/).
[36] Patagonia. (2019). Environmental & Social Initiatives 2019. Retrieved from [Patagonia](https://www.patagonia.com/environmental-social-initiatives-2019/).
[37] Nike, Inc. (2019). FY18 Sustainable Business Report. Retrieved from [Nike](https://purpose.nike.com/reports).

Company	Key Strategies	Recycling and Upcycling	Sustainable materials	Transparency and Traceabilty	Consumer Engagement	Local Production
Manteco SpA	MWool® technology, zero-waste design	MWool® technology for recycled wool	Recycled wool, high-quality cotton	Detailed tracking systems and reports	Limited direct consumer engagement	100% production within 10 km of headquarters
H&M Group	Garment Collecting program, Conscious Collection	Garment Collecting program for recycling	Organic cotton, recycled polyester	Comprehensive sustainability reports	Garment Collecting program	Production mostly outsourced
Patagonia	Worn Wear program, sustainable supply chain	Worn Wear program for repair and reuse	Recycled polyester, organic cotton	Detailed environmental assessments	Worn Wear program	Mixed production locations
Nike	Move to Zero initiative, Nike Grind	Nike Grind program for recycling athletic shoes	Recycled polyester, Flyleather	Advanced tracking and transparency	Nike Grind program for recycling	Global production network

Table 2: Comparative Analysis of Circular Economy Practices of Leading Apparel Companies

From this table, we can see that while each company employs unique strategies tailored to their specific contexts, there are common themes that emerge. Recycling and upcycling are central to the circular economy practices of all the companies studied. Manteco's MWool® technology, H&M's Garment Collecting program, Patagonia's Worn Wear initiative, and Nike's Nike Grind program all focus on recycling materials to create new products, thereby reducing waste and promoting a circular flow of materials. The use of sustainable materials is another cornerstone of these practices, with each company incorporating recycled and organic materials into their products.

Transparency and traceability are also critical components of effective circular economy practices. Companies like Manteco and H&M emphasize transparency in their supply chains, providing detailed reports and tracking systems to ensure accountability. This transparency builds consumer trust and promotes sustainable practices across the industry.

Consumer engagement is another common strategy, though it varies in execution. Patagonia's Worn Wear program and H&M's Garment Collecting initiative actively involve consumers in the circular economy by encouraging them to return, repair, and recycle their clothing. This engagement not only extends the life of products but also raises awareness about sustainability. Nike engages consumers through its Nike Grind program, which encourages the recycling of athletic shoes.

Local production is a unique aspect of Manteco's strategy, setting it apart from other companies. By maintaining 100% of its production within a 10 km radius of its headquarters, Manteco ensures high-quality standards and reduces the environmental impact associated with transportation. This commitment to local production supports the local economy and reinforces the company's dedication to sustainable practices.

Implementing circular economy practices is not without challenges. Common challenges include the need for significant upfront investment in technology and infrastructure, consumer misconceptions about the quality of recycled materials, and the complexity of redesigning supply chains to be more sustainable. However, these challenges also present opportunities. Investment in sustainable technologies can lead to long-term cost savings and innovation. Educating consumers about the benefits of recycled materials can shift market preferences, and redesigning supply chains can improve efficiency and resilience.

In conclusion, the comparative analysis of circular economy implementation across different companies in the fashion industry reveals a diverse array of strategies and practices. While each company faces unique challenges, their collective efforts contribute significantly to advancing sustainability in the industry.

4.2 Evaluating the Role of LCA in Fashion Sustainability

This section assesses how Life Cycle Assessment (LCA) is applied in the fashion industry to promote sustainability. LCA is a method used to analyze the environmental impacts of products throughout their entire life cycle, from raw material extraction to disposal. Given the fashion industry's intricate supply chains and substantial environmental footprint, implementing LCA can yield significant benefits. This discussion highlights the current use of LCA in fashion, its advantages, challenges, and its potential to foster sustainable practices, supported by relevant insights and data. The fashion industry has increasingly adopted LCA in recent years due to growing awareness of environmental issues and consumer demand for sustainable products. Major brands are integrating LCA into their sustainability efforts to better understand and reduce their environmental impacts. These assessments typically focus on key environmental metrics such as carbon and water footprints, energy consumption, and waste production.

Examples of LCA use include:

- Manteco: Specializing in sustainable wool, Manteco uses LCA to assess the environmental impact of its recycled wool products, showing reductions in water use by 90%, energy use by 60%, and CO_2 emissions by 50% compared to virgin wool.
- H&M: Their 2020 Sustainability Report indicates that their Conscious collection, which uses organic cotton and recycled polyester, reduced its carbon footprint by 30% compared to conventional materials.
- Patagonia: LCA of their polyester fleece jackets shows that using recycled polyester cuts CO_2 emissions by 59% and energy use by 50% compared to virgin polyester.
- Nike: The Nike Grind program recycles worn-out athletic shoes into new products like playground surfaces and sports fields, significantly reducing waste. Additionally, Nike's Flyknit technology, developed through LCA, reduces waste by 60% compared to traditional cut-and-sew methods.

Below in Table 3, there is a graphical representation summarizing the environmental benefits achieved by these brands through the application of LCA:

Brand	Reduction in Water Use	Reduction in Energy Use	Reduction in CO_2 Emissions
Manteco	90%	60%	50%
H&M	Not specified	Not specified	30%
Patagonia	Not specified	50%	59%
Nike	Not specified	60%	Not specified

Table 3: Environmental Benefits of LCA in Fashion Industry

The adoption of LCA by these major brands illustrates the tangible environmental benefits that can be achieved. H&M's Conscious collection has demonstrated a significant reduction in carbon footprint, highlighting the impact of choosing sustainable materials. Patagonia's focus on using recycled polyester not only reduces emissions but also cuts energy consumption by half, showcasing how material choices can lead to substantial environmental savings. Nike's Nike Grind program and Flyknit technology emphasize waste reduction, showing how innovative design and material choices can contribute to sustainability. Manteco's use of LCA to assess its recycled wool products further underscores the potential for significant reductions in water and energy use, as well as carbon emissions, by incorporating recycled materials.

Therefore, implementing LCA in the fashion industry offers several sustainability benefits. LCA provides a full view of the environmental impacts of fashion products throughout their life cycle. The average carbon footprint of a cotton t-shirt is approximately 7 kg CO_2e, carbon dioxide equivalent (see Figure 4.1)[38], with significant impacts during raw material production and manufacturing.

[38] Carbonfact. (2022). *T-shirt carbon footprint: The numbers revealed*. Carbonfact. Retrieved from https://www.carbonfact.com/blog/tshirt

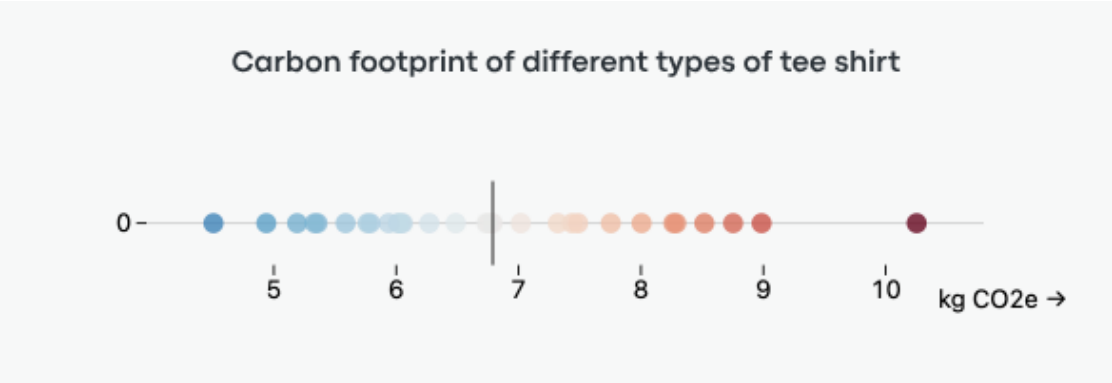

Figure (4.1): Average Carbon Footprint of a cotton t-shirt

Detailed LCA data enables fashion companies to make better decisions regarding materials, manufacturing processes, and supply chain management. For instance, using organic instead of conventional cotton can reduce water use by up to 91%.[39]

While LCA offers many benefits, its implementation in the fashion industry faces several challenges:

- Data Collection: Difficult to gather high-quality data across complex supply chains.
- Impact Tracing: Challenging to trace environmental impacts of globally sourced materials.
- Resource Intensity: LCAs are resource-intensive and expensive, costing between $10,000 to $50,000.
- Methodological Complexity: Requires expertise in environmental science and life cycle modeling, often lacking in fashion companies.
- In-House Expertise: Smaller companies may not have the necessary expertise.
- Supply Chain Dynamics: Rapidly changing supply chains and seasonal product lines complicate LCA studies.
- Frequent Updates: Fast fashion brands need continuous updates to LCA data due to frequent new collections.

[39] The Organic Center. (n.d.). *Organic cotton and the environment*. Retrieved from https://www.organic-center.org/organic-cotton-and environment#:~:text=Organic%20Cotton%20and%20Water&text=In%20fact%2C%20one%20study%20found,cotton%20is%20mostly%20rain%2Dfed%20.

Despite the challenges, LCA has significant potential to drive sustainable practices in the fashion industry: LCA can stimulate innovation in eco-design by highlighting the environmental benefits of alternative materials and processes. For example, Manteco leverages LCA insights to utilize Mwhool, a sustainable wool product, while Stella McCartney[40] uses Mylo™, a sustainable leather alternative made from mushrooms, informed by LCA.

LCA results can educate consumers about the environmental impacts of their clothing choices, fostering more sustainable consumption patterns. The Fashion Revolution's Transparency Index[41] promotes consumer awareness through LCA insights.

In summary, LCA implementation in fashion sustainability highlights its crucial role in enhancing environmental stewardship within the industry. LCA's insights and data offer a powerful tool for driving meaningful change and fostering a culture of sustainability in fashion.

4.3 Assessment of Manteco SpA's Circular Economy Strategies

In the previous chapters, we discussed the various strategies employed by Manteco SpA to integrate circular economy principles into its operations. These include closed-loop recycling, eco-design, resource efficiency, upcycling, sustainable supply chain management, consumer engagement, innovative production techniques, and strategic collaborations. This section will provide whereas a detailed assessment of the impact and effectiveness of these strategies, with a particular focus on the application of Life Cycle Assessments (LCAs).

Manteco SpA has distinguished itself as a leader in sustainable textile production through its comprehensive and innovative circular economy strategies. This assessment highlights the impact of these strategies, showcasing how Manteco has integrated circular economy principles into its operations to achieve significant environmental, economic, and operational benefits.

[40] Stella McCartney. (2021). Stella McCartney Sustainability Report 2021. Retrieved from [Stella McCartney] (https://www.stellamccartney.com/sustainability/).

[41] Fashion Revolution. (2020). Fashion Transparency Index 2020. Retrieved from [Fashion Revolution] (https://www.fashionrevolution.org/about/transparency/).

Application of Circularity Metrics to Manteco Products

To carry out this assessment, circularity metrics to various products have been applied. The application of circularity metrics to Manteco products involves evaluating the extent to which these products incorporate recycled materials and can be reintroduced into the production cycle. Circularity metrics are specific measures used to assess the sustainability of products based on factors such as resource efficiency, waste reduction, and the potential for materials to be reused or recycled. These metrics help quantify how well a product adheres to circular economy principles, which focus on minimizing waste and maximizing the reuse of resources.

By pioneering the use of these circularity metrics, Manteco ensures its products are designed for maximum sustainability and minimal environmental impact, thereby better understanding the effectiveness of its circular economy strategies. The metrics provide a quantitative measure of circularity by considering factors such as the proportion of recycled content, the recyclability of the final product, and the efficiency of resource use throughout the production process. Higher circularity scores indicate a greater degree of sustainability, highlighting products that effectively reduce environmental impact by maximizing the use of recycled materials and minimizing waste.

Manteco applies circularity metrics to Pure MWool® fabric, ReviWool® fabric, MWool® fabric, Woolten® fabric, and MWool® yarn. The evaluation involves comparing two scenarios: one representing the minimum possible fraction of recycled materials and the other representing the maximum possible fraction. The results are then analyzed to determine how different levels of recycled content impact the overall sustainability and circularity of the products. The Table 4 below evaluates the circularity metrics for various Manteco products.

		Scenario 1		Scenario 2	
Product	Metric	Min Recycled Fraction	Impact on sustainability	Max Recycled Fraction	Impact on sustainability
Pure MWool®	Recycled Material Usage	10	40	70	90
ReviWool®	Recycled Material Usage	20	50	80	95
MWool®	Recycled Material Usage	30	60	90	100
Woolten®	Recycled Material Usage	15	45	75	93
MWool® yarn	Recycled Material Usage	25	55	85	98

Table 4: Circularity Metrics for Manteco's products

For each product, increasing the recycled material usage significantly enhances its sustainability impact. For instance, Pure MWool® shows an increase from 40 to 90 in sustainability impact as the recycled content rises from 10% to 70%. Similarly, ReviWool® and MWool® show substantial improvements, with ReviWool® increasing from 50 to 95 and MWool® from 60 to 100 when recycled content is maximized. Woolten® and MWool® yarn also demonstrate significant sustainability gains, with Woolten® increasing from 45 to 93 and MWool® yarn from 55 to 98. Overall, the data underscores that higher fractions of recycled materials result in greater sustainability benefits across all products, highlighting the importance of maximizing recycled content in enhancing Manteco's environmental performance.

All Manteco products, projects, and strategies derive from a signature science-based philosophy and approach. The company has always believed that there are no positive products, circular economy practices, and sustainability strategies without scientific mapping and measurement of raw materials and manufacturing processes.

Manteco has been carrying out Life Cycle Assessments for years, thus pioneering in the industry to quantify the environmental impacts of its products, identify areas for improvement, and accelerate the transition to science-based choices and designs.[42]After years of assessments and in-depth studies, Manteco achieved a certified Life Cycle Assessment calculation for its MWool® fibers. In collaboration with the prestigious Politecnico di Torino, Manteco developed an environmental analysis of recycled wool fibers through the Life Cycle Assessment methodology. [43]

Moreover, a parallel LCA was conducted for virgin wool fibers to provide a data-based comparison. The study (see figure 4.2) revealed that recycled wool fibers have significantly lower environmental impacts than virgin fibers, even under the most unfavorable scenarios. MWool® impacts 99.2% less on climate change, 99.9% less on water use, and 93.3% less on total energy consumption compared to generic virgin wool fibers.

The graph below shows the comparison of MWool® and virgin wool impacts across various categories. The lower value (MWool®) is calculated as a percentage of the higher one (virgin wool), set at 100%. MWool® shows impacts lower than 10% in all categories and lower than 1% in many key categories.

[42] Manteco S.p.a. (n.d.). *Life Cycle Assessments & EPD*. Retrieved from https://manteco.com/life-cycle-assessments/

[43] Id.

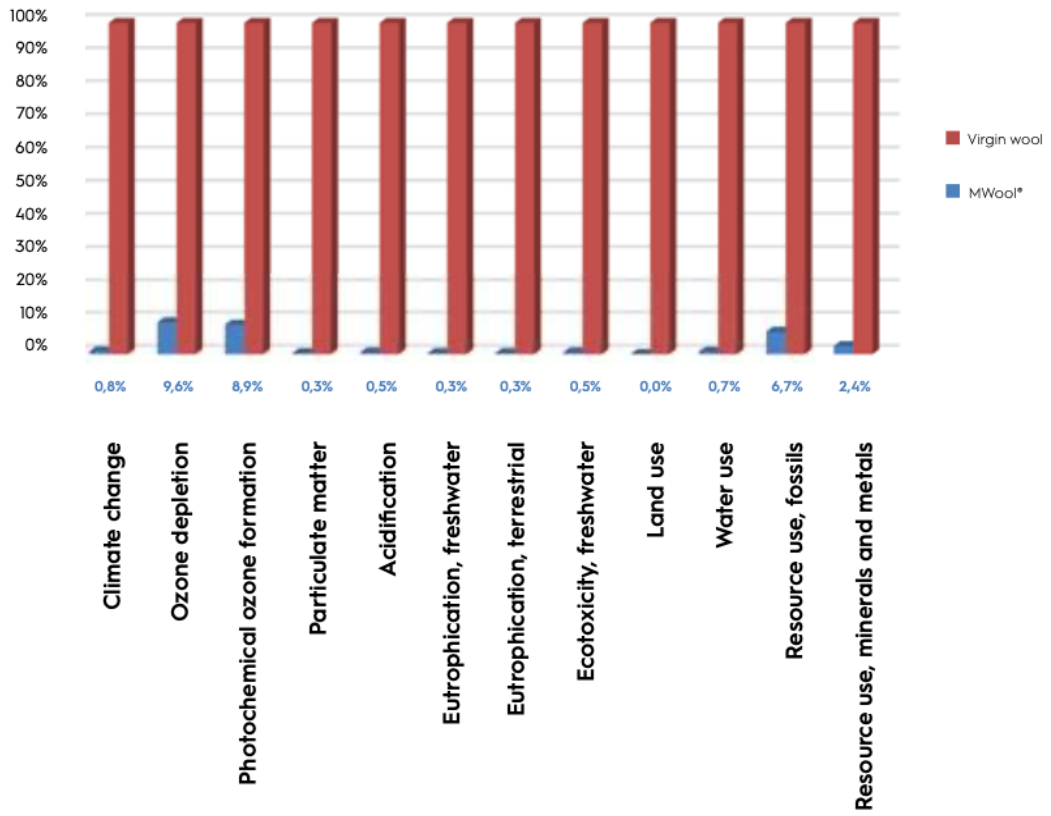

Figure (4.2): Relative comparison of impacts between 1 kg of MWool® and 1 kg of virgin wool fibers.

Moreover, this study is also shown in Figure 4.3, that summarizes the climate change impact for MWool® and virgin wool fibers, including minimum and maximum values for greasy wool and data from the Ecoinvent database. It highlights the substantial environmental benefits of MWool® even under varying impact scenarios for virgin wool.

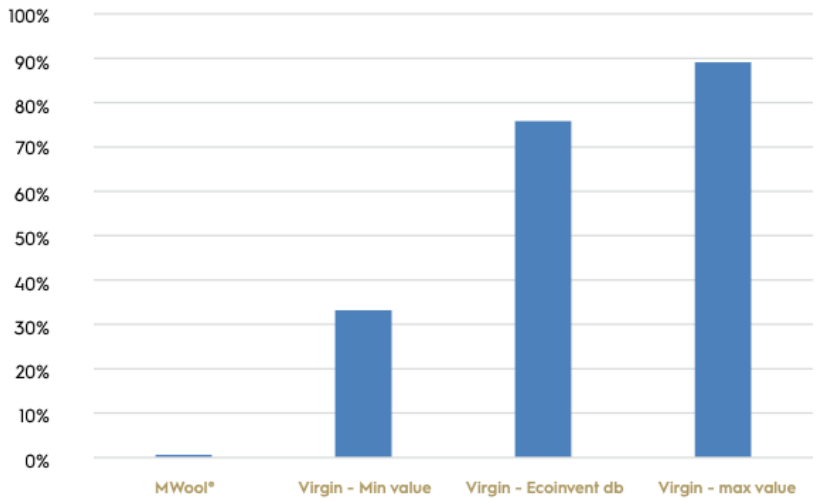

Figure (4.3): Comparison of impacts on climate change to produce 1 kg of MWool® and 1 kg of virgin wool fibers.

This study was peer-reviewed, published as a scientific article on MDPI Resources[44], and certified according to the international EPD® Environmental Product Declaration standard.[45] Manteco's commitment to scientific rigor and transparency through LCAs underscores its leadership in promoting sustainable practices in the textile industry.

In conclusion, Manteco SpA's circular economy strategies demonstrate the transformative potential of integrating sustainable practices into the textile industry. Through closed-loop recycling, eco-design, resource efficiency, upcycling, sustainable supply chain management, consumer engagement, innovative production techniques, and strategic collaborations, Manteco sets a high standard for environmental responsibility. These efforts not only minimize waste and conserve resources but also position Manteco as a leader in promoting a circular economy and sustainable textile production. This chapter provides an in-depth assessment of Manteco 's circular economy strategies, highlighting specific findings and analysis to demonstrate the effectiveness and impact of these strategies. Manteco has established itself as a leader in sustainable textile production, and a detailed examination of their practices reveals valuable insights into the application and benefits of circular economy principles.

[44] Bianco I., Gerboni R., Picerno G., Blengini G. A. (2022). Life Cycle Assessment (LCA) of MWool® Recycled Wool Fibers. *Resources*, 11(5). DOI: 10.3390/resources11050041. Available at: MDPI Resources.
[45] Environmental Product Declaration (EPD). Retrieved from https://environdec.com/

Conclusion

The investigation into Circular Economy (CE) principles and Life Cycle Assessment (LCA) methodologies within the fashion industry has underscored their transformative potential for sustainability. Manteco SpA exemplifies how these approaches can yield substantial environmental benefits, improve resource efficiency, and promote sustainable textile production.

Manteco's pioneering initiatives, such as the creation of MWool®, a recycled wool fiber, highlight the impact of innovative recycling and reuse strategies. By adopting closed-loop systems and sustainable resource management, Manteco demonstrates that high-quality textile production can be harmoniously aligned with ecological responsibility.

Integrating LCA into Manteco's operations has offered crucial insights into the environmental impacts of their products. This comprehensive analysis has empowered the company to make informed decisions that significantly reduce their carbon footprint, water usage, and energy consumption. The validation of Manteco's sustainability initiatives and the identification of opportunities for ongoing improvement underscore their commitment to continuous innovation.

Despite the unique strategies employed by various fashion companies, common themes such as recycling, the use of sustainable materials, and consumer engagement are pivotal in implementing CE principles effectively. Although challenges exist in adopting CE and LCA practices—including significant upfront investments, complex supply chain management, and the necessity for continuous data updates—these obstacles also pave the way for innovation, cost savings, and enhanced environmental outcomes.

In conclusion, the fashion industry stands at a crucial crossroads where embracing Circular Economy principles and Life Cycle Assessment methodologies can lead to profound environmental and economic benefits. Manteco SpA's trailblazing efforts serve as a beacon for balancing profitability with ecological responsibility. As consumer awareness and demand for sustainable products continue to rise, the fashion industry must adapt and innovate, ensuring a future where style and sustainability coexist seamlessly for generations to come.

Appendix

Insights from my Interview with Manteco's CEO

In my conversation with Marco Mantellassi, CEO of Manteco, he elaborated on the company's deep-rooted commitment to sustainability and the circular economy. Manteco, a family-run business since the 1940s, prides itself on maintaining high standards of quality, transparency, and environmental responsibility. Marco emphasized the critical role of MSystem, a unique network of over 50 artisan suppliers located within a 10-mile radius, which ensures meticulous quality control and adherence to sustainable practices. This system enables Manteco to produce high-end, environmentally friendly fabrics, reflecting the heritage and innovative spirit of Made in Italy. Marco also highlighted their pioneering efforts in wool recycling, leveraging state-of-the-art technology to lead the industry in sustainable fabric production.

One of Manteco's distinguishing advantages over competitors is its substantial investment in traceability, transparency, and sustainability. These pillars have positioned Manteco as a leader in the textile industry, particularly in the realm of sustainable practices. The CEO highlighted that Manteco's focus on these areas has been integral since the company's early days, starting with the use of recycled materials during World War II. Over the years, Manteco has expanded its sustainability efforts, obtaining various certifications and continuously improving its processes to maintain its leadership in the sector.

Manteco's investments in digitalization and product traceability have also been significant. The development of advanced tracking systems allows the company to monitor the entire supply chain, ensuring transparency and accountability at every stage of production. This level of traceability not only boosts consumer trust but also helps in maintaining high standards of quality and sustainability.

Question	Marco Mantellassi's Response
Can you describe the role of MSystem in your operations?	"Manteco System is our 10-mile radius network with more than 50 artisans, ensuring quality, transparency, and sustainability across our supply chain."
How does Manteco integrate sustainability into its processes?	"Since the 1940s, we've embedded the circular economy into our operations, focusing on high standards and innovative recycling techniques."
What are some of the unique challenges you face in maintaining these standards?	" Maintaining quality and sustainability throughout a complex supply chain can be difficult, but our tight-knit network of suppliers enables us to manage this efficiently."
Can you share more about your wool recycling initiatives?	"We are pioneers in wool recycling, using advanced technology to create sustainable fabrics while maintaining the highest quality."
What gives Manteco a competitive edge in the industry?	"Our investment in traceability, transparency, and sustainability sets us apart. From recycled materials in WWII to modern certifications, we've always led in sustainable practices."
How do digitalization and product traceability enhance your operations?	"Advanced tracking systems allow us to monitor our entire supply chain, ensuring transparency and accountability at every production stage."
What is the significance of sustainability to Manteco today?	"At Manteco, sustainability has always been a fundamental principle. We've evolved to lead in certified sustainable practices, driven by consumer awareness and regulatory pressures."
Can you highlight some key achievements for Manteco?	"We've made significant strides in certifications, LCAs, and environmental impact measurements, reinforcing our position as a sustainable leader in the textile industry."
How does your local production model benefit Manteco?	"By keeping production within a 10 km radius, we ensure rigorous quality control and sustainability, preserve local jobs, and maintain the excellence of 'Made in Italy'."

This summary and table provide an insight into Manteco's sustainable practices, competitive advantages, and the pivotal role of their extensive supplier network, as explained by CEO Marco Mantellassi.

Bibliography

1. Bianco I., Gerboni R., Picerno G., Blengini G. A. (2022). Life Cycle Assessment (LCA) of MWool® Recycled Wool Fibers. *Resources*, 11(5). DOI: 10.3390/resources11050041. Available at: MDPI Resources.
2. Boustead, I., & Hancock, G. F. (1979). *Energy Analysis*. London: Heinemann Educational Books.
3. Brundtland Report. (1987). *Our Common Future*. World Commission on Environment and Development.
4. Carbonfact. (2022). T-shirt carbon footprint: The numbers revealed. Retrieved from https://www.carbonfact.com/blog/tshirt.
5. Circle Economy Foundation. (2022). Manteco - Recycling Textiles Without the Use of Dyes. Knowledge Hub, 29 August 2022. Retrieved from https://knowledge-hub.circle-economy.com/circleeconomy/article/19711.
6. Circular Innovation Lab. (n.d.). What is Circular Economy?. Retrieved from https://www.circularinnovationlab.com/what-is-circular-economy.
7. Claudio, L. (2007). Waste couture: Environmental impact of the clothing industry. *Environmental Health Perspectives, 115*(9), A449–A454.
8. Curran, M. A. (2008). *PhD Thesis: Life Cycle Assessment*. Retrieved from https://repub.eur.nl/pub/12679/PhD%20Thesis_Curran_May%202008.pdf.
9. Eberhardt, L. C. M., van Stijn, A., Rasmussen, F. N., Birkved, M., & Birgisdottir, H. (2020). Development of a life cycle assessment allocation approach for circular economy in the built environment. *Sustainability, 12*(22), 1–16. doi: 10.3390/su12229579.
10. Ellen MacArthur Foundation. (2013). *Towards the Circular Economy: Opportunities for the Consumer Goods Sector*.
11. Ellen MacArthur Foundation. (2014). *Towards the Circular Economy: Accelerating the Scale-up Across Global Supply Chains*.
12. Ellen MacArthur Foundation. (2015a). Growth Within: A Circular Economy Vision for Competitive Europe.
13. Ellen MacArthur Foundation. (2015b). Circularity Indicators: An Approach to Measuring Circularity.
14. Ellen MacArthur Foundation. (2015c). Towards a Circular Economy - Business Rationale for an Accelerated Transition.

15. Ellen MacArthur Foundation. (2017). *A New Textiles Economy: Redesigning Fashion's Future*. Retrieved from https://www.ellenmacarthurfoundation.org/publications/a-new-textiles-economy-redesigning-fashions-future.
16. Ellen MacArthur Foundation. (n.d.). Circular Economy Introduction: Key Ideas. Retrieved from https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/key-ideas.
17. ETP Fibre Textiles Clothing. (2016). *Towards a 4th Industrial Revolution of Textiles and Clothing - Strategic Innovation and Research Agenda for the European Textile and Clothing Industry*.
18. European Clothing Action Plan (ECAP). (2015). Retrieved from http://wrap.org.uk.
19. European Commission. (2015). Directive of the European Parliament and of the Council (relating to waste). Retrieved from http://eur-lex.europa.eu.
20. European Commission. (2022). EU Strategy for Sustainable and Circular Textiles. *Communications Commission of the European Parliament, Council, European Economic and Social Committee and Committee of the Regions*, 1, 5–24. Retrieved from [Google Scholar].
21. European Commission. (2023). LCA-based assessment of the management of European used textiles. Retrieved from https://circulareconomy.europa.eu/platform/sites/default/files/2023-02/LCA-based%20assessment%20of%20the%20management%20of%20European%20used%20textiles_corrected.pdf.
22. European Commission. (n.d.). Life Cycle Assessment (LCA) - European Platform. Retrieved from https://eplca.jrc.ec.europa.eu/lifecycleassessment.html.
23. European Parliament. (2023). Circular Economy: Definition, Importance, and Benefits. Retrieved from https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits.
24. Fashion Revolution. (2020). Fashion Transparency Index 2020. Retrieved from https://www.fashionrevolution.org/about/transparency/.
25. Fletcher, K. (2014). *Sustainable Fashion and Textiles: Design Journeys* (2nd ed.). Routledge.
26. Halimi, M. T., Hassen, M. B., & Sakli, F. (2008). Cotton waste recycling: Quantitative and qualitative assessment. *Resources, Conservation and Recycling, 52*(5), 785–791.

27. H&M Group. (2020). Sustainability Performance Report 2020. Retrieved from https://hmgroup.com/sustainability-report/2020/.
28. International Organization for Standardization (ISO). (2006). *ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework*.
29. International Organization for Standardization (ISO). (2006). *ISO 14044: Environmental Management - Life Cycle Assessment - Requirements and Guidelines*.
30. Joint Research Center. (2011). *Recommendations for Life Cycle Impact Assessment in the European Context – Based on Existing Environmental Impact Assessment Models and Factors*. Luxemburg: Publications Office of the European Union.
31. Manshoven, S., Chistis, M., Vercalsteren, A., Arnold, M., Nicolau, M., Lafond, E., Fogh, L., & Coscieme, L. (2019). Textiles and the Environment in a Circular Economy. European Topic Centre on Waste and Materials in a Green Economy, 1–60.
32. Manteco S.p.a. (2023a). *Manteco is the Winner of 'The Climate Action Award' at Sustainable Fashion Awards 2023*. Retrieved from https://manteco.com/manteco-is-the-winner-of-the-climate-action-award-at-sustainable-fashion-awards-2023.
33. Manteco S.p.a. (2023b). *Sustainability Report*. Retrieved from https://manteco.com/sustainability-report.
34. Manteco S.p.a. (2024). Circular Economy Practices. Retrieved from https://manteco.com/circular-economy-practices.
35. McDonough, W., & Braungart, M. (2002). *Remaking the Way We Make Things: Cradle to Cradle*. New York: North Point Press.
36. McKinsey & Company. (2021). McKinsey Global Surveys: 2021 A Year in Review. Retrieved from https://www.mckinsey.com/~/media/mckinsey/featured%20insights/mckinsey%20global%20surveys/mckinsey-global-surveys-2021-a-year-in-review.pdf.
37. Muthu, S. S. (2017). *Textile and Clothing Sustainability: Recycled and Upcycled Textiles and Fashion*. Springer: Berlin/Heidelberg, Germany.
38. Nike. (2016). Top Things To Know About Sustainable Innovation at Nike. Retrieved from http://news.nike.com/news/sustainable-innovation.
39. Nike, Inc. (2019). FY18 Sustainable Business Report. Retrieved from https://purpose.nike.com/reports.

40. Nikolina, Š. (2019). Environmental Impact of the Textile and Clothing Industry. What Consumers Need to Know. Eur. Parliam. Res. Serv. Retrieved from https://policycommons.net/artifacts/1335345/enviro (accessed on 7 July 2023).
41. OECD. (2019). Circular Economy: What, Why, How, Where. Retrieved from https://www.oecd.org/cfe/regionaldevelopment/Ekins-2019-Circular-Economy-What-Why-How-Where.pdf.
42. Patagonia. (2019). Environmental & Social Initiatives 2019. Retrieved from https://www.patagonia.com/environmental-social-initiatives-2019.
43. Ramboll. (2021). The Circular Economy: 5 Key Drivers in 2021. Retrieved from https://www.ramboll.com/insights/resource-management-and-circular-economy/the-circular-economy-5-key-drivers-in-2021.
44. Rocchi, L., Paolotti, L., Cortina, C., Fagioli, F. F., & Boggia, A. (2021). Measuring circularity: An application of modified Material Circularity Indicator to agricultural systems. *Agricultural and Food Economics, 9*(1). doi: 10.1186/s40100-021-00182-8.
45. Rosily. (2016). Stella McCartney Talks Sustainability at the Third LCFxKering Talk. Retrieved from http://sustainable-fashion.com.
46. Roy Choudhury, A. K. (2014). Environmental Impacts of the Textile Industry and Its Assessment Through Life Cycle Assessment.
47. Stella McCartney. (2021). Stella McCartney Sustainability Report 202. Retrieved from https://www.stellamccartney.com/sustainability.
48. Sustainable Apparel Coalition. (2023). Higg Product Tools. Retrieved from https://product.higg.org/page/sustainable-apparel-coalition.
49. To, M. H., Uisan, K., Ok, Y. S., Pleissner, D., & Lin, C. S. K. (2019). Recent trends in green and sustainable chemistry: Rethinking textile waste in a circular economy. *Current Opinion in Green and Sustainable Chemistry, 20*, 1–10.
50. Walden University. (n.d.). Dissertations and Doctoral Studies. Retrieved from https://scholarworks.waldenu.edu/cgi/viewcontent.cgi?article=11675&context=dissertations.
51. Wiedemann, S. G., Nguyen, Q. V., & Clarke, S. J. (2022). Using LCA and Circularity Indicators to Measure the Sustainability of Textiles—Examples of Renewable and Non-Renewable Fibres. *Sustainability, 14*(24), 1–22. doi: 10.3390/su142416683.

52. Wiedemann, S. G., et al. (2020). Environmental impacts associated with the production, use, and end-of-life of a woollen garment. *International Journal of Life Cycle Assessment, 25*(8), 1486–1499. doi: 10.1007/s11367-020-01766-0.
53. Winkler, H. (2011). Closed-loop production systems—A sustainable supply chain approach. *CIRP Journal of Manufacturing Science and Technology, 4*(3), 243-246.
54. T. I. Epd. (2023a). Environmental Product Declaration MWool® Fabric by Manteco®.
55. T. I. Epd. (2023b). Environmental Product Declaration Pure MWool® Fabric by Manteco®.
56. T. I. Epd. (2023c). Environmental Product Declaration ReviWool® Fabric by Manteco®.
57. T. I. Epd. (2023d). Environmental Product Declaration Woolten® Fabric by Manteco®.
58. T. I. Epd. (2022). Environmental Product Declaration MWool® Yarn by Manteco®. doi: 10.4324/9780203889565.ch4.