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Weaving the Circle

Exploring the potential and challenges to upcycle

post-industrial textile waste of an outdoor apparel company

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Baci,

Dylan

Abstract

The textile industry is known for its complex global supply chains and being subject to a raft of sustainability issues. As renowned apparel brands begin to adopt circular economy principles to close their material loop, upcycling of post-industrial waste streams presents a promising solution. The Oberalp Group has taken initiatives to address its material sustainability issues by starting some upcycling initiatives and aiming to upcycle its leftover fabric material. Through this research, the potential and challenges behind upcycling such waste is explored using Oberalp as an exploratory case study. It uncovers the nuances behind the fabric's characteristics, such as color, type, quantity and location in supply chain that are determined by design decisions and have implications on the fabrics ability to be incorporated into a new design or disposed of. The capability and willingness of garment producers and other industry partners is an important factor in being able to be flexible enough to take on an upcycling project that requires specific expertise and added resources. Other external factors such textile recycling technology and recycling capacity and certain standard industry practices also determine eventual upcycling possibilities for the leftovers. Fundamentally, the findings revealed the signficance that the company's existing business model and internal culture towards material circularity play in both hindering and realizing the potential to upcycle fabric waste. From eco-design and life cycle thinking across the organiztion, to an envigorated engagement with suppliers, the focal company and its value chain have several factors that influence upcyclability. An emergent theory from rounds of interviews with Oberalp personnel explains the greater phenomenon and is presented, as well as some propositions for the company going forward.

Keywords: Post-industrial textile waste, Textile Upcycling, Sustainable Supply Chain Management, Circular Business Models

Abbreviations:

CBM- Collaborative Business Model

CSR- Corporate Social Responsibility

FP- Fabric Producer

GP- Garment Producer

GRS- Global Recycled Standard

GT- Grounded Theory

LCA- Life cycle Assessment

LCT- Life Cycle Thinking

SAC- Sustainable Apparel Coalition

SCG- Supply Chain Governance

SCM- Supply Chain Management

TSI- Transnational Standard Initiative

Executive Summary

Background

The textile industry is known for its complex global supply chains and being subject to a raft of sustainability issues. The life cycle of clothing spans many stages that occur across the complex value chain: from resource production and extraction, fiber and yarn manufacturing, textile manufacturing to apparel assembly, packaging, transportation and distribution and usage, ending with disposal or recycling. This has made it very challenging for companies to understand the critical sustainability issues and impacts that occur along the way. Currently, these industries operate in an entirely non-linear way that relies primarily on a model of take-make-dispose with styles quickly becoming obsolete and clothing used for a short period of time, consequently encouraging more consumption. Approximately 12% of total input material is lost in production as factory offcuts and overstock liquidation. This high-quality material represents not only an economic loss to producers and society but poses a threat to the environment at the end of the material's life cycle. Since production waste is not considered hazardous, has a lower value than virgin raw material, and the technological infrastructure to handle it is not widely available, it has not gotten much of the attention (Dobilaite, Mileriene, Juciene, & Saceviciene, 2017; GreenBlue, 2017; Tomovska, Jordeva, Trajković, & Koleta, 2017). It can occur across the various stages of production and comes in different forms, ranging from garment offcuts and defective fibers to overstock of roll ends. Since this waste of relatively high value occurs within industrial systems, a solution to address it must come from the producers themselves to engage with their industrial partners.

The apparel industry has been embracing values of corporate social responsibility (CSR) to address the inherent sustainability challenges in its activities. With a vast global supply network and a linear, resource-intensive business model, the textile and apparel industry must rethink the value of its materials by embracing circularity principles and think about the life cycle of its products to engage its supply chains appropriately.

Case Study: The Oberalp Group

The Oberalp Group, based in Bolzano, Italy, demonstrated a commitment to Corporate Social Responsibility (CSR) over the last few years through a number of internal changes and initiatives, some of which involve circular business models. While the company has made significant progress in sustainable supply chain management, the Sustainability Manager, has expressed the next frontier of their sustainability efforts to focus on dealing with their apparel production waste. It does not know the full extent of the environmental impacts associated with the life cycle of its products nor the waste that occurs at each stage, making it difficult to make any decision to begin a circularity initiative.

Using Oberalp as a case study for this research, it can serve as a model to understand some of the deeper systemic issues related to adopting circular practices in apparel supply chains regarding the management of production waste.

Problem Definition

There is a growing imperative for industry to become more circular with its material flows, which requires a comprehenshive look at the impacts throughout the life cycle of a product across the value chain. Synthetic fibers represent the largest and fastest growing type of fabric used globally and many of them have the benefit of rendering higher quality recycled products than natural fibers (A. Östlund et al., 2015). Post-industrial flows of material waste are "clean" compared to post-consumer flows, meaning they have a lot of potential for recycling. While there are many technologies available that recycle synthetic fibers, some to near virgin quality, they are widely unavailable and not economically viable due to the low cost of virgin raw materials. Where recycling does occur for post-industrial flows, it is largely "downcycled", meaning it is converted into something of lower value.

The apparel industry is still not taking full advantage of the potential of employing an upcycling process that relies less on virgin raw materials. Brands can play a bigger role in promoting material circularity upstream in their supply chains and it requires a different approach in supply chain management. Increased textile reuse and recycling could potentially reduce the production of virgin textile fiber and avoid extraneous processes further downstream, and subsequently reduce the environmental impact of the product's life cycle (Sandin & Peters, 2018). Therefore, considering textile upcycling upstream in the industry value chain can spur innovation that can have a cascade of environmental benefits.

Using the Oberalp Group as a case study, the following research questions were posed to investigate the company and contribute to the greater body of literature:

RQ 1: What is the potential for upcycling of apparel production waste in an outdoor apparel company like the Oberalp Group?

RQ 2: What challenges does the Oberalp Group face that hinder its ability to upcycle more of its upstream production waste?

Method

A simplified version of Grounded Theory method was used in this research project through the progressive identification and integration of *categories of meaning* from the data (Locke, 2001). Coding of literature through thematic codes was done using NVivo software. Several rounds of semi-structured interviews were conducted with individuals at Oberalp to collect information to answer the research questions. Activities such as constant comparative analysis of the interview data and theoretical coding generated multi-order categories that underwent rounds of refinement and eventually the second-order themes that help describe the broad aspects of the Oberalp context.

General Findings

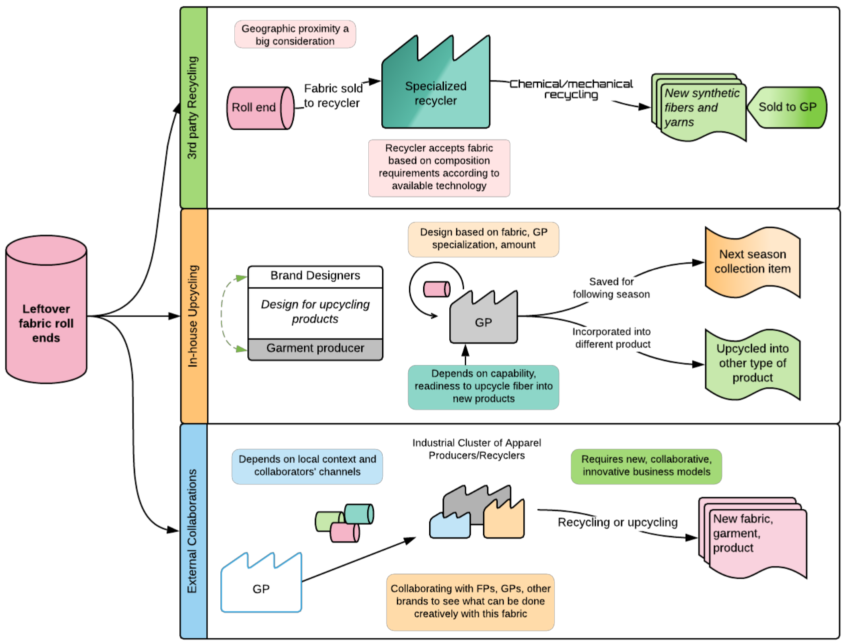
RQ 1: What is the potential for upcycling of apparel production waste in an outdoor apparel company like the Oberalp Group?

Oberalp's garment purchasing process and immediate value chain was highlighted, revealing that the 1st-tier supplier, the garment producer (GP), conducts most of the material transactions and is the only player that tracks post-industrial waste in Oberalp's value chain. Of the tracked material, Oberalp only received data on leftover fabric roll ends, making them Oberalp's priority for material circularity as they are high quality material. Having already done a few smaller upcycling projects with production leftovers in conjunction with some partners, Oberalp's potential strategic directions and supply chain capacities are the center of being able to realize larger scale upcycling. The company recognises multiple recycling strategies as potential opportunities to handle these leftovers. It could send the material to undergo fiber-to-fiber recycling by a third party. However, a greater priority is to collaborate with ready and capable

GPs with similar values to innovate and produce new garments from the leftover fabric. The company sees life cycle thinking and design strategies as integral in making this a reality while engaging with other like-minded partners across the industry and with local channels around their producers to create innovative solutions.

RQ 2: What challenges does the Oberalp Group face that hinder its ability to upcycle more of its upstream production waste?

Oberalp faces several internal and external obstacles that make upcycling its leftover fabric a challenge. The most encompassing obstacle is the organization's current business model and company culture that does not place a high enough value on its fabric leftovers nor on material circularity. This obstacle has downstream effects on designing principles that dictate the materials and colors chosen and potential for those fabrics to get reincorporated into a value chain. External obstacles include the limited recycling capacity to accept blended fibers, the limited capability of GPs to engage in these projects, and the nature of the textile industrial status quo that requires purchase order minimums. This generates leftovers to begin with and subsequently requires more inputs to generate ad hoc upcycling projects. The nature of upcycling itself is a challenge as it requires specific expertise, special collaboration, and ultimately a clear idea of what the final product must be like in order to scale it with GP partners.



Possible Recycling Routes for Oberalp's Production Leftovers

Source: created by author

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1 Introduction

The global textile industry is highly fragmented with thousands of actors involved and one of the most complex global production networks and supply chains (Global Fashion Agenda & The Boston Consulting Group, 2017; Ellen Macarthur Foundation, 2017). The life cycle of clothing spans many stages that occur across the complex value chain: from resource production and extraction, fiber and yarn manufacturing, textile manufacturing to apparel assembly, packaging, transportation and distribution and usage, ending with disposal or recycling (Rapsikevičienė, Gurauskienė, & Jučienė, 2019). This has made it very challenging for companies to understand the critical sustainability issues and impacts that occur along the way. Currently, these industries operate in an entirely non-linear way that relies primarily on a model of take-make-dispose with styles quickly becoming obsolete and clothing used for a short period of time, consequently encouraging more consumption (Global Fashion Agenda & The Boston Consulting Group, 2017). This linear industry is very resource intensive and wasteful, posing a tremendous impact on natural resources, the environment and society.

The industry relies mostly on non-renewable resources for raw material production – including petroleum to produce synthetic fibers, fertilizers to grow cotton, and chemicals to produce dye, and finish fibers and textiles (Ellen Macarthur Foundation, 2017). The apparel industry's biggest pressures on the environment are related to energy emissions from and the chemicals used in production processes, the land and water used to produce the natural fibers, and the sheer amount of waste created from use (Global Fashion Agenda & The Boston Consulting Group, 2017). Figure 1-1 below demonstrates the global flow of apparel fiber and their ultimate destinations. Of the total fiber input used for clothing, 87% is landfilled or incinerated as pre- and post-consumer waste, representing a lost opportunity of more than USD 100 billion annually (Ellen Macarthur Foundation, 2017). As Figure 1-1 shows, less than 1% of fabric material used to produce clothing is recycled to produce new clothing of similar quality. When apparel is collected and the materials are recycled, they are often recycled into lower-value applications such as mattress stuffing or insulation material. Approximately 12% of total input material is lost in production as factory offcuts and overstock liquidation. This high-quality material represents not only an economic loss to producers and society but poses a threat to the environment at the end of the material's life cycle.

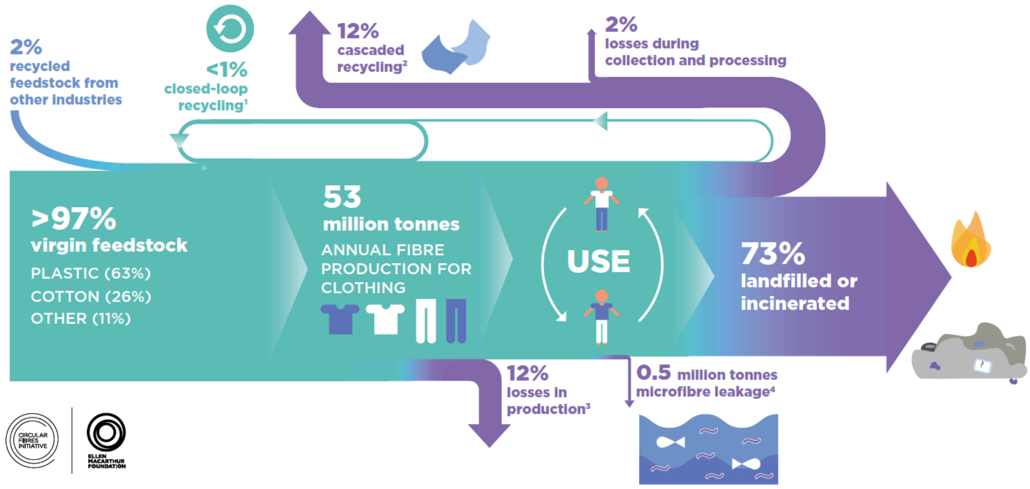

Figure 1-1 Global Material Flows for Clothing 2015

Source: Circular Fibers Initiative Analysis, retrieved from (Ellen Macarthur Foundation, 2017)

In addition to the massive environmental impacts of the textile industry, there is a rapid projected growth in global demand, particularly from emerging markets. With the projected growth of global textile consumption at 63%, from 83 million tons today to almost 130 million tons in 2030 (see Figure 1-2 below), there is a clear need to address the fundamental sustainability issues around textile and apparel production and consumption. Figure 1-2 shows this dramatic projected growth, as well as the increasing share that synthetic fibers will have.

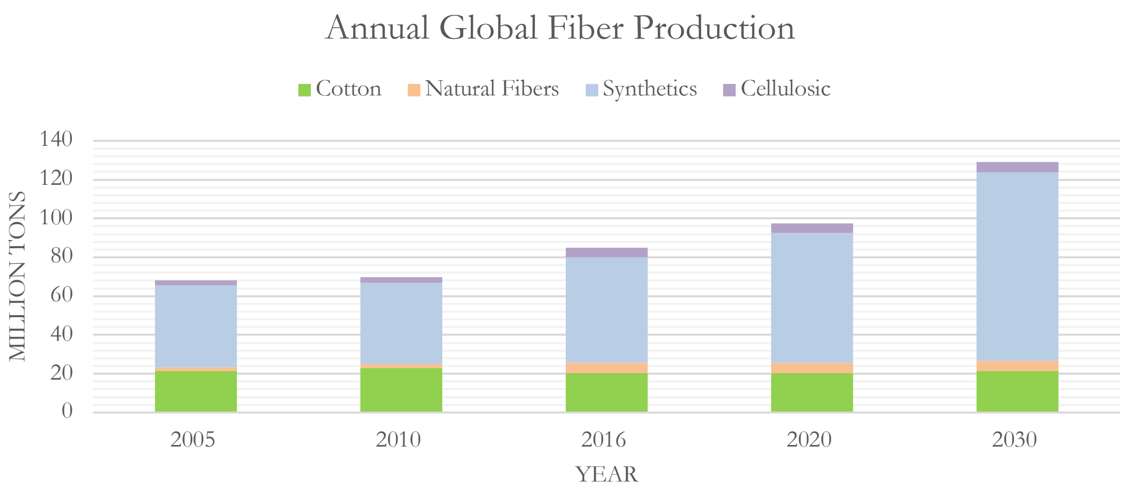

Figure 1-2 Annual Global Fiber Production

Source: Own figure with data from (Quantis International, 2018)[1]

The materials used in textiles are largely unfit for circular production and consumption systems. For example, polyester and other synthetic fibers (representing 63% of virgin material feedstock) require large amounts of petrochemicals and fossil fuel energy to produce, while growing cotton (26% of feedstock) requires high volumes of fertilizer, pesticides and water (Ellen Macarthur Foundation, 2017). Furthermore, recyclability of these materials becomes very complicated when the fibers are blended for different functional purposes, reducing their potential to be recycled (Å. Östlund, Syrén, Jönsson, Ribitsch, & Syrén, 2017). While recycling end-use fibers would be the best solution to close the material loop of the industry, there needs to be a comprehensive change in how textile supply chains use raw materials more efficiently to reduce the amount of waste that emerges from them.

In a global survey of the industry, *Pulse of the Fashion Industry* (2017) assigned a "Pulse Score" to different segments of the industry based on a range of sustainability criteria along the product life cycle. The Pulse Score is "a global and holistic baseline of the sustainability performance in the fashion sector" (Global Fashion Agenda & The Boston Consulting Group, 2017, p. 28) based on the Higg Index (discussed later in Section 2.1.6). In assigning a global Pulse Score, apparel companies ranging from large brands to small fashion houses perform very poorly in terms of their waste management practices. While some actors had performed

[1] This data represents total global fiber production, including other industrial purposes, where fiber for apparel represents the single largest portion.

well with respect to improving the social sustainability dimensions of their production and made improvements on chemicals usage, water pollution and energy efficiency (See Figure 1-3 below), the indicator scores for waste management across all tiers were persistently poor[2]. Figure 1-3 exhibits the disparity in performance across performance quartiles in each impact category but highlights the waste category as consistently underperforming across performance tiers, indicating that the industry as a whole has not done enough to address waste management compared to other impact categories. Aside from the clear environmental impacts from the waste generated, this is also a huge lost value to the manufacturers and the brand companies themselves, representing a potential opportunity to make greater use of this lost material.

Figure 1-3 Average Pulse Score by Impact Area and Performance Quartile

Source: Figure from Pulse of the Fashion Industry 2017 (Global Fashion Agenda & The Boston Consulting Group, 2017), based on data from the SAC Higg Index Brand Module and expert interviews

The negative impacts of the industry also have potential to pose reputational risks to the brands as the regulatory landscape changes and consumers become more aware (Larsson, Buhr, & Mark-Herbert, 2013). Apparel retailers have come under increasing scrutiny from civil society

[2] In the *Pulse of the Fashion Industry 2017* report, the score for waste also includes multiple phases of a product life cycle and is not limited to manufacturing waste. Much of this impact also comes from end-of-life waste generation.

because of poor working conditions and negative environmental impacts in their complex supply chains, which has motivated them to acknowledge corporate responsibility in their supply chain networks (Larsson et al., 2013). While retailers have taken decisive steps towards corporate responsibility of their value chains, in practice they have taken incremental steps in key areas that have gotten more visual attention. Since production waste is not considered hazardous, has a lower value than virgin raw material, and the technological infrastructure to handle it is not widely available, it has not gotten much of the attention (Dobilaite, Mileriene, Juciene, & Saceviciene, 2017; GreenBlue, 2017; Tomovska, Jordeva, Trajković, & Koleta, 2017).

While the disposal of textiles after consumer use poses the largest issue with circularity in the industry, as referenced in Figure 1-1, production waste is another significant source. It can occur across the various stages of production and comes in different forms, ranging from garment offcuts and defective fibers to overstock of roll ends. Unlike post-consumer waste, which is usually a heterogenous blend of varying fabric types of lower quality, production waste is typically of high quality and homogenous in nature, making it ideal for reuse or recycling (Le, 2018). Since this waste of relatively high value occurs within industrial systems, a solution to address it must come from the producers themselves to engage with their industrial partners.

The apparel industry has been embracing values of corporate social responsibility (CSR) to address the inherent sustainability challenges in its activities. With a vast global supply network and a linear, resource-intensive business model, the textile and apparel industry must rethink the value of its materials by embracing circularity principles and think about the life cycle of its products to engage its supply chains appropriately.

1.1 The Case Study: The Oberalp Group

The Oberalp Group, based in Bolzano, Italy, consists of four mountaineering brands that produce outdoor apparel, technical equipment, and other mountain sport accessories with 103 producers in 20 countries and a distribution presense in 24 countries (Oberalp Group, 2018). Each of Oberalp's product divisions is responsible for the product development process, industrialization and control of the manufacturing process. Meanwhile, administration, procurement, research and innovation, and sustainability are centralized functions that work across product divisions and brands.

Consumers often affiliate outdoor brands with ideas of sustainability, fair-trade and environmental stewardship, even when they do not know what kinds of initiatives these companies may take (Dargusch & Ward, 2010). Oberalp has demonstrated a commitment to Corporate Social Responsibility (CSR) over the last few years through a number of internal changes and initiatives.

In 2012, Oberalp created the Sustainability Department that currently manages the Group's sustainability efforts and coordinates across business areas. One of its sustainability focus areas involves promoting fair factories, where it has partnered with Fair Wear Foundation[3] to monitor and certify the labor practices of its suppliers. They have developed an internal supplier evaluation system that ensures compliance with their Code of Conduct and helps them use it for dialogue and improvement with the suppliers. Since this initiative, 97% of their textile suppliers are monitored and compliant and 79% of their production volume come from

[3] Fair Wear Foundation is an independent, non-profit organization that aims to improve labor conditions in the textile industry.

suppliers who have been their partners for more than 5 years. In addition to consolidating their producers based on efficiency and expertise, thus reducing the total number by 12% between 2017-2018, Oberalp has been able to engage more with its suppliers to pursue other initiatives and adopt more circular business models throughout various stages. For example, through collaboration with a recycler in Italy, one of its brands produces a 100% recycled wool jacket made from locally sourced materials, and due to the product's success, it is able to expand its style offerings. It has also looked at carryover fabrics from previous collections and production offcuts as opportunities for several small-scale upcycling projects such as wool gloves and smartphone insulators. These investments in product and process innovation through life cycle thinking have spurred the company to think on a larger scale of how to address its production waste and take a bigger step towards closing its material loop.

"Sustainability is a choice we invest in because we believe in it. It's a crucial part of our company values and daily business"

(Oberalp Group Sustainability Report, 2018)

As Oberalp's sustainability report demonstrates, it is commited to a culture of corporate responsibility and collaborating with its value chain to reduce its impacts. While the company has made significant progress in sustainable supply chain management, the Sustainability Manager, has expressed the next frontier of their sustainability efforts to focus on dealing with their apparel production waste. In the Sustainability Department, they believe the company's responsibility extends to production waste and they want to understand the underlying systemic issues so they can begin to address it.

Part of the problem is that while the Oberalp group has ensured social sustainability compliance of the great majority of its suppliers, it does not have much information on its suppliers' environmental performance. It does not know the full extent of the environmental impacts associated with the life cycle of its products nor the waste that occurs at each stage, making it difficult to make any decision to begin a circularity initiative.

Using Oberalp as a case study for this research, it can serve as a model to understand some of the deeper systemic issues related to adopting circular practices in apparel supply chains regarding the management of production waste.

1.2 Problem Definition

There is a growing imperative for industry to become more circular with its material flows, which requires a comprehenshive look at the impacts throughout the life cycle of a product across the value chain. The apparel industry in particular can be seen as an extreme case for managing environmental issues because of the frequent shifts in product portfolios and its internationally organized product chains that substantially influence and extend the stages where the impacts can occur (Ashby, Hudson-Smith, & Shand, 2013).

Synthetic fibers represent the largest and fastest growing type of fabric used globally and many of them have the benefit of rendering higher quality recycled products than natural fibers (A. Östlund et al., 2015). As mentioned, post-industrial flows of material waste are "clean" compared to post-consumer flows, meaning they have a lot of potential for recycling. While there are many technologies available that recycle synthetic fibers, some to near virgin quality, they are widely unavailable and not economically viable due to the low cost of virgin raw materials. Where recycling does occur for post-industrial flows, it is largely "downcycled", meaning it is converted into something of lower value (discussed later in Section 2.1.5).

Academia and industry have conducted significant research in creating a more circular apparel industry by improving waste management and recycling post-consumer waste (Muthu, 2017). While this is an integral part of the solution, the literature mostly considers downcycling of these flows and the business models of collecting the waste from consumers (Bell, Lee, Riley, & Slater, 2017). This overlooks the role that brands can play in to promote material circularity upstream. Handling post-industrial waste requires a different approach in waste management, not only considering the higher quality of the waste (Tomovska et al., 2017), but the actors necessary to mobilize that kind of change.

The apparel industry is still not taking full advantage of the potential of employing an upcycling process (described later in Section 2.1.5) that relies less on virgin raw materials (Cassidy & Han, 2013). This is one of the industries with the largest potential for recycling and innovative recovery potential for upcycling innovations, but it is not exploited enough (Rapsikevičienė et al., 2019). Increased textile reuse and recycling could potentially reduce the production of virgin textile fiber and avoid extraneous processes further downstream, and subsequently reduce the environmental impact of the product's life cycle (Sandin & Peters, 2018). Therefore, considering textile upcycling upstream in the industry value chain can spur innovation that can have a cascade of environmental benefits.

As Sung mentions in an comprehensive review on the literature of upcycling, "in order to ensure the success of upcycling – in terms of environmental, economic, and social impacts, more case studies (industry- and product/material- specific) are required to list systemic issues to tackle" (Sung, 2015, p. 33). The evolving field of sustainability in supply chain management also needs greater understanding of the role and impact of supply chain relationships in achieving sustainability goals (Ashby et al., 2013). Using the context of an apparel company that engages with its supply chain to improve its sustainability performance can contribute to this gap in the literature.

The Oberalp Group feels responsible for the leftovers it produces upstream in its value chain and wants to explore opportunities for upcycling this material. Therefore, this research project aims to investigate the context of Oberalp and contribute to the body of literature on understanding production waste upcycling in the apparel industry.

1.3 Research Questions

To achieve the objectives of this project, the following questions have guided the flow of research to understand the Oberalp context specifically, and the circumstances of the apparel industry at large.

RQ 1: What is the potential for upcycling of apparel production waste in an outdoor apparel company like the Oberalp Group?

A bigger picture of Oberalp's apparel supply chain, internal capacity, and current practices is necessary to uncover what kinds of production waste material streams can be upcycled. This research question will seek to identify what kind of waste stream has potential for large-scale upcycling projects and what kinds of technologies and organizational strategies in supply chain management the company deems necessary to upcycle this waste.

The potential examined in this question can also includes the future upcycling opportunities with other waste streams as various factors regarding technology, organizational and supply chain management improve. These possibilities can provide a basis for future research in conjuction with understanding the challenges uncovered by the following research question.

RQ 2: What challenges does the Oberalp Group face that hinder its ability to upcycle more of its upstream production waste?

This question aims to get a comprehensive understanding of internal and external obstacles that inhibit upcycling of Oberalp's production waste. These obstacles can refer to the nature of the fabric used, the company's existing business models, and challenges within the greater industrial ecosystem that limit the potential to upcycle production waste streams and close the material loop.

1.4 Limitations and Scope

The scope of this research project will focus on post-industrial synthetic textile waste as it represents the majority of Oberalp's fiber consumption and, as demonstrated in Figure 1-1, is the largest type of fiber waste globally. While the author initially wanted to select a particular fiber typology according to predetermined criteria and analyze its value chain for upcycling opportunities and interview specific suppliers to get their perspectives, preliminary data on Oberalp's value chain ruled out a specific fiber type. As an outdoor apparel company that produces complex and technical clothing, Oberalp has a massive variety of fabric types with varying fiber blends and colors, which would make selecting a single one to analyze broader systematic issues not worthwhile. Additionally, the author was informed that reaching out to speak directly with relevant suppliers (mostly in Asia) would have posed issues with confidentiality and would have been challenging given the time frame. Therefore, the author was limited to specifically speaking with individuals that worked directly in Oberalp and to considering the broader systemic issues that the company has with being able to use its post-industrial textile waste. These circumstances limited the possibility to include a broader array of stakeholder perspectives in the value chain in developing a theory to describe the phenomena, thus limiting the ability of using data triangulation for analysis. The focus on one case study the use of interviews of only internal individuals can also have implications on the conclusions reached.

Based on the interviews with Oberalp staff, the suppliers discussed were primarily those in the first-tier, namely the garment producers, due to the nature of transactions within the industry and the degree of information they would exchange with these suppliers. Therefore, upstream suppliers that created the fabric were minimally considered.

Much of the research available and general societal attention focuses on post-consumer waste from the fast fashion industry, which is more visible than post-industrial waste. This meant that certain assumptions had to be applied to this research about upcycling processes and challenges facing its industry-wide scaling. The focus on post-consumer waste has implications for the conclusions the authors arrived to, which was taken into consideration in the writing of this thesis.

Furthermore, this project centered its research around waste management practices through upcycling/recycling as a tool to bring new value to waste material to increase circularity instead of other commonly cited tools, such as waste reduction. Therefore, subjects such as zero-waste design and process optimization were given little attention for the sake of this project. Textile recycling technology, specifically for synthetic fibers and blends, is continuously improving and there are several emerging actors that are developing and proliferating these technologies.

This research includes the prominent examples of such technologies that are either in the development stage or in commercial expansion.

1.5 Audience

As an independent master's research project, this thesis intends to contribute to the growing body of academic literature on material upcycling in general, but also to the literature surrounding textile industry circularity. As it uses an apparel company, Oberalp, as a case study, the author hopes this work can provide insight to the individuals at the company who were part of making this work possible and can serve as a foundation for further research to help address sustainability issues they care about. This project could also inform sustainability specialists in apparel companies that are interested in circularity initiatives to address their production leftovers.

1.6 Disposition

Chapter 1 introduced the background to the greater issue of waste from the textile/apparel industries and made the justification for researching upcycling as a form to close the material loop. This chapter sets out the two research questions that guide the research It also introduced Oberalp as the focus for the case study.

Chapter 2 delves into the literature review that informed the author in his research and eventual data collection from Oberalp. It covers an array of topics ranging from an overview of the apparel industry, life cycle assessments, case studies of textile waste management, to supply chain management, recycling technologies, and different definitions of upcycling. Each section of the chapter also attempts to identify gaps in the literature relating to the focus of this thesis project.

Chapter 3 explains the method and analytical framework used to carry out this research project. This chapter explains grounded theory and how it has previously been applied to supply chain management research. It explains how the grounded theory method guided the data collection and analysis for this project.

Chapter 4 presents the findings from the multiple rounds of interviews with Oberalp personnel. It first presents the context of how apparel purchasing transactions occur with suppliers, then it presents the rounds of coding used during the literature review and the categories developed from the interviews. This chapter presents the findings based on how they answer the two guiding research questions, illustrated with quotes from the interviews. It concludes with the "emerged theory" from the research.

Chapter 5 discusses the findings of the research and how it contributes to the body of literature, to practice, and the limitations. It also provides the author's insights to how Oberalp can review its business model going forward.

Chapter 6 concludes the thesis by recalling the research questions and the main findings, and presents relevant topics for future research.

2 Literature Review

The literature review for this project covers refined thematic categories identified in the collected secondary data sources deemed relevant to understanding the case study. This section will cover multiple topics and relevant subtopics with a focus on how they can relate to an international apparel company like Oberalp that sells garments made primarily from synthetic fibers.

2.1 The Apparel Industry

The apparel industry (also frequently called clothing, garment or fashion) is a vital part of the global economy, with the global apparel market worth around $3 trillion and accounting for 2% of the world's Gross Domestic Product (EDGE, 2017). Devoted to the creation of clothing, this industry includes the different sectors that contribute to each stage of garment production. The apparel industry is an integrated production network where production is separated into specialized activities and each activity is located where it can contribute the most value to the product. The industry is also characterized by unpredictable demand, short product life cycles, quick response times, large product varieties, and a volatile, inflexible and complex supply chain structure (Choi, 2016). This results in an inherently linear business model that focuses on producing, distributing and using clothing with little consideration for the implications of its material impact.

As for a simplification of the apparal industry, the textile industry produces fibers and fabrics, which around 60% of total production is destined for apparel production (Quantis International, 2018). Apparel designers then choose what fabrics are needed and send assembly specifications to garment producers (GP). From the produced garment, it is then in the hands of distributors and retailers before arriving to the consumer. The apparel industry could also include auxiliary sectors related to post-consumption, such as second-hand organizations, collectors, and recyclers (Choi, 2016). Despite this oversimplification, the sustainability issues facing the industry are extremely complex and global in nature.

2.1.1 Outsourcing

The current nature of global apparel production comes from clothing brands, typically based in Europe or North America, outsourcing their production facilities overseas for the primary reason of cost savings (Sardar, Lee, & Memon, 2016). Production planning decisions consider a number of different variables when considering the location decision of each activity such as material quality, lead times and reliability of delivery, access to quality inputs and transport and transaction costs (El Messiry & El Messiry, 2018). Sourcing is a complicated process and is based on the nature of the product, the requirement of the company, the capability of the producer, and ultimately the demands of the target customer (Todeschini, Cortimiglia, Callegaro-de-Menezes, & Ghezzi, 2017), where almost 75% of the world's fashion market being concentrated in Europe, the United States, China and Japan (EDGE, 2017).

Beyond simply selecting suppliers, managing what happens along this value chain is also very complicated. As El Messiry and El Messiry explain, "the number of suppliers in any industrial product can increase almost exponentially throughout a value chain, which means that the reality of an organization being able to control all aspects and impacts of its supply chain is a goal rather than a certainty" (2018, p 220).

Where apparel production has been outsourced comes down to labor cost, where the unit production cost of garments in emerging and developing markets are a fraction of those in developed markets (Sardar et al., 2016). As Figure 2-1 demonstrates, the vast majority of apparel exports come from Asia, where production costs have been low but also where these specialized industries have concentrated.

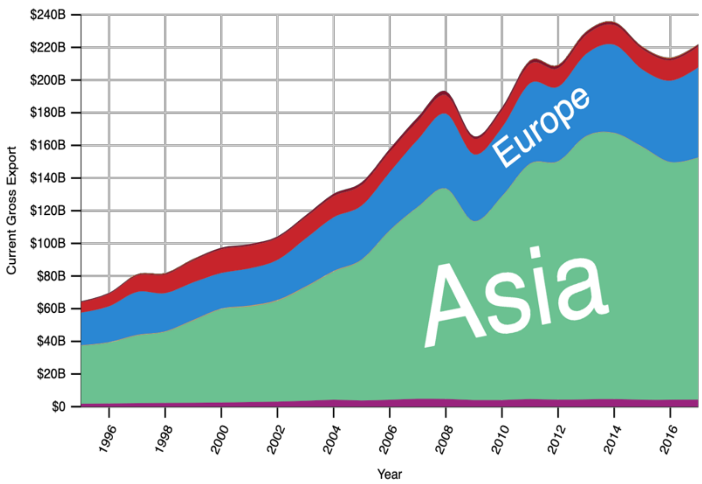

Figure 2-2 Gross exports of knit apparel 1995-2017 adjusted for inflation

Country	Share of gross global exports
China	32.8%
Bangladesh	7.6%
Vietnam	5.5%
Turkey	4%
India	3.6%
Cambodia	3.3%

Figure 2-1 Top 6 exporters of knit apparel in 2017 based on value of exports

Source: Atlas of Economic Complexity, Growth Lab at Harvard University, 2017

Even with this regional concentration of production, the structure of these supply chains is very complex and very few facilities are vertically integrated[4], meaning that materials can get processed at very different places along their life cycle. This is often determined by the highly specialized core competencies of each supplier, where certain suppliers only produce one type of fabric, while others only produce one type of garment. When considering the different components that go into producing a single garment, and the sheer variety of a single company's product portfolio that changes from season to season, it becomes clear that managing social and environmental impacts along a supply chain can be complicated with such disperse information.

2.1.2 Production stages and Types of Textile Waste

Varying types of waste can occur along key production processes in the apparel value chain. The following is a simplified overview of the typical apparel value chain from diverse literature sources (Ashby et al., 2013; Domina & Koch, 1997; Goldsworthy & Ellams, 2019; Muthu, 2017):

- Product design is done by the focal companies[5] (or brands) and are often the target of pressure from civil society as they have relations with both customers and a degree

[4] A vertically integrated manufacturer is when a company owns and controls the various stages of production, from raw material to assembly and logistics to distribution. Source: https://www.sgtgroup.net/textile-quality-management-blog/sourcing-apparel-vertical-vs-horizontal-integration-pros-and-cons

[5] In supply chain literature, a focal company is one that initiates the transaction across a supply chain by conceiving and designing the product or service offering. It can also be seen as the one that governs the supply chain, but this can depend on the relative power between buyer and supplier.

of control over the supply chain. It is in the product design and development phase where the value chain impacts of a product are determined, specifically through the choice of raw materials, longevity, and ability to be recycled.

- Fiber production involves the creation of the raw material. Considering synthetic fibers as the scope of this project, they are produced from limited stocks of crude oil. The processed crude oil is polymerized and cleaned, creating polyester chips (in the case of polyester), requiring heavey metal catalysts.
    - With yarn and fabric production, filaments are produced by melting the polyester chips and forcing it through spinneret holes. The extruded filaments are collected into thread forms, then stretched and drawn to yield polyester yarns. The yarn is then either weaved or knit to create a two-dimensional fabric. Often in this process additives are used to simplify the production.
- The fabric is then dyed and finished, which involve processes that specify color and modify the properties of the fabric based on the need.
- Garment or apparel production (or often referred to as assembly) is the actual manufacturing process of the article of clothing itself. Here, the fabrics are cut to specification and sewn together, combined with other materials such as zippers or buttons.

As Figure 2-2 below demonstrates, there is some form of waste at each major life cycle stage of textile production. The term "pre-consumer leftovers" is commonly used, which refers to any type of leftovers that emerge through the value chain but never reach the consumer. "Post-industrial" leftovers can refer specifically to waste that emerges from fiber, fabric and garment production and is the responsibility of the respective supplier to dispose of (Englund, Wedin, Ribul, de la Motte, & Östlund, 2018; Runnel, Raihan, Castle, Oja, & Bhuiya, 2017). This type of waste is generated by four different groups: fiber producers, textile mills, fabric and garment manufacturers (Domina & Koch, 1997).

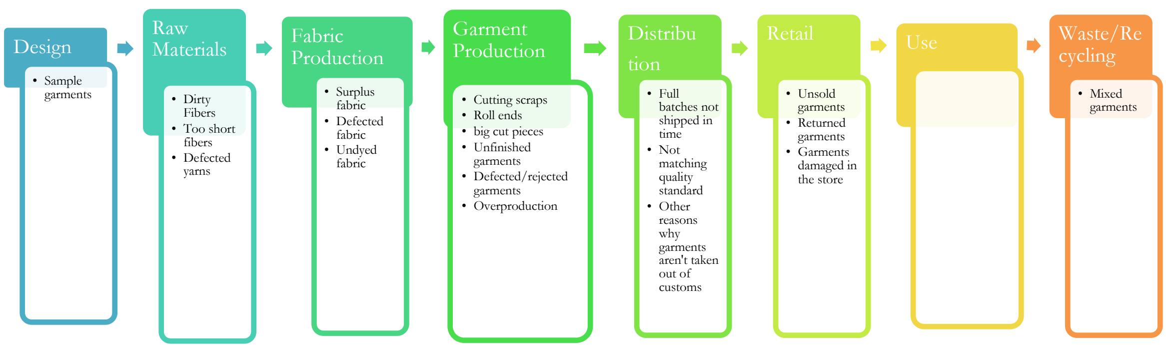

Figure 2-3 Simplified value chain and examples of waste/ spill from each phase

Source: Based on data from (Runnel et al., 2017)

The production waste is generally heterogenous, and often from a single producer waste can vary based on material composition, piece size, reason for discarding the materials from production, and the method of segregation, among other reasons (Bhuiya, 2016; Dobilaite et al., 2017). End of roll fabric in particular is problematic as many brands order more fabric than required in order to replenish stocks in case certain product lines are more popular than expected (Cassidy & Han, 2013). This means that there is a large amount of fabric waste at the onset of the printing and assembly processes.

Some studies have demonstrated that the volume of production leftovers is systematically underreported and thus underestimated by the industry. One study by University of Cambridge (Park & Evans, 2017) found that factories in Sri Lanka were losing 15-20% of input material as post-production waste, while a survey by Runnel et al. (2017) of 7 factories in China and Bangladesh (respectively) found that at least 25% of the input used by these factories is lost. In this survey, they found that data from factories about leftovers is inaccurate and not comprehensive enough; simple spreadsheets and irregular inventories do not capture the complexity of the waste produced. Often times, these factories do not have a systematic categorization of production waste, making comparing methods challenging. This study found that as a result of general unawareness of the situation, production leftovers are under-represented in the discussion of circular economy.

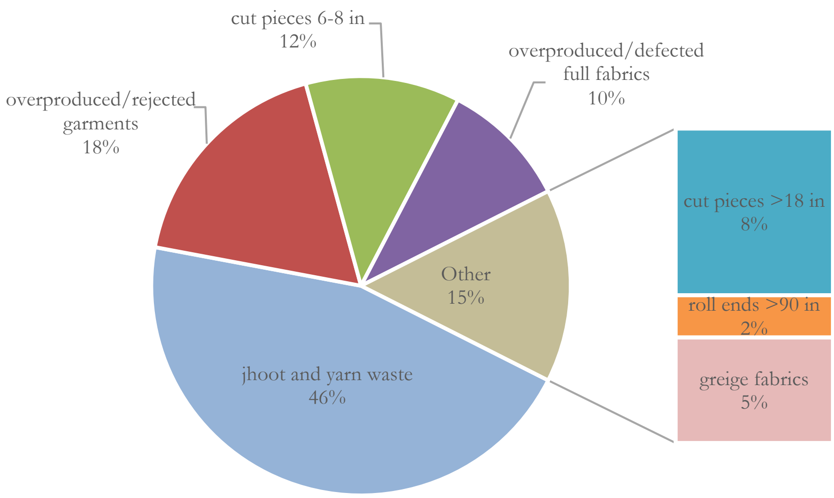

Figure 2-4 Proportion of different types of leftovers from a vertically integrated fabric and garment factory in Bangladesh[6,7]

Source: Own figure with data from (Runnel et al., 2017)

In Runnel et al.'s study (2017) a vertically integrated fabric and garment factory in Bangladesh, they were able to get a glimpse of what categories of waste were most represented in the mix.

The type of leftover waste that emerges from production has implications for how it is sorted, collected, and subsequently treated when considering circularity strategies. This vertically integrated facility is a unique example in that all the major processes occur in one place, meaning strategies to deal with this waste can be more comprehensive. The apparel industry is much more specialized and fragmented, meaning that these waste categories can occur at different facilities, adding another layer of complexity to their management and circularity strategies.

[6] This particular factory produces 7 million garments per month and generates an average 300 tonnes of spill per month.

[7] Textile waste traders in Bangladesh refer to garment leftovers as 'jhoot'.

2.1.3 CSR in the Apparel Industry

It is recognized that brand reputation and corporate image are important for future business profitability. Rising scrutiny of the global implications behind the apparel industry's activities has put pressure on brands and retailers to focus on the core sustainability problems associated with their production. This has motivated them to acknowledge corporate responsibility in their supply chain networks, not only to manage risks around a corporate image, but to capitalize on improvements in competitiveness and reputation (Li, Zhao, Shi, & Li, 2014).

Corporate social responsibility (CSR) has had many different kinds of definitions in literature, which demonstrate different understandings of the concept. While there is no single definition that captures CSR, in essence, it can be perceived as the movement of a business to take responsibility for the impact of its activities on customers, employees, communities and the environment (Dargusch & Ward, 2010). The strength of a company's CSR strategies is the focus on the core problems associated with its production, which brings about the ongoing challenge of clarifying the objectives of a respective company's corporate responsibility (Larsson et al., 2013). These objectives can vary from company to company based on its values, norms, and rules. Motivation to adopt CSR practices can vary, and literature has classified CSR as strategic, altruisitic, or coerced (Li et al., 2014). When a company engages in strategic CSR, it recognizes the economic, social and environmental value it can receive through a comprehensive strategy that addresses its impact areas. In considering an apparel supply chain, strategic CSR can be seen as an effective tactic to coordinate and facilitate management of problem areas across the supply chain system as suppliers are key stakeholders.

Notably, the concept of shared value emerges in the literature, where CSR objectives are in line with values of a company's stakeholders, namely the suppliers in the network whom are critical to engage (Larsson et al., 2013). Therefore, a company's values define its sustainability strategy, which involve holistically and purposefully identifying initiatives that support that strategy and have traceability and visibility across its operations (Ashby et al., 2013).

In Larsson et al.'s empirical findings of how apparel companies engage with their value chains, they identified four broad categories: in-house activities, first-tier suppliers, subcontractors and second-tier suppliers, and raw material suppliers. Following the scope of this project, we will look at the first two. With *in-house activities*, a brand adopts a company culture and subsequent internal capacity changes related to achieving the CSR objectives and engaging with the value chain. According to Larsson et al., first-tier suppliers, represent the best chance of influencing corporate conduct as formal business contracts exist and there are more direct transactions. First-tier suppliers are pivotal because they are the ones that engage with second-tier suppliers, where information is much less transparent and difficult for focal companies to manage. This is where long-term investments in relationship building to achieve CSR objectives are important.

Dargusch & Ward (2010) conducted a survey of several outdoor apparel companies and their CSR practices. While all the companies engaged in different types of CSR practices, a small number of firms engage in multiple forms of CSR that address different dimensions of sustainability, specifically regarding the management of their supply chains. These firms also had differing views on how the three broad categories of CSR issues (social, financial, and environmental) were relevant to their business. While most of them highly valued social and environmental issues, very few of them expressed a systems view[8] of CSR across the categories, which reflected in the fact that a large number of of these firms did not engage in CSR initiatives in their supply chains. The authors found that this discrepancy with so few firms engaging in with multiple CSR initiatives in their supply chains comes from the fact that a firm's capacity to engage in supply chain management (SCM) practices is mediated by its size and available resources. Participants in the study expressed that certain SCM practices were complex and required substantial skills, resources, and capacity to undertake. Using an exemplar case:

> "Nike is a massive corporate machine with the resources needed to maintain social standards and transparency within their supply chain" (Dargusch & Ward, 2010, p 102).

This demonstrates that while a company's values are integral in defining it CSR strategies, its internal capacity and resources to be involved in certain CSR-related practices in its supply chain may be limited. Much of the public scrituny falls on the big brands in the apparel sector, which have the more visible CSR initiatives. More research could be done on how small and mid-sized firms within different fields in the apparel industry engage in SCM practices with their smaller resources and influence.

2.1.4 Life cycle Assessments and Life cycle Thinking

Life cycle assessments (LCA) and life cycle thinking (LCT) have been increasingly part of the discourse to reduce the environmental impacts textile and apparel production. In terms of impacts related to production, this perspective looks at the impacts of the specific processes along the value chain to identify hotspots where high levels of resource use and pollution occur. This can guide design improvements for production processes, quantitatively identifying environmental problems in the whole production process to make technical adjustments to realize positive environmental benefits (Zhang et al., 2018).

LCAs classify and combine flows of materials, energy, and emissions into and out of each product system by the type of impact their use or release has on the environment. One study[9] of the global apparel industry by Quantis International analyzed pollution impacts along key life cycle stages using the following five indicators:

- Climate change (or greenhouse gas emissions, in kilograms of carbon dioxide equivalent (kg CO_2 eq)
- Freshwater withdrawal, in cubic meters (m^3)
- Human health, in Disability Adjusted Life-Years (DALYs)
- Ecosystem quality, in Potentially Disappeared Fraction (PDF) of land per square meter per year ($PDF*m^2*y$) which relates to likelihood of species loss
- Resource depletion, energy in megajoules (MJ)

[8] According to the authors of this study, this implies that the three sustainability categories had to be managed in an integrated manner to achieve good CSR outcomes.

[9] This study considered multiple fiber materials (cotton, natural fibers, synthetic, cellulosic).

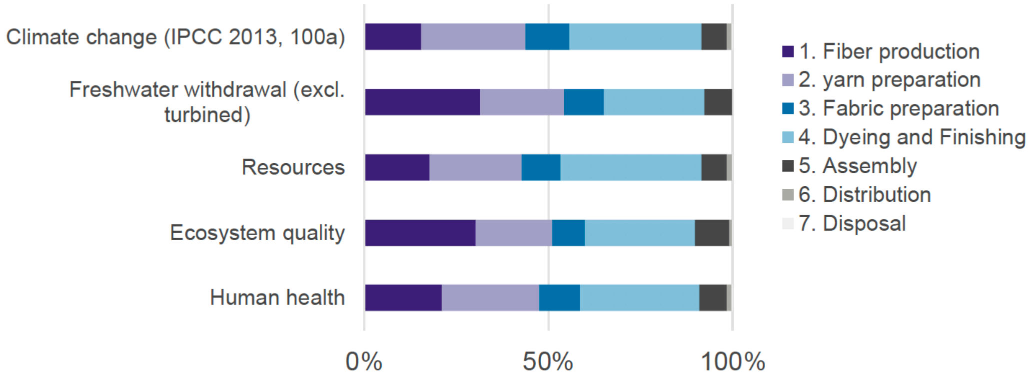

Figure 2-5 Contribution of each life cycle stage of the global apparel industry by each of the five impact indicators

Source: (Quantis International, 2018)

The study came to the conclusion that Dyeing and Finishing, Yarn Preparation and Fiber Production were the three main drivers of the industry's global pollution impacts (see Figure 2-4 above). For the Resource indicator, it primarily considered abiotic resource depletion based on the energy-intensity of the respective life cycle stages. In the report's long-term impact reduction scenario of closing the loop with recycled fibers, considering fabrics with a 40% share of recycled fibers, the study showed that the impact reduction potential for closing the loop is significantly lower than other action items such as switching the industry to renewable energy and increasing energy efficiency. While this report uses an internationally recognized life cycle impact assessment method[10] and looks specifically at production processes, the impact categories primarily focus on the impacts of energy use and emissions released during production and does not include waste that could be generated by the respective processes.

Another study by Zhang et al. (2017) used LCA to identify textile production processes with high energy costs and levels of pollution that would benefit from 'best available technology'[11] development. The focus of this LCA was primarily the environmental performance of the whole system, looking primarily at emissions (both direct and indirect) related to air and water in order to classify important hotspots and evaluate where optimization benefits for specific cleaner technologies could be applied.

A study by the Swedish Environmental Protection Agency (A. Östlund et al., 2015) looked specifically at the potential environmental benefits of mechanical and chemical recycling processes and examined the following impact criteria: acidification potential, eutrophication potential, ozone layer deplection, photochemical oxidant formation, human toxicity, freshwater aquatic ecotoxicity, and terrestrial ecotoxicity. It found that in general, both types of fiber recycling provide environmental benefits compared with conventional disposal (landfill and incineration), yet certain fibers such as Lyocell[12] consume more energy in production than cotton. This justifies the need to monitor the efficiency of different recycling steps (chemical treatment, waste disposal, transportation, processing effectiveness) with consideration of broader impact categories. Some authors also point out the potential issue of

[10] IMPACT 2002+ cQ2.2 Further information: https://www.quantis-intl.com/pdf/IMPACT2002_UserGuide_for_vQ2.21.pdf

[11] " Best available technology" often refers the state-of-the-art technology available for a particular process.

[12] Lyocell is made from cellulose fiber made from dissolving bleached wood pulp. It is considered a natural fiber.

transportation from collection to the recycling site, as well as subsequent problem-shifting between geographic regions, as another issue that may lower environmental benefits (Sandin & Peters, 2018). Using this perspective, the environmental benefits are dependent on whether the recycled fibers actually replace virgin fibers, but also the type of fiber being recycled. As will be covered in Section 2.3.3, material blends pose an challenge to recycling and can consequently effect the efficiency of the process and the associated environmental benefits of recycling.

In theory, an LCA should capture the resource and pollution impacts along an entire value chain, including production leftovers. But the common literature in textile production does not consider this. These LCA studies look at established impact categories that guide the whole methodology, notably ecological impacts, and human health. While these studies used established methods for conducting the LCAs, an issue is that they often have narrow categories that may not capture the full extent of production impacts. Because of the strong focus on climate change and other emissions, there is a risk that many studies have not managed to identify all the major environmental gains and losses of various textile production and recycling practices (Sandin & Peters, 2018). More impact categories should be studied, such as production material waste, to better inform industry and society about the breadth of impacts at various stages. More research should also go into understanding the environmental potential of cascade systems designed to get the most out of a given virgin or recycled material, refering to textile downcycling or upcycling. Further studies could explore the benefits of combining different types of recycling routes for different fabric types as well, including the comparison of open and closed-loop recycling systems. This could expand the ongoing LCA discourse of informing waste reduction strategies to include better waste management strategies in the textile industry.

With regards to more general LCT, *The Pulse of the Fashion Industry* (Global Fashion Agenda & The Boston Consulting Group, 2017) mentioned in Section 1 looks at the impact of fashion from the design phase to end-of-use and assesses the industry's level of sustainability, identifying key issues and focusing on eight impact areas, including social and environmental dimensions of sustainability. Though this is a report for a broader audience, it uses LCT in its analysis of areas where the industry could improve its performance. When considering the waste impact area for the processing and manufacturing stages (see Tables 2-2 and 2-3 below), it features labor practices, health and safety, energy and chemicals as having impacts of higher priority, while waste (including cuttings, roll ends, samples) features lower on the list. This demonstrates the greater attention that those impact areas have over waste generation in the manufacturing stage and reflects the subsequent attention that society and industry have dedicated in addressing the problem. Refering to Figure 1-3, the fashion industry has clearly not addressed waste management sufficiently, necessitating a different perspective on production waste. While the author of this thesis does not want to undermine the magnitude of those findings, he believes more attention could be given to material waste along the supply chain so it can be seen as the next frontier in supply chain sustainability.

Impact area	Magnitude of impact	Biggest drivers
Water	High	Water use in dyeing Water use in cleaning, rinsing of fibers
Energy	Very high	Share of renewable energy use Energy efficiency of equipment
Chemicals	Very high	Lack of waste water treatment in dyeing Chemicals for fiber treatments
Waste	Medium	Waste of fibers/fabrics (e.g., roll ends, off-cuts, samples)
Labor practices	Very high	Low level of wages, non-compliance to min. wage laws, gender inequality Worker wellbeing, bonded and child labor
Health & safety	Very high	Building safety Chemical exposure of workers
Community & ext. eng.	Low	
Ethical practices	Low	Prevalence of corruption

Figure 2-6 Processing Stage: Magnitude of impact and drivers for each impact area

Impact area	Magnitude of impact	Biggest drivers
Water	Low	Water use in garment finishing
Energy	Medium	Share of renewable energy use Energy efficiency of equipment
Chemicals	Low	Toxicity of materials used for prints
Waste	Medium	Waste from cut-and-sew, samples
Labor practices	Very high	Low level of wages, non-compliance to min. wage and overtime laws, gender inequality Worker co-determination (unions)
Health & safety	Very high	Issues in building safety Insufficient length of rest times
Community & ext. eng.	Medium	Setup of local infrastructure and services to workers
Ethical practices	Medium	Prevalence of corruption

Figure 2-7 Manufacturing Stage: Magnitude of impact and drivers for each impact area

Source: (Global Fashion Agenda & The Boston Consulting Group, 2017)

Additionally, the *Pulse of the Fashion Industry* only considers recycling post-consumer textile waste in its analysis, excluding the potential of waste upstream. In reference to earlier in this section, this reinforces the need for more studies to look at the environmental benefits of recycling pre-consumer/post-industrial waste in particular as the majority of studies look at post-consumer waste by default as it represents the majority of textile waste, even though the logistics behind recycling it are much more complex.

2.1.5 Recycling Routes

According to the European Waste Hierarchy, material or product recycling is less preferable to reuse and overall waste prevention[13]. However, after considering process optimization to reduce waste in textile production, recycling is certainly more preferable than immediate landfill disposal or incineration, where the value of the material is lost. As textile production is very energy and resource intensive, recovery of these materials through the application of

[13] Following the EU Waste Framework Directive.

recycling technologies offers potential for regenerating value and recirculating the materials, contributing to the vision of a circular economy model (Ellen Macarthur Foundation, 2017; Le, 2018).

There has been increasing interest in textile recycling, from a regulatory, industry, and societal perspective, to reduce the impact of textile production and potentially reduce the production of virgin textile fibers. While reuse means prolonging the practical service life of a textile product by transferring it to new owner, recycling typically involves a technical process. Le (2018) defines recycling as "the process of taking a product or material, breaking it down to make a material that is more valuable (upcycling), of equal value (recycling), or lower value (downcycling)". This processing can involve either pre- or post-consumer textile waste for use in new textile or non-textile products (Sandin & Peters, 2018).

There are different recycling routes and categories that describe the flows and processes of materials. Four major classifications of recycling have been identified in the literature, with Figure 2-5 below showing how they specifically relate to textiles. These classifications include *mechanical* and *chemical* recycling, which in reality is overly simplified because textile recycling routes can include a mix of these different processes. Section 2.3.3 will go into more detail to specifically describe mechanical and chemical recycling of polyester fiber in particular.

Figure 2-8 Classification of recycling regarding textile waste

Source: Own figure based on information from (GreenBlue, 2017; Le, 2018)

Other classifications of recycling involve the ultimate value and quality of the material. As aforementioned, textile *downcycling* is a process where materials are converted into products of lower value (or as inputs for such products), that do not fully utlize the material properties, such as insulation or fill materials (Le, 2018; Sandin & Peters, 2018). This is usually the case with fibers that are difficult to recycle or whose quality is too poor to be used again for apparel.

In contrast, textile *upcycling* is where waste materials are converted into something of higher value or quality, essentially maintaining the materials' value through subsequent life cycles (Sung, 2015). The context of upcycling varies based on material and industry discussed as it involves the specific material properties. While mechanical and chemical recycling are considered preferable to disposal, upcycling is seen as one of the most sustainable circular solutions. It provides reductions in environmental impacts or contributes to a higher environmental value or performance of materials by altering the linear progression of material utilization into cycles of reuse (Cassidy & Han, 2013; Cumming, 2016; Sung, 2015), consequently reducing material and energy use to create virgin materials. Upcycling and downcycling are often referred to as "cascading" either up or down a material value chain (Sandin & Peters, 2018; Sung, 2015). A subsequent section will go into further detail of what upcycling means in the textile industry.

Another classification for recycling routes to describe the flow of material in a circular economy are *open-* or *closed-loop* recycling. Open-loop recycling refers to when materials from a product are used to create a different product (such as clothing to matress filler) and is often associated with downcycling, though this is not always the case (Le, 2018; Sandin & Peters, 2018). An example of successful open-loop *upcycling* is when PET[14] bottles are chemically recycled to produce monomers that are then used to create new polyester fibers.

Closed-loop recycling, on the other hand, keeps the material flowing within the same product value chain and is reused to create the same kind of product (GreenBlue, 2017; Sandin & Peters, 2018), such as fiber-to-fiber recycling. In the case of textile materials, closed-loop recycling involves processes where textile waste is converted back to new yarn and fabrics to be used for subsequent apparel production (Le, 2018). Closed-loop recycling is often associated with upcycling as the quality and value of the material is preserved in subsequent life cycles.

Finally, with a more technical specification, *fabric recycling* is where the fabric of a product is recovered and reused in a new product, whereas when the fabric is dissembled and the original fibers are preserved, it is referred to as *fiber recycling*.

Textile recycling technology is a key enabler in transitioning to a circular system, specifically regarding closed-loop upcycling (Le, 2018) and must be used as levers for improving sustainability in the industry. As will be discussed later in this literature review, recycling efforts must be amplified through coordinated efforts across industry stakeholders and the life cycle stages of textile products.

2.1.6 Transnational Standard Initiatives

With focal companies paying greater attention to their complex supply chains in pursuit of expanding their CSR practices, more holistic strategies are necessary across borders and the wider textile industry. Initiatives to govern international supply chains have emerged from non-state actors, namely civil society and industry, with the aim of increasing collaboration across relevant actors. Transnational companies[15] have become active in new forms of voluntary governance and concern specific issues, actor participation and a 'system of rules' (Meier, 2013).

With growing pressure on the textile industry to improve its sustainability performance, new multi-stakeholder institutions have formed with the aim of developing tools and strategies for the textile industry. Transnational standard initiatives (TSI) are voluntary schemes that certify the sustainability performance of different facets of a brand's supply chain including labor, chemical safety, and material certification (Meier, 2013). They aim to benchmark practices and increase collaboration and innovation among participants. Because of the growing number of initiatives, focal companies "shop around" for initiatives and knowledge on how to improve

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[14] Polyethylene terephthalate, a petrochemical, is widely used to make polyester textiles and solid-state applications such as bottles, containers, films and engineer-grade polymers (GreenBlue, 2017).

[15] Includes small, medium and large enterprises that operate across borders.

the sustainability of their supply chains (Poldner, 2013). However, the literature on these kinds of member organizations and initiatives have questioned their effectiveness not only on the individual institutional level, but also on an industry-wide level in dealing with competition on issues that inherently necessitate cooperation.

In researching TSIs, Meier (2013) sought to determine what was necessary for the effective implementation of these sustainability initiatives in the textile industry. Looking at two schemes regarding labor practices (one of which Oberalp participates in), he identified three primary elements of the institutional design that were important for effective implementation of the schemes' objectives: transparency, strictness and stakeholder involvement.

Information asymmetry[16] often exists between focal companies and their suppliers, which can inhibit successful supply chain management (Ashby et al., 2013; Seuring, 2004). Therefore, transparency mechanisms underpin the effectiveness of the TSI and must be an important part of the institutional design (Meier, 2013). Strictness, as Meier defines it, refers to how well-elaborated, clear, and strong rules that limit choices are to the design of the whole scheme. For example, a scheme that has very precise measurable, and practical guidelines for meeting certification can lead to higher effectiveness by engaging the actors better. Finally, stakeholder involvement throughout the scheme is fundamental, from development and governance, to implementation and auditing. The scheme must have mechanisms for relationship building between parties, whether they be partners or competitors, as stakeholders contribute resources such as knowledge capabilities that can help with achieving the scheme objective.

While there are many such initiatives, those that specifically engage a range of industry stakeholders are of particular interest because of the potential for exchanging knowledge and catalyzing collaboration across the value chain. Two textile industry schemes involved in the certification of textile waste management and recycling in the supply chain are the Global Recycled Standard (GRS) and the Higg Index.

Owned and administered by Textile Exchange, GRS is a full product standard that sets holistic requirements for third-party certification of recycled content, chain of custody, and other practices in the value chain (Textile Exchange, 2017). Its goal is to increase use of recycled materials in products by providing brands with a tool for more accurate product labeling. Through this standard, GRS aims to encourage innovation in the use of reclaimed materials, establish more transparency in the supply chain, and provide better information to consumers. By requiring that each stage of production be certified, GRS encourages actors in the value chain to collaborate and share information on what kind, where and how much waste is generated, building a practice of comprehensive waste management. In relation to the scope of this project, it has specifications for collected pre-consumer material in the value chain, allowing it to contribute to product certification when it is reclaimed. A GRS label would help communicate to consumers that a minimum of recycled material is present in the garment, providing brands an incentive to consider upcycled post-industrial waste in their pursuit of sustainability efforts.

The Higg Index is a suite of assessment tools created by the Sustainable Apparel Coalition (SAC) used to evaluate the sustainability of apparel and footwear supply chains. It helps

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[16] This occurs when one party in an economic transaction possessed more or better knowledge than the other. Source: https://www.investopedia.com/terms/a/asymmetricinformation.asp

standardize methodology for comprehensive measurement and evaluation of the environmental performance of apparel products along the supply chain in three levels – the brand, the product and the specific facility (Muthu, 2015). By adopting a life cycle perspective, the Higg Index helps scientific learning within an organization by identifying vital aspects of environmental sustainability and improvement opportunities. The Higg Index covers waste management and sets requirements for tracking waste streams and developing action plans for waste reduction, specifically benchmarking and encouraging leading practices such as upcycling waste and achieving a higher environmental value (Sustainable Apparel Coalition, 2018). It has particular value in being a starting point for commitment, learning and collaboration among actors in the value chain, but specifically between SAC members.

SAC has caught the attention of academia and industry for being the first multi-stakeholder strategic alliance network in the global apparel industry founded by corporate players (Poldner, 2013). SAC brought together a network of leading apparel brands and retailers for the purpose of developing a common strategy to find opportunities for sustainability improvement and innovation in global supply chains (Muthu, 2015; Sustainable Apparel Coalition, 2018). It is unique in its governance structure that encourages members to share best practices to improve supply chain performance and innovation, and through the coalition's density of network interactions. Collaboration on a project like the Higg Index by bringing knowledge and feedback from coalition members gives SAC a competitive impact compared to similar industry initiatives (Muthu, 2015; Poldner, 2013). The coalition has proven successful in achieving its objectives and increasing industry-wide transparency, not only through its holistic approach of integrating all aspects of the supply chain, but through communication between members.

Production waste is an issue across the textile value chain and requires industry collaboration to find innovative solutions based on determining industrial synergies between key actors (Boiten, Han, & Tyler, 2017; Chizaryfard & Samie, 2016; Todeschini, Cortimiglia, Callegaro-de-Menezes, & Ghezzi, 2017). In order for a meaningful transition to more circular material loops, there needs to be a common language, shared understanding, and careful analysis of what is necessary to close these loops (Boiten et al., 2017). A strategic alliance of key stakeholders like SAC, whose focus is to foster collaborations for sustainability innovations and improvements, is key in addressing an industry-wide problem. More research needs to be done as to what kinds of best-practices big industry players in organizations like SAC share and how they have been able to drive meaningful progress towards circularity in the industry, specifically regarding the common problem of production waste.

2.1.7 Economics of textile recycling and waste management

While recycling systems aim to recapture the full value of materials by extending their life cycles, economic forces often dictate waste management practices and reinforce the linear model. Increasing rates of production and consumption of apparel goods will continue to create excess textiles in the market which, when combined with cheap raw materials such as petroleum in the case of polyester, can make textile recycling an inefficient option when considering the costs of additional processes (GreenBlue, 2017; Koszewska, 2018; Larney & van Aardt, 2010). As with many raw materials, there needs to be a price parity between recycled polyester with virgin polyester in order to scale recycling.

Circle Economy, a non-profit organization, describes textile waste as "excess", to emphasize that it is not the inherent value of these materials that is lacking but rather the lack of an effective, interconnected system to realize their value (Boiten et al., 2017; GreenBlue, 2017; Kinden & Cunningham, 2017). Koszewska (2018) investigated the challenges behind closing the loop in the textile industry and found that the practical and economic viability of textile recycling depends on several factors. Apparel designers think about making products that deliver the features their customers desire, and in the case of outdoor clothing, they need to have certain technical specifications. Aspects of the material such as the fiber composition, the construction and the fabric finish greatly influence the ability of the material to be recycled. Fiber blends and fabric technical finishes pose a problem for recycling (explained in detail in Section 2.3) and can significantly increase the cost (GreenBlue, 2017; Le, 2018; Å. Östlund et al., 2017). As the Circle Economy report (Kinden & Cunningham, 2017) on circular textiles infrastructure mentions, a lack of an efficient and comprehensive system is a big obstacle to greater recycling. There is a lack of up-scaled, accessible and efficient recycling infrastructure that can collect, sort and process this waste at a reasonable cost. Without a greater network of textile recycling plants at local and regional levels, logistical costs discourage more circular practices. As the following section demonstrates featuring case studies aroud the globe, these factors can determine what waste management practices apparel producers choose. Koszewska (2018) also noted that this lacking system results in low-quality materials and blends dominating the recycling market, and often leading to downcycling of otherwise valuable material.

More effective textile recycling markets require greater demand for high quality recycled textile materials (GreenBlue, 2017). The literature has suggested that consumer perception of recycled materials as lower quality is an inhibitor of greater demand for these materials in the market, but that brands must employ strategies to amplify demand for these products from consumers, which can then signal its supply chains to respond accordingly. (Boiten et al., 2017; Global Fashion Agenda & The Boston Consulting Group, 2017; Koszewska, 2018) This can be done in a variety of ways, such as marketing campaigns and standardized labeling to educate consumers (GRS is an example).

The quality and quantity of textile materials are seen as important and interdependent variables in the development of a stable recycling market, with both feedstock and output (Ellen Macarthur Foundation, 2017; GreenBlue, 2017). These affect the cost to recyclers, as well as the scale, efficiency and profitability of their operations. Across all textile industry segments, post-industrial waste sources have a greater chance of achieving cost-effective, high quality recycling in an open-loop system as the fiber type is more homogenous, making it easier to sort and ensure a quality specification, and the economics to aggregate sufficient and consistent quantities are more favorable than with post-consumer sources (GreenBlue, 2017). Apparel producers' biggest contribution to the recycling process lays in sorting their production waste. The way in which this is handled and processed will ultimately determine the value as it arrives to the recycler, where larger quantities of higher quality waste will bring better margins to the recyclers (Tomovska et al., 2017). The cost of introducing such sorting operations on site can be viewed as a burden for apparel production managers, as they must bring in new procedures, labor and technology. The degree of sorting that does occur depends on the market where the waste will be used as it can influence the price they can fetch for waste collection and transport (Rapsikevičienė et al., 2019).

Instances where substantial waste collection and recycling does occur through formal and informal secondary channels, such as in Bangladesh and Turkey (in greater detail in the subsequent section), there are several market forces at play. Lack of transparency and information asymmetry in the supply chain are a common problem in textile supply chains (Meier, 2013; Todeschini et al., 2017), where production leftovers have been discovered to be consistently underreported (Runnel et al., 2017). In a case study investigating the practices of garment producers in Bangladesh, Runnel et al. discovered that this lack of transparency has created an excessive aftermarket for production leftovers that results in several inefficiencies. Brands plan for expected production inefficiency and can buy between 3-10% extra fabric to cover unavoidable cutting scraps. Garments are measured in number of ready-made pieces, while fabric for woven and knit fabrics are measured differently; consequently, the input-output ratio of materials is not actually tracked. Without a proper waste collection and recycling system that values certain kinds of waste, there is no incentive for producers to sort their leftover waste, leading to the mixing of leftovers in bulk. Since producers make small profit margins from regular production, the extra margin from selling their waste to secondary traders can be large. Because of this extra margin and the lack of a developed recycling infrastructure, they have little incentive to sort and report their waste. Furthermore, as covered in the following section, these secondary markets downcycle the leftover waste and lose the potential value of the material. While this is a form of material circularity that is better than disposal, it is by default inefficient.

As covered in Section 2.3, textile recycling technologies exist, but their infrastructure is not yet efficiently scale for many reasons, most notably related to distorted market signals. More research should go into addressing how information sharing across supply chains can help adjust pricing systems so that textile waste can be directed to a use best suited for its physical properties with the least processing possible. This research can investigate how changes in price of recycled materials through fiscal or financial interventions can have cascading effects throughout the textile value chain.

2.1.8 Case Studies of Post-Production Waste Management

As global textile value chains are so increasingly complex and dispersed, so are the methods with which they handle their production waste. This section will briefly cover case studies conducted on the apparel industries in four different countries to investigate how producers handle their production waste and what motivated their behaviors. They are in Lithuania (Dobilaite et al., 2017), Macedonia (Jordeva, Tomovska, Trajković, & Zafirova, 2015), Bangladesh (Bhuiya, 2016; Runnel et al., 2017), and Turkey (Altun, 2012).

In Lithuania, Dobilaite et al. (2017) focused on garment producers[17], where cutting waste amounted to 20-25% of total production materials used in the factories observed. This waste was not sorted, and the vast majority was disposed of in landfills. As Figure 2-6 exhibits, qaste from roll ends was a neglible share of total material used and was found to be partially used by employees. The nature of the industry's mixed and synthetic fibers inhibits greater recycling of this waste. While the trend of recycling waste compared to landfilling waste dramatically changed during the period of this study, the researchers concluded that enterprises tended to manage waste in the relatively easiest way possible, namely, to dispose of it by landfill. This context demonstrates that textile waste was undervalued and not perceived of as a resource for futher use.

[17] Typically, the first-tier suppliers for clothing brands.

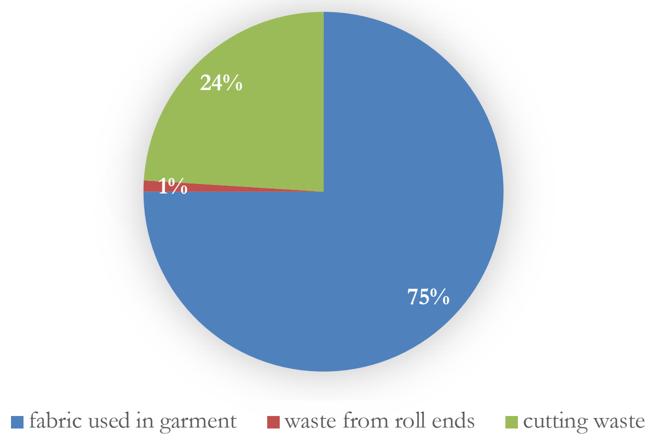

Figure 2-9 Distribution of all materials used by a Lithuanian garment producer over a period of one month (data from 2012)

Source: Own figure with data from (Dobilaite et al., 2018)

Jordeva et al.'s (2015) study in Macedonia sought to analyze the waste generated by the apparel industry and its attitudes towards recycling. It looked at the type of fabric, fiber content and presence of lycra as a high content of lycra would make recycling more difficult. It also considered the distinction between woven[18] and non-woven fabrics since standard mechanical recycling (discussed in Section 2.3.2) requires cutting and opening of the fabric, which necessitates a loose structure, making woven fabrics harder to process.

The study (Jordeva et al., 2015) found that the vast majority of companies disposed of their waste via government managed landfills, where disposal costs were only around 1% of their total budget. The authors believed this was a significant factor that deterred greater recycling. In the instances where recycling would occur, mechanical recycling was preferred over chemical recycling because of the cost-efficiency. Part of this was due to the fact that 42% of companies surveyed produced woven fabrics and a similar percentage consisted of blended fibers, meaning their waste was more expensive to mechanically recycle. The lycra analysis revealed that the majority of companies produced up to 30% of materials containing lycra, adding another layer of complexity to recycling. When asking the managers on their attitudes towards recycling their waste, around 45% of managers said that a lack of market for recycled material was a key factor, while 33% said that the legislative context was, meaning that they did not feel the government supported them enough. Almost half of the managers said they would agree to collect, sort and sell the apparel waste if it was profitable, while another fraction would do so if they had long term agreements with recycling companies or individual buyers. This study concluded that turning recycling into a profitable operation is the main driver in the pursuit of reducing pre-consumer waste.

[18] The basic difference between woven and knit fabrics is in the yarn or thread that composes them. A knit fabric is made up of a single yarn, looped continuously to produce a braided look. Multiple yarns comprise a woven fabric, crossing each other at right angles to form the grain. Source: https://www.dutchlabelshop.com/blog/tips-tricks-tutorials/difference-knit-woven-fabric/

The study of the Turkish textile industry (Altun, 2012) proved very different from the previous cases. Aside from collecting manufacturers' waste management practices, this study included information from recyclers, as manufacturers and recyclers cooperate significantly with handling waste. A majority of manufacturers preferred to sell their waste to recyclers as textile waste is a cheaper feedstock in some processes (see Figure 2-7). Depending on the process and the type of waste, in-line recycling[19] was a common practice in yarn-spinning processes.

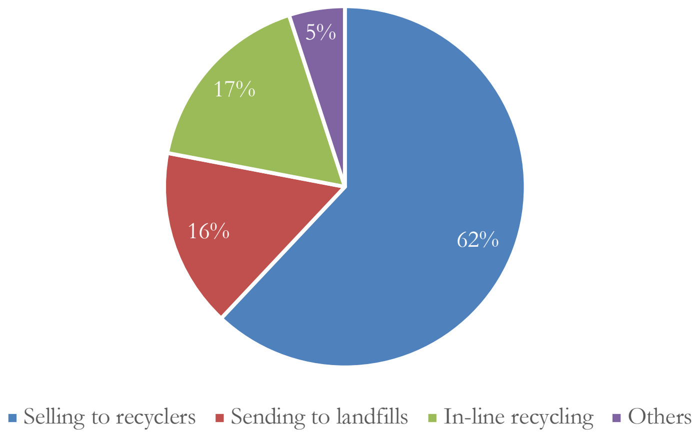

Figure 2-10 Disposal behaviors of manufacturers in Turkey

Source: Own figure with data from (Altun, 2012)

Nearly a third of recyclers would use fiber/yarn wastes, while half would use a combination of fiber, yarn and cutting waste. Depending on the fiber content and type, the overwhelming majority would use mechanical methods to recycle the waste they purchased, such as animal or plant fibers produce new yarn. Synthetic fibers were typically chemically treated and downcycled.

The recycled materials would have several applications, with over half of them being converted into something other than new fiber to be used for apparel (See Figure 2-8). It could be said that these materials were "downcycled", yet this survey included the whole textile industry, not simply apparel, meaning the types of waste generated were much broader and could therefore have more applications downstream. Recyclers in Turkey actually expressed an issue with the

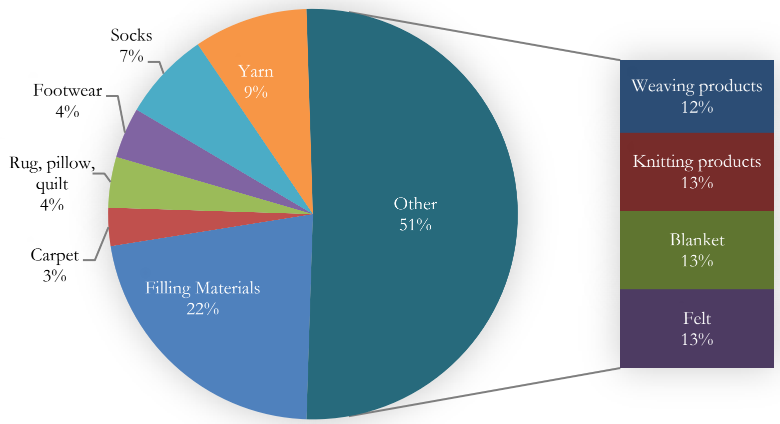

Figure 2-11 Application fields of recycled materials according to survey of Turkish recyclers

Source: Own figure with data from (Altun, 2012)

short supply of waste, so they have resorted to importing textile waste. This case is unique in that Turkey has a more developed textile industry ecosystem where actors across various textile

[19] In-line recycling in this process refers using the yarn waste at the same manufacturing site.

life cycle stages can benefit from each others' byproducts. More research should be done in these kinds of industrial clusters to understand how their synergies can be examples for creating more circular textile production systems.

The case study in Bangladesh offered a very different industrial context on textile waste management. Producers along the value chain do not track the waste that is produced, and at the time of this study, there were no national regulations that specifically addressed textile waste nor was there formal data available about garment manufacturing byproducts. As aforementioned in the previous section, this has created a large informal trading sector of apparel production waste. Factories sell as much of their waste as possible, ranging from cuts and rejected or excess clothing and fabric to auxiliary materials to make as much money as they can. A vast majority of respondents sold their waste to local waste traders in bulk, followed by selling to another company. A small number did in-house recycling or downcycling to recover materials. Most factories did not have a comprehensive waste management system, resulting in bulk amounts of unsorted waste. Informal traders or intermediaries would collect and sort the waste and then sell it to be either reused or to recyclers. When recycled nationally, these materials would be destined for downcycling into lesser value products. While the context of Bangladesh demonstrates an ecosystem that values production leftovers, the full value of these materials is not being captured at the detriment of the garment industry. This study also sought the perspective of these manufacturers on the possibility of upcycling their production leftovers. They generally felt positively about the opportunities that upcycled products could achieve higher value from waste and bring new business possibilities by attracting investers and customers. They expressed that there were supportive conditions for leftover upcycling, that their customers (brands in this case) and manufacturers were interested. When asked about perceived barriers to upcycling, they admitted that a lack of technical knowledge on upcycling, lack of trained labor and partners, and specific customer requirements (such as quality, virgin fibers, cuts and finishes) inhibited greater adoption.

Remarkably, their responses were quite comprehensive for what reinforcement they believed was necessary for waste upcycling. They emphasized cooperation possibilities through greater local and international partnerships for upcycled product development, marketing and distribution. Then, greater access to data and information, though the study did not elaborate on the meaning of this. The producers also wanted a fair price for the upcycled product, meaning that consumer attitudes needed to be reflected in this and that a market needed to be developed. Beyond the consultation and technical training on new techniques, the producers said they also needed the infrastructure and facility updates to accommodate these system changes, which they said would require financing. Finally, producers mentioned their concern for maintaining product quality and ensuring time deliveries to maintain customer satisfaction.

These case studies demonstrate the variety of waste management practices and contexts of garment producers in countries across the world. This significant diversity in local contexts underpins the economic, technical and cultural factors that influence the decisions these producers make when deciding how to manage their production waste. Despite these differences, some key themes emerged from this literature. The state of the current market does not support greater textile recycling and upcycling even less so. Greater demand for recycled materials that can send market signals will trigger change within the industry. Technological capabilities of the producers themselves and the need for more locally developed recycling ecosystems are industry-wide problems that also need addressing.

This complexity highlights the challenges that brands may have when thinking of pursing circularity initiatives, particularly when they have such global supply chains. Research should focus on better quantifying the waste generated upstream in textile supply chains and understand the motives for the different waste management practices. A global supply chain with such dispersed and complex practices necessitates research that captures the big picture to inform more comprehensive material circularity solutions for the whole industry.

2.2 Textile Upcycling

Over the last decade, upcycling has gained increasing attention from industry and academia. While the term is considered a neologism, having only recently appeared, upcycling is investigated for the role it plays in reducing solid waste generation and the need for virgin materials (Sung, 2015). But specifically regarding textiles there has been a greater focus on small scale projects involving post-consumer fabric upcycling, or garment repurposing/recreation, instead of post-industrial waste and fiber recycling.

In the book Textiles and Clothing Sustainability (Muthu, 2017), there are many examples of upcycling that use post-consumer garments and unused leftover stock. The focus is primarily on the small-scale design processes involving mechanical techniques to recycle (or reuse/repurpose, depending on the producer's definition) waste fabric into new products such as bags, shoes, and other apparel items. See Appendix A for images of upcycled garments using production leftovers and the brands that created them.

A few companies have succeeded in operating within a niche market to create upcycled fashion products using small-scale business models. Han et al. (2017) surveyed several upcycling firms to explore the differences in key processes between upcycling apparel and traditional apparel designers and manufacturers. They hypothesized that "as upcycling designers source from waste streams and do not place purchase orders with fabric suppliers, the design and production process for upcycling must be significantly different from the design process for original garments" (2017, p. 72). Table 2-3 summarizes the activities and approaches in key textile upcycling phases that differ from traditional production, specifically regarding post-industrial waste. This table makes evident the different practices that an apparel brand may have to consider throughout the life cycle stages, necessitating creativity and flexibility, and ultimately a change in business model.

Phase	**Key difference in upcycling vs conventional apparel production**
Sourcing	Post-industrial textiles: clothing manufacturers, textile mills- excess orders, unsold stock, faulty products, dead stock and offcuts Main issues: consistency and supply, sorting of the source materials and obtaining the correct quantity of source materials
Research	Sourcing and design based Availability of waste textiles, quantity, quality, location in the supply chain
Design Process	Drawings, mood boards In house teams design, pattern-cut and make samples of initial designs and ranges Flexible design and "patchwork" pattern cutting techniques Non-seasonl slow design process by collection as producted, not by season Design and production stages combined due to one-off and customized nature of design.
Promotion	Consultancy for larger brands Trade shows Public engagement linked to brand
Production	Build separate upcycling facility Innovative modular production technique Exclusive small-scale production by designers Design and production occur simultaneously

Figure 2-12 Summary of distinct practices of upcycling designers and brands through various stages

Source: Own table using data from (Han et al., 2017)

This study brings the attention of upcycling to the design phase as working with existing garments as raw material to generate upcycled designs has different challenges in design and production possibilities, including limited fabric choices, fabric properties and piece size (Han et al., 2017; Muthu, 2017). Furthermore, this upcycling requires a high level of sorting to ensure fiber and fabric types are appropriate for the upcycled designs and end users. Through the specific design process and skilled craftmanship, it transforms the material components into new, high-value products. Pattern cutting techniques must take into account inconsistencies in supply with interchangeable fabric options, requiring a great deal of flexibility and creativity from the designers and manufacturers themselves. Along with fabric sorting and deconstruction, the tailored design can add a significant cost due to the need for labor, thereby limiting this upcycling to small-scale production. See Appendix B for an overview of the upcycled fashion design and production process model devised by Han et al. (2017).

While there are broad calls for the apparel industry to embrace more circular business models in managing its waste, there has been little literature investigating the potential for scaling upcycling projects for mass production.

Cassidy and Han (2013) identified several key challenges that hinder scaling upcycling in the mass fashion industry. First, large and consistent quantities of textiles must be made readily available for large manufacturers. Since design is directly informed by available materials, it is necessary for information on the availability of source materials to be on hand from the outset, in order to achieve consistency of design throughout production (Han et al., 2017). Currently, the lack of consistency in fabric types and colors result in one-off upcycled products as the most common form. Larger companies would benefit from large sections of waste fabrics, offcuts, and excess fabric yet they would also need specialist deconstruction plants to collect, sort, grade and clean these fabrics. This would require new technologies, a skilled workforce and flexibility from the producers (garment producers in particular), as the industry typically operates with color, pattern and product consistency. Industry has the benefit of ready availability of post-industrial waste as these have more consistent quality and reliable supply than post-consumer waste, making it best suited for translating upcycling into mainstream retail (Han et al., 2017).

As Cassidy and Han explain, "the difficulty experienced with balancing an upcycling process for mass production and 'maintaining healthy sales figures' [is that] the process is basically one of 'bespoke, hand-crafted, individual pieces' and that a considerable revolution would be required to make sufficient changes to the traditional manufacturing system". Adopting these kinds of capacities are capital intensive and would require greater flexibility from the manufacturers as there are mass manufacturing imperatives that could affect competitiveness (Boiten et al., 2017), such as the possibility of needing to slow down production to lengthen lead times to balance the supply of waste and demand for upcycled goods (Han et al., 2017).

The decision to use recycled content must begin with the product development and design team and then be implemented through the sourcing of certified recycled fibers, yarns, and/or fabrics. Challenges when using recycled content include an increased cost due to the additional processing costs, limited color selection, consumer acceptance, less uniform fibers associated with mechanical recycled natural fibers, which lead to production difficulties, and an uncertain supply chain (Muthu, 2017, p. 66).

2.3 Synthetic Fiber Recycling Technologies

The focus of this section will be on synthetic fiber recycling technologies due to its relevance to the case study and its wide use globally. Two general classifications, mechanical and chemical recycling, will be briefly covered here along with references to how these processes are involved in the material cascade. Particular attention will be given to the processing of post-industrial waste and fiber-to-fiber upcycling, even though similar processes can treat post-consumer waste. Recycling polyester, both chemically and mechanically, has net environmental benefits compared to simply disposing it, partially because the material derives from a nonrenewable resource (A. Östlund et al., 2015).

2.3.1 Fiber/Fabric Sorting

Waste sorting is the first important step in the textile recycling process and can occur at each facility along the apparel value chain. As seen in Figure 2-1, different types of waste occur along each stage that would cascade into different recycling routes depending on various factors. See Appendix C for more detail on the recycling routes both post-industrial and post-consumer waste can take. While there are external collecting and sorting companies, the majority of sorting (when it does occur) is done at the point of origin manually, requiring extra labor and packaging equipment.

In the case of apparel producers, they sort can sort waste based on the destined end use specified by contract recyclers, such as fiber composition, color, size, or fabric type (Muthu, 2017; Tomovska et al., 2017). This kind of classification based on material properties can increase the quality of the bulk, separating the waste based on its value for its most appropriate cascade route, whether it be upcycled or downcycled.

Since production waste is new, clean and does not typically require special treatments before recycling, it is cheaper to recycle than post-consumer streams (Jordeva et al., 2015). Some streams of can be recycled back into the manufacturing process if the facility is vertically integrated (Jordeva et al., 2015), but most actors in the value chain handle bulk production in individual stages.

This sorting process is also key in gathering and sharing information on production waste that informs supply chain management strategies for brands. While some literature investigates the possibilities of developments in textile tagging and automated sorting technology throughout the value chain to handle post-consumer flows at collection and sorting sites (Englund et al., 2018), innovations in such technologies would render sorting easier on site to handle the variety of waste that a single factory can produce

2.3.2 Mechanical Recycling

Mechanical recycling processes fall under the secondary class of recycling and can produce fabric, yarns or fibers. While it is the simplest recycling technique, the possibilities of end products are limited by the fiber material and quality. This is particularly the case with natural fibers such as wool and cotton whose quality is reduced after the recycling process because the fiber length is shortened (A. Östlund et al., 2015). It is most often employed with single fiber content fabrics as they have the highest possibility for the best quality fiber-to-fiber output.

Higher grade post-industrial waste can be respun into yarns that can then be woven or knitted into fabrics for apparel use again, essentially upcycling the waste. Lower-grade fibers or unrecyclable blends can be downcycled into wipes, thermal insulation, fillings and other end products (Muthu, 2017), which is more often the case with post-industrial textile waste

(GreenBlue, 2017). When natural fibers are mechanically recycled for use in new garments, they often require a certain percentage of virgin natural fiber, or occasionally recycled polyester (Elander & Ljungkvist, 2016; Muthu, 2017; A. Östlund et al., 2015).

Mechanical recycling of polyester can occur in two ways; one that is directly fiber to fiber using purely mechanical processes and another that involves melting, which can include PET bottle waste streams. In the first process, the sorted textile waste is sheared, shredded, and can then undergo a number of different processes resulting in either newly spun thread for knitting or weaving of new textiles. For the re-melt process, the PET bottles are pulverized, chopped, and can then be melted together with the chopped textile waste, followed by extrusion into resin pellets, which are then melted again to form yarns destined to become fibers for fabric production. Polyester from post-industrial waste or post-consumer PET bottles most often undergo fiber-to-fiber mechanical recycling (See Appendices B and C) since the waste material properties are relatively close to 100% PET (Le, 2018). This requirement for pure polyester to render the process more efficient can pose a problem for different blends. However, repeated cycles of mechanical recycling of PET can degrade the polymers and prevent it from upcycling to apparel-grade fiber purposes (GreenBlue, 2017).

2.3.3 Chemical Recycling

Chemical recycling is classified as tertiary recycling and involves regenerating processes which break down (depolymerize) the polymer into its components (monomers, oligomers, and other intermediates). This can be used for either artificial cellulosic fibers or synthetic fibers (polyester, nylon, polyurethane), which have no limit to the number of times the material can undergo chemical recycling (Muthu, 2017). For fiber-to-fiber recycling, the resulting monomers are used as building blocks for creation of virgin quality PET, where they are then repolymerized into long chains that form polyester fibers, filaments and yarns. A similar depolymerization process using different chemical solvents can be used to recycle nylon, or polyamide, another commonly used synthetic fiber by Oberalp. These technologies are often considered to be closed-loop processes since they have the potential to regenerate materials of virgin quality (Le, 2018; A. Östlund et al., 2015).

Chemical recycling of synthetic fibers can be hampered by blended fabrics because of their disparate physical and chemical properties. The use of polymers, dyes, additives, and processing agents also pose a problem where removing such substances may result in degradation of polyester during the recycling processes and may require advanced processes for their removal (A. Östlund et al., 2015). There is still limited understanding of the interaction of certain chemicals in recycling processes and what other technical issues may arise. However, Muthu (2017) explains that chemical recycling processes have been successful with certain blends, such as polyester-cotton and nylon-elastane, through a selective degradation method using specific solvents, where the dissolved polyester can be filtered and respun into new fiber. Despite these innovations, these solvents can be expensive and pose environmental concerns, limiting their widespread use.

While chemical recycling has the best potential for closing the material loop for synthetic fibers, existing chemical recycling companies have strict limitations on the kinds of blends they are willing to accept in order to maintain the efficiency of their processes (See Appendix E). This greatly limits the feedstocks they are able to accept.

Chemical recycling is a much more energy intensive process and requires a high capital investment, making it practical if performed on a larger scale with a consistent supply of high quality, sorted feedstock to render it profitable. Furthermore, the lack of widespread collecting infrastructure, distance of recyclers from producers, lack of comprehensive government policies to create a favorable market, and the low price of virgin raw input materials have prevented the proliferation of chemical recycling (GreenBlue, 2017; Tomovska et al., 2017).

2.3.4 Scaling Recycling Across the Textile Industry

While these existing technologies for chemical and recycling technologies have proven to be effective in closing the material loop, as previously discussed, they are not scaled sufficiently to have a significant impact on the industry. Academia and industry reports have highlighted the factors they believe are necessary to enable widespread textile recycling (Chizaryfard & Samie, 2016; Ellen Macarthur Foundation, 2017; Le, 2018; Muthu, 2017; Rapsikevičienė et al., 2019).

A global textile value chain requires a collaborative environment across industry stakeholders, particularly when trying to coordinate and synchronize efforts that create the right conditions for a circular economy. Fostering recycling technologies would require logistics coordination for the collection and transport of materials to enable a continuous feedstock supply. Greater information exchange across the value chain and including recyclers regarding technology developments and waste classification is also necessary to ensure greater efficiency based on what recycling routes are most efficient for the particular waste streams.

Automated textile waste sorting and fiber identification technologies are increasingly necessary to deal with the heterogenous post-consumer waste streams at existing recyclers (Bell et al., 2017; Le, 2018), but they may be important as well with expanding the capacity of these facilities to accept production waste as well to ensure the highest quality feedstocks. Different identification ans sorting technologies exist and must be scaled for commercial operations. Research has also pointed out the importance of traceability systems in the textile supply chain to ensure the flow of information on fabric composition and chemicals used in processing so that the efficiency of recycling processes can be increased (Englund et al., 2018; Le, 2018; A. Östlund et al., 2015). Though this is less problematic for post-industrial waste, especially from known producers, these kinds of information systems must be integrated on the larger scale for recycling systems to handle several kinds of waste streams with varying properties. Information management systems in the textile industry can come in multiple forms and have different objectives, most notably in spurring greater collaboration. This is where TSI's such as the Higg Index and GRS can play important roles as they can help integrate international standards across global value chains. The potential of block chain technology is discussed briefly in the next section.

With the mass variety of fabric blends and chemical finishes used in the industry, recycling technologies need to become more advanced to deal with this heterogeneity. They must be able to have a higher tolerance for fabric blends for fiber-to-fiber recycling and be capable of handling a wider variety of chemicals present in these waste streams. More specific recycling routes can be developed based on certain criteria so as to better categorize waste streams and ultimately increase recycling efficiency. This would necessitate more information-sharing and better sorting technologies, as aforementioned.

Scaling of industry-wide recycling potential should also seek to create conditions that favor industrial symbiosis (Boiten et al., 2017). This would involve a holistic process design approach that places complementary facilities close to each other that could use each other's byproducts and reduce waste generation. Proximity of facilities that operate in various textile life cycle stages would benefit from these "industrial clusters" and help close the material loop (Boiten et al., 2017; Nikolakopoulos et al., 2017). Further research into fostering these industrial synergies in the textile industry is needed.

As discussed in Section 2.1.7, greater demand for recycled materials will help scale recycling technologies, and this must occur through comprehensive industry-wide actions involving the education of consumers and changing the perspective of product design to think in a more circular manner.

2.4 Circular Economy and Supply Chain Management

This section will integrate literature that explores the concepts of circularity, innovation, business models and supply chain management in the textile and apparel industry. It will cover prominent research in academia that is of relevance to the discussion of the Oberalp case study.

Towards a Circular Textile Industry

Embedding principles of the circular economy in the textile and apparel industries has been one of the driving forces behind paradigm change in the business (Todeschini et al., 2017). Aiming to develop circular material flows to maximize value and minimize waste, the circular economy requires a multi-stakeholder and cross-disciplinary approach that spurs collaboration and innovation, both in technology and business models (Boiten et al., 2017; Todeschini et al., 2017).

Addressing the environmental issues of a supply chain repeatedly evoke closed-loop concepts and LCT in research as they apply a connected and holistic view of supply chains. Notably, it is meant to create value for all the stakeholders involved and a competitive advantage to a focal company. The inherent value in high-quality production waste provides an opportunity for actors along the value chain, and engaging in supply chain behaviors can bring about strategic and competitive advantages with cascading benefits (Ashby et al., 2013).

2.4.1 Sustainable Supply Chain Management

Clothing brands and retailers are playing an increasingly important role in closing the material loop in their value chains through coordinated decision-making across actors that manage the flow of materials and information. While SCM has been discussed in management literature and defined in varying ways regarding sustainability principles, in essence it extends organizational boundaries and encompasses responsibility across the full life cycle of a product (Ashby, Leat, & Hudson-Smith, 2012; Sarkis, Qinghua Zhu, & Lai, 2011).

SCM literature on textile supply chains presents different approaches and theories to how a focal company can manage the material and information flows across a supply chain through coordinated strategies and actions. In investigating SCM, Seuring (2014) briefly explores the traditional approaches of industrial ecology: a geographical approach that analyzes local or regional networks of material flows while a product-based approach usually builds on the life cycle of products when analyzing SCM approaches. He presents the concept of "integrated chain management" as distinct from traditional SCM to be more holistic by integrating both the management of material and information flows and collaboration structures and management partnerships, while considering the role individual actors play along each step. Employing LCT, this approach requires defined objectives across actors, material and information flow analysis at each actor level, strategy development and subsequent implementation. Going one step further, this approach could look at the focal company within the broader network of actors to include the wider context of the political-economic reality in which it exists.

Other literature takes a different approach to SCM in the textile sector by including the broader concept of governance, which is a higher level of decision-making that reflects the overall mission and vision of an organization ("Governance vs Management, Is There a Difference?," 2019). Li, Zhao, Shi, & Li (2014) label it "sustainability governance in fashion supply chains" (SCG) by focusing on the CSR behavior and sustainability performance of focal companies and their supply chains. In particular, this research highlights a key concern of SCG is corporate legitimacy and reputational risks that the organizational strategy and mindset. This approach puts a greater focus on the institution, the structures and mechanisms that guide, regulate and control supply chain actors' activities. It is neither a decision-making process, nor a management activity, but a framework in which decision making is carried out (Li et al., 2014, p. 826). With SCG, a focal company designs a special set of institutional arrangements for the stakeholders and uses governance mechanisms, encompassing economic and relational contracts. The authors identified the influencing factors of SCG based on: characteristics of internal members that include the centrality of the focal company and capabilities of suppliers, characteristics of transactions including the density of the supply chain and the complexity of its transactions, and characteristics of external stakeholders such as consumer demands and government policy. This study underscores the role that SCG plays in obtaining a competitive advantage for a focal company in the fashion industry.

Literature broadly looks to deconstruct the influencing factors and theories behind supply chain management in apparel supply chains. It recognizes the power and responsibility that a focal company has when dealing with its value chains and the importance of collaborating with actors. While the reviewed literature takes varying perspectives in how a focal company engages with supply chain management, it largely integrates concepts that prevail in this field such as organizational theory and LCT to provide managerial insight. It also has implications for how supply chains are inherently strategic and involve improving performance and competitive advantage through interactions and continuous innovation.

2.4.2 Collaboration and New Business Models

The single biggest challenge in creating more sustainable supply chains, especially in complex global industries like that of textile and apparel production, is the management and coordination of all actors (Ashby et al., 2013). A systems approach and LCT are necessary to understand the material and information flows and manage capabilities for effective supply chain management, and ultimately innovative solutions to sustainability issues. The traditional, linear business models that dominate the apparel industry dampen CSR efforts that aim to achieve greater sustainability. Focal companies need to systemically integrate sustainability concerns into how they conduct business and create value by adopting collaborative, innovative business models with sustainability principles as a foundation.

Bocken et al. (2016) investigated various business model strategies for a circular economy, and particularly addressed closing material loops to recapture value from waste. These kinds of business models can be "micro" in scope, such as reintegrating the material into a manufacturing process within the same facility, or "macro", when the materials' or products' value is retrieved in a different system. As it applies to this project, "extending resource value" as a business model involves capturing the value of otherwise "wasted" material and turning it into new value. The value proposition is focused on exploiting the residual value of resources and turning it into something of new value, and in the case of apparel production waste, upcycling it into a new garment. This study also refers to the aforementioned concept of industrial symbiosis that involves offering a value proposition to a multitude of actors in a business network, requiring a degree of collaboration to facilitate the transactions and spur innovation. It does not simply need to involve businesses closely located to one another, but also across an industrial network. In this study, Bocken et al. (2016) proposed a circular economy strategy framework, where product design and business model strategies need to be implemented in conjunction, where the business must have an overall vision of "circularity" as its foundation. Therefore, a circular business model must be innovative to capture the business potential of the circular economy and include strategies that integrate a system of actors and activities.

Chizaryfard & Samie (2016) investigate collaborative business models (CBM) in being able to unlock barriers to sustainable innovation across stakeholders, particularly in textile waste management. In presenting key concepts such as the customer, organizational architecture, economics, and value proposition, they argue that a CBM should develop a joint value creation system among stakeholders, requiring a degree of collaboration and innovation at its core. Through their case study, Chizaryfard & Samie (2016) argue that CBMs have to be market-oriented and purposeful in order to be successful, and that the landscape for a CBM should avoid having a fixed nature but should be flexible and adaptive to the actors' varying circumstances. The study also found multiple purposes that regulate a CBM, notably the need of creating systemic innovation in order to create new value and find a new market. Because of the inherent risks and uncertainty associated with exploring new markets and opportunities, collaborative decision-making is crucial. While CBMs can take many forms, there are fundamental elements necessary for them to be successful: they must have information sharing structures between collaborative actors; these actors must develop shared values in terms of finding potential opportunities for collaboration; actors must have a comprehensive understanding of the essence of each other's business value; actors must identify common solutions to shared risks; and the CBM must make effective use of each other's competence and capabilities. CBMs can therefore be an effective tool for innovation within a value chain.

For a focal company to commit to CSR and change its business model requires a degree of innovation to think outside the box. Innovative business models can offer solutions to overcome how companies create value for all stakeholders, requiring collaboration to unlock these opportunities. In researching the innovation potential of a fashion focal company when interacting with supply chains, van Bommel (2013) found that the level of innovation power of a focal company can correspond with the acquaintance with and participation in activities in its supply network. van Bommel illustrated that the innovation power of a focal company was based on the innovation characteristics of the company itself (internal capacity) and the cooperative characteristics of its supply network (relationship with suppliers). By understanding these characteristics, a company's strategy and related activities with its supply network can be better understood. These activities can be divided into 'product' related or 'organization' related, attesting to the varying scales and approaches a company can take to pursue sustainability. This links back to Bocken et al.'s (2016) business model framework where product design and business model strategies need to be implemented in conjuction when considering broader circular objectives. In his study, van Bommel also concluded that companies with a higher degree of innovative power will participate in proactive activities within their supply networks, yet the most relevant innovation characteristics appear to be the insight the organization has into recent developments and trends in the fashion sector

Literature on business models, collaboration and innovation regarding circularity provide us with insight into the foundations of a focal company's journey towards sustainability in the supply chain. Considering this, circular business models begin with the focal company's vision and include the whole value network and activity system, including product and organizational strategies that aim to redefine a company's value proposition.

2.4.3 Eco-Design and Life Cycle Thinking Approach

The collaborative and multidisciplinary approach necessary to create a more circular textile industry begins with the design phase. When considering LCT, the design stage has been identified as a key area to address the impacts of products, with a suggested 80-90% of product life cycle impacts determined at this stage through the material and process choices (Goldsworthy & Ellams, 2019). Eco-design incorporates LCT and plays a pivotal role in the sustainability of apparel supply chains from material selection, process design, production, to end-of-life treatment. It requires close collaboration with the supply chain, necessitating the sharing of resources between designers and manufacturers as they can better understand each other's demands and capabilities (Wang & Shen, 2017). The design process model can include designers and upstream producers collaborating in terms of fabric selection for minimizing waste and increasing recyclability. Diverse sustainability criteria, from material impact, to carbon footprint and process toxicity are considered in the eco-design approach for new and existing products, allowing both a retrospective and proactive view on sustainability improvements (Todeschini et al., 2017; Wang & Shen, 2017). This change in the mass-production paradigm towards sustainability from the design phase requires supporting designers in the interdisciplinary understanding for material and process choices they make.

One study by Goldsworthy and Ellams (2019) aimed to foster collaborative circular design in apparel production by incorporating LCT and developing new collaboration tools. By engaging expert perspectives from material scientists, industry stakeholders, and consumer behavior and LCA researchers, their research unveiled the value of interdisciplinary LCT methods and tools to bring these circularity principles into practice. The project's multi-stakeholder workshops helped ensure material circularity perspectives were included early in the collaborative design process, supporting designers in understanding the life cycle implications of the material and process choices they made, which is a vital part of enabling future recycling and recirculation of material resources (Goldsworthy & Ellams, 2019, p. 3). This research project used a visual mapping exercise that mapped material and chemical transformations of fibers from feedstock, through to new fiber and product and back to feedstock, with the intention of reinforcing this thinking across actors. Through this mapping and information sharing, multiple iterations of design concepts emerged with new understandings of design and material circularity. With LCT being the backbone of the design process, this project reinforced the importance of identifying expertise and capacities along the value chain that can guide the identification of innovation opportunities, defining shared values and understanding of material life cycles, and combining knowledge through iterative processes.

Design for Recycle, one of the three tenets of eco-design, refers to extending a product's lifetime by optimizing its ability to be repaired, refurbished, and to recover the materials it is made from (Wang & Shen, 2017). Designers face the challenge of reconciling function, aesthetic and sustainability in the eco-design of a product, requiring the aforementioned perspectives of LCT and a systems approach. It requires thinking beyond the recyclability of materials, but also the broader context of value chain and the capabilities and values of such actors. Eco-design can provide managerial insights for the firm and the greater supply chain, but also help move away from traditional transactional relationships to symmetrical and strategic partnerships with the value chain (Goldsworthy & Ellams, 2019; Wang & Shen, 2017).

Literature that views eco-design as a new business model has emphasized LCT and the importance of collaboration with suppliers, beginning with aligning stakeholder values and goals in order to maintain a long-term relationship (Todeschini et al., 2017), connecting to the previous section of aligning stakeholder values and understanding capabilities. While literature on eco-design for the reduction of a product's impacts at the end-of-life treatment, more research could look into the value of life cycle thinking that could make use of the inevitable waste created in the supply chain.

2.4.4 Supply Chain Information: Transparency and Traceability

Underpinning collaboration and innovation in supply chain management for a more circular apparel industry is the sharing of information. From strategies related to the eco-design of more recyclable products and improved collaboration and logistics for waste collection and recycling (Boiten et al., 2017), to fostering a more robust global textile recycling industrial ecosystem by stimulating demand and promoting cooperation between actors (GreenBlue, 2017; Le, 2018), information sharing across the value chain continues to be a foundation for greater success.

With complex and global textile supply chains come a flood of different information on the material circulation in the industry, complicating decision-making processes and hindering progress towards a circular economy. Academic literature and industry reports repeatedly mention the importance of transparency and traceability in textile supply chains (Ellen Macarthur Foundation, 2017; Global Fashion Agenda & The Boston Consulting Group, 2017; Runnel et al., 2017; Todeschini et al., 2017), making it a topic of focus when discussing radical changes at the intersection of technology and supply chain management. Not only does it have implications for greater accountability for improved working conditions in a supply chain, but also improved strategic decision-making and potential for innovative problem solving with material circularity.

Reverse Resoures, a non-profit organization, conducted a study (Runnel et al., 2017) on production leftovers in supply chains and discovered the discrepancy of information across value chain actors. As referenced in Section 2.1.2, the data collected by suppliers is often inaccurate or underreported. With the objective of improving industry circularity, Runnel et al. state that "open data from factories would help to improve interconnections and transparency through supply chains and create further significant value for the whole industry" (2017, p. 22). They see the value that "big data" can have to digitally support the textile industry in reducing fragmentation across value chains. Regarding production waste, traceability throughout life cycle stages would provide an opportunity for the industry to establish collective "virtual ownership" and give a perspective of the material flows and efficiency indicators across stages.

Blockchain technology[20] has been a growing topic in literature for the role it can play with improving transparency and traceability in the textile industry. Through a decentralized information exchange network accessible to all actor participants, this digitized data can help transform the industry. In their research on the potential of blockchain technology to improve garment quality in the textile supply chain, El Messiry & El Messiry (2018) point out certain features and characteristics of blockchain that could be useful in the industry. These include compliance, transparency, tracking, tracing, error reduction and many others. The researchers propose a framework by adding information on important metrics to the blockchain at each point along the supply chain. Since transactions and processes can be traced back by any actor to each manufacturing stage when issues arise, blockchain has potential in being a useful tool

[20] Blockchain is an information technology that facilitates online transactions. It is a decentralized and distributed ledger that can record transactions across multiple points in a network. It has been most used in the finance sector but has been applied to improve transparency in other sectors as well. Source: (Runnel et al. 2017) & (El Missery & El Missery, 2018)

in implementing TSI's that require transparency and greater collaboration for innovative circular solutions.

Beyond the technology available to transmit information, the textile industry lacks a common standard that assesses sustainability performance and can serve as a platform for collaboration, with the field being very fragmented (Global Fashion Agenda & The Boston Consulting Group, 2017). Section 2.1.6 discusses TSIs and their potential to set industry-wide standards for performance assessments and sharing industry best-practices. Common standards such as the Higg Index and the GRS not only help communicate information between industry stakeholders for improved traceability and transparency, but ultimately help educate consumers by educating them on product life cycle impacts and build the necessary confidence in recycled material quality. Information technology innovations can help with TSI compliance by detecting issues along the supply chain and reinforce collaborative relationships between actors and expertise groups, especially when it comes to eco-design and spurring upcycling projects (Goldsworthy & Ellams, 2019). Strategic activities requiring LCT necessitate supply chain transparency in order to make these decisions. Appropriate information tools would help the industry collaborate on how to shorten or close material loops, requiring accurate data. Greater information across the supply chain can also help build trust, which is necessary for effective CBMs in dynamic industries (Chizaryfard & Samie, 2016).

The tracking of fabrics through innovative tagging technologies could help increase the efficiency of sorting, and ultimately recycling by determining proper recycling routes, for both post-industrial and post-consumer waste streams (Englund et al., 2018). This information would include exact fiber composition, chemical dyes, finishes, and other details. These technologies could reduce the cost of recycling and improve the economies of scale of these operations industry-wide. According to Englund et al. (2018), an ambitious goal would be for tags to convey information about the production and life cycle impacts according to industry standards to increase transparency about the product. These kinds of initiatives are important for promoting consumer sustainability education as they can inform consumers about sustainability issues and help change their perceptions about the quality of recycled material, such as with GRS. A kind of product storytelling about its lifecycle could be useful in changing consumer mindsets. This kind of consumer information tagging can be important for the long-term competitive advantage of brands (Englund et al., 2018).

Transparency and traceability are continuously developing fields in textile industry sustainability with innovations and research bringing forth opportunities for radical change. More research can focus on the technical applications of these developing tools in improving decision-making and innovation strategies for circularity within the industry.

3 Method

Using the context of Oberalp as a case study for this project, the objective is to gain an in-depth understanding of the challenges a textile company faces in being able to adopt greater circularity and potentially upcycle its high-value production leftovers. By employing Grounded Theory as the methodological approach for this exploratory case study, this research aims to provide new insight on the phenomena with Oberalp and contribute to the greater body of literature. The research questions that guided this research were the following:

RQ 1: What is the potential for upcycling of apparel production waste in an outdoor apparel company like the Oberalp Group?

RQ 2: What challenges does the Oberalp Group face that hinder its ability to upcycle more of its upstream production waste?

3.1 Exploratory Case study

The author became interested in the complexities of supply chain management and how a company can close its material loop through engaging with its value chain. Based on the need identified in literature to research the phenomenon of managing post-industrial leftovers for a more circular textile industry, this research does an in-depth inquiry into Oberalp to provide insights into the issues it is facing in being able to close its material loop in its value chain. As an exploratory case study, this research aims to begin the conversation on what obstacles and opportunities Oberalp has, but also explore what topics would need further investigation, not only for Oberalp, but for the textile industry as a whole.

3.2 Theoretical & Methodological Approach: Grounded Theory

Organizational theory is often the foundation for understanding the complex variables related to management studies as it can help explain organizational behaviors, designs and structures (Sarkis et al., 2011). More recently it has been applied to other fields in management studies, specifically SCM literature, to provide a framework for understanding the adoption, diffusion, and outcomes of SCM practices. Systems theory has also been used to understand supply chain management by applying some of the key principles of complexity, subsystems, and the dynamic nature of the system components (Caddy & Helou, 2007). When adding the dimension of sustainability in supply chain management, this can dramatically increase the complexity of the case at hand.

Issues that result from modern supply chain complexities require a research methodology that informs research as to how different components of inter- and intra-organizational systems interact with each other and affect the whole (Randall & Mello, 2012). Since there are many complex and interrelated phenomena involved in supply chains and sustainability such as power and dependence between firms, supplier negotiations and collaboration, and innovation, a researcher must understand how the phenomena impact the system and how key actors in the value chain perceive and react to these problems given the dynamic environments the operate in. While a literature review by the author on the application of organizational theory to understanding SCM revealed its importance in understanding the field, the author has chosen a different approach regarding what kind of methodology and theoretical framework to use in this case-based research project so not limit his understanding of the subject matter and allow connections to emerge from the research and interviews with the company.

3.2.1 Application of Grounded Theory to Supply Chain Management

Grounded Theory (GT) provides such a methodology to understand SCM by "providing a process that recognizes, categorizes, and relates key individual and organizational variables in a theoretical framework" (Randall & Mello, 2012). GT is an inductive research method that aims to understand phenomena against the backdrop of a larger system through the comprehension of parts (Locke, 2001). It is a pattern-seeking process that relates behavior from personnel at various levels and functions within and across firms and phenomena to higher-level concepts within a theory building framework (Randall & Mello, 2012). It allows for looking at different units within a case study and relating those identified variables by uncovering the environmental and organizational structures and processes upon which organizations in a supply chain act and are affected by.

Beyond simply describing what is happening, GT helps develop categories with dimensions and the propose relationships between these categories. Notably, GT is meant to generate new theory to describe these phenomena based on the case-specific findings. Most importantly, GT provides research results that are understandable to practitioners because the findings are grounded in the practitioners' experience.

Grounded Theory Process

GT in management research involves the progressive identification and integration of *categories of meaning* from the data that results in a theory as a final product (Locke, 2001). This theory is the explanatory framework with which to understand the phenomenon under investigation.

To arrive to this theory, GT research uses a few key strategies: *constant comparative analysis, theoretical sampling, and theoretical coding*. First, GT begins with categories, which can be either descriptive concepts or analytical and emerge from the data and evolve as the research progresses. Coding is when categories are identified, which becomes progressively higher-level and context specific as data is collected on the case at hand. With constant comparison analysis, the researcher goes back and forth between the identified categories to determine similarities and differences between them. This allows the researcher to create subcategories of meaning and to ultimately link categories that capture variation across data sets. Theoretical sampling involves collecting further data to triangulate with existing data with the goal of refining the categories to the point of *saturation*, where a theory can emerge from the data that depicts the relationships between categories and the phenomenon. GT encourages the researcher to continuously review earlier stages and even the processes of the research and reconsider assumptions as new data and categories can emerge.

3.3 Data Collection

By using a more exploratory approach to understanding this case study, the author began with gaining general background knowledge on the sector to better understand the case study. Once preliminary questions were formed, the subsequent data collection for this research then involved the identification of macro categories relevant to the question. Following the iterative GT method, the author would modify the questions after multiple consultations with the company and referring to literature. Therefore, the research questions did not explicitly guide the collection of literature, but rather an "open research approach" was used, allowing for an eventual focus to emerge once the case context was better understood.

3.3.1 Literature Review

Data collection began with desk research to gain a holistic understanding of topics relevant to the case study using secondary data sources ranging from industry and think-tank reports to books and academic literature. The author primarily used Google Scholar and LUBsearch to access online databases to collect academic literature, and then collected data from textile circularity projects funded by NGO's or governments.

Prior to framing the research question with Oberalp, the author began "open coding" using the qualitative analysis software, NVIVO, with a broad scope and gathered data on general topics regarding the textile industry, textile recycling technologies, circular business models, and supply chain management in the textile industry. After narrowing the scope further and clarifying the questions with Oberalp, the literature topics were subsequently distilled, and the focus began on understanding upcycling, collaboration and information sharing in the textile industry.

Following the GT method, the literature did not constrain the research, but acted as a lens to understand the case context as concepts, themes and relationships emerged. The literature was then coded according to these emergent categories. Some coded literature was not included in the final literature review as it was not deemed relevant to the case after the rounds of interviews, while some coded literature was included because the author found the topic relevant in discussing the findings and future implications for research.

3.3.2 Interviews with Oberalp

Primary qualitative data on the case study was conducted through multiple rounds of semi-structured interviews (both on-site and by phone) with four key individuals from Oberalp. These individuals were selected by contacts at the Sustainability Department on their relevance to upcycling projects for the company. The order in which the interviews were conducted was also suggested by the key contacts as preliminary information on the context of Oberalp's post-product waste/leftovers and supply chain was important to understand prior to further investigation. Questions were developed for each of the interviewees based on their expertise and how they would contribute to answering the key research questions. After a material stream was identified, the interviews focused on understanding the existing capacities of the organization, its suppliers, and understanding the nature of the challenges these actors face both internally and externally in being able to close the material loop. Different possible recycling scenarios were discussed with the interviewees based on the state-of-the-art textile circularity practices based on the literature. As they were semi-structured, new themes emerged during conversations as the author would reference previous interviews and build upon discussed themes to get the interviewees' perspective.

Interviewee	Position	# of Interviews	Language of Interview
1	Sustainability Manager	4	English
2	Innovation & Special Project Manager	2	English
3	Purchasing Specialist	2	Italian
4	Fabrics Sourcing and R&D	1	Italian

Table 3-1 List of Interviewees at Oberalp

List of Interviewees at Oberalp

Interviews were recorded and the content was coded based on the categories derived from the literature and then cross-coded with other interviews. Categories that were not discussed or deemed as insignificant during the interviews were removed from the literature review. This is where "theoretical sampling" took place, relating statements to identified higher level categories. Follow-up interviews were used to clarify certain topics as new categories emerged and others became less relevant. During the first interview with the Purchasing Specialist, the author received a document that showed how the company was tracking its leftover fabric at each of its garment producers. While the data from this document is not directly used in this project for quantitative analysis, it did contribute to an understanding of the complexity behind Oberalp's challenges. Elements of this document and how the company classifies its leftovers are summarized later in the Findings section and connected to the subsequent discussions.

3.4 Analysis of Findings

Based on the categories created from the literature and those distilled from the Oberalp interviews, the author sought to find patterns that relate the collected data to higher-level concepts within the theory-building framework of GT. This stage in the research began with constant comparison to find concepts that were similar or different between the coded literature and the interviews, where emerging concepts were validated through cross-comparison of the collected data. The new categories that emerged from interviewing the different professionals were compared with the existing literature and then larger categories were created.

When conducting the subsequent rounds of interviews and cross-comparing the emerging concepts, the author needed to be aware of the potential bias in the interview process when asking questions that would seek to reinforce emerging concepts. The data needed to emerge naturally through objective interpretation of recurring instances without intentionally leading interviews.

Through GT, the author was able to use the pattern searching method to understand the underlying structures and systemic issues. These findings were presented as directly as possible as they were grounded in the practitioners' experience.

4 Findings

This section presents the categorized interview information after rounds of interviews with four personnel at Oberalp using the GT analytical framework. Having begun with the codes used in NVivo derived from the literature review, the author presents the recurring categories mentioned across the interviews and relates them directly to the presented research questions. Subsequent sections will elaborate on these interview findings. This concludes with broader 2nd order themes that help describe the phenomenon of Oberalp.

4.1 The Case Context: Oberalp's Value Chain

Prior to uncovering the codes from the literature and interviews, it is necessary to understand the context of Oberalp's purchasing process, value chain and the production waste that became the focus of this research. Interviews with the Sustainability Manager and the Purchasing Specialist clarified situation. Figure 4-1 illustrates a simplification of Oberalp's value chain to include material-and information flows and transactions.

Oberalp does clothing orders one year in advance, with two seasons per year. It attempts to optimize its bulk orders during these seasons for specific garments to specific suppliers. The brands at Oberalp have different Product Managers (PM) and design teams that design and develop their portfolios of products They use a technical sheet per product, which is the standard industry instrument for product development that undergoes multiple rounds of discussions and iterations with the selected garment producers (GP), the 1st-tier supplier that will be the focus of this project. In its final iteration, the technical sheet will have a bill of materials necessary to produce the requested quantity of said product and the GP will place the order with the fabric producers (FP). The GP calculates the final price for the order, including the various needed materials and processes. These prices are based on how much of each kind of fabric the GP needs to make each product order. As will be described later, both GPs and FPs have order minimums, meaning that brands must order that minimum even if they do not need it, which is often the reason for production waste in the form of leftover roll ends. While Oberalp does research and development activities with FP, they do not buy the fabrics directly from them.

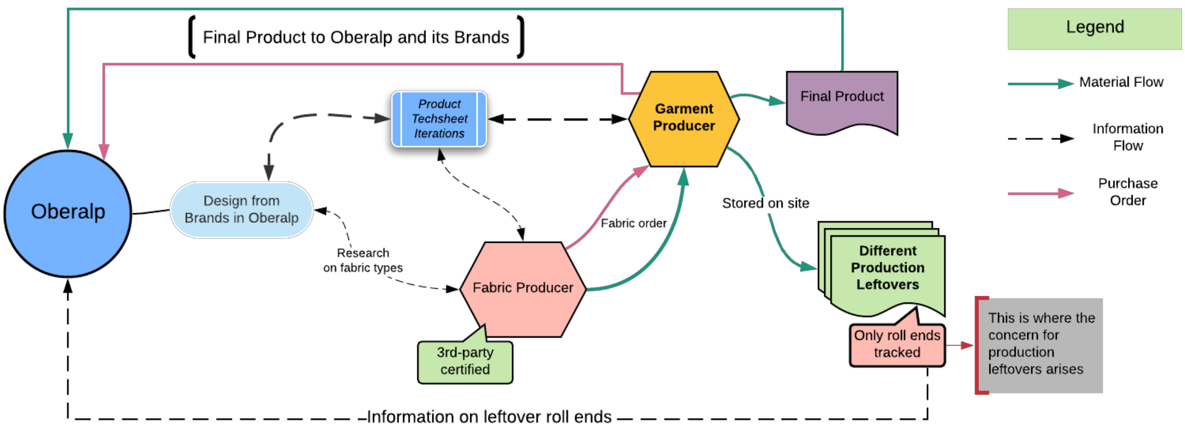

Figure 4-1 Simplified Oberalp Value Chain and Relationships

Source: Created by author

The transactional relationship, and subsequently the information received from the supply chain, is primarily through the GP, the 1st-tier supplier. To Oberalp's knowledge, GPs do not record the overall amount of production waste from each batch produced for Oberalp. The only information that Oberalp receives from its global GPs regarding production waste or leftovers is the quantity of unused fabric roll ends, which are stored on site as a courtesy of the GP. Table 4-1 below demonstrates the extent of the data that Oberalp has on its apparel production waste. It shows the season, the type of order (sample or bulk), material composition, color, final location and quantity. The variety of fabric blends, colors, their disparate locations, and inconsistent quantities give insight into the complexity behind managing these materials from an SCM perspective.

season	SMS/ BULK	composition	DESCRIPTION	location	COLOUR	YD or MT final quantity
S19	BULK	95%PA 5%EA	DYNASTRETCH NYLON 248	VIETNAM	0980 asphalt 1	26
W19	BULK	95%PA 5%EA	DYNASTRETCH NYLON 248	BANGLADESH	0910 BLACK OUT	20
W19	BULK	95%PA 5%EA	DYNASTRETCH NYLON 248	BANGLADESH	8960 poseidon	25
W19	SMS	75%PA 19%PP 6%EA	DYNASTRETCH PP NYLON 196 BS	BANGLADESH	8960 poseidon	10
W19	SMS	66%PA 23%PL 11%EA	DURASTRETCH PA PEACH BAMBOO ECO DWR 188	CHINA	0910 black out	30
W19	SMS	66%PA 23%PL 11%EA	DURASTRETCH PA PEACH BAMBOO ECO DWR 188	CHINA	3860 ombre blue	60
S19	SMS	94%PA 6%EA	DURASTRETCH ENGINEERED ECO DWR HEAVY BS	BANGLADESH	8730 malta	10
S18	BULK	75%PA 17%PL 8%EA	DURASTRETCH MELANGE STRETCH BS	CHINA	8968 POSEIDON MELANGE	160
S18	BULK	75%PA 17%PL 8%EA	DURASTRETCH MELANGE STRETCH BS	CHINA	0936 BLACK OUT MELANGE	90
S19	SMS	63%PA 27%PL 10%EA	DURASTRETCH BAMBOO LIGHT ECO DWR 174 BS	BANGLADESH	6640 parachute	10

Figure 4-2 Sample of Oberalp's datasheets showing key information of leftover roll ends

Source: Document from Purchasing Specialist

4.2 Coding from Literature Review and Oberalp Interviews

Building upon the established context from preliminary interviews with two Oberalp individuals, this section will explain the aggregate NVivo coding structure from the literature review, to the categories identified through multiple rounds of interviews, to the final overarching themes.

Figure 4-2 below presents the multiple orders of coding throughout the research process, beginning with the codes used in the literature review. The NVivo codes guided the author's background knowledge on key topics such as the textile industry and its production waste, circular business models, upcycling, recycling technologies, LCT, supply chain collaboration, etc. Through the interviews, the author sought to discern how these broader thematic codes applied to Oberalp to uncover the challenges and potential for upcycling the identified waste stream as dictated by the research questions. During the interviews, several topics and subtopics emerged which built upon one another after subsequent interviews with the different experts. From these internal perspectives, the author did the constant comparison of the findings which allowed the first order categories to emerge. As Figure 4-2 demonstrates with the color-coding scheme, these emergent categories were then defined as being either a challenge, a potential, or both regarding the upcycling of fabric leftovers. This categorization scheme illustrates the complexity behind this problem and how interrelated these categories are, with category clusters featuring a mix of challenges and potentials, indicating that there is not a linear explanation for the phenomenon.

Figure 4-3 Research Coding Scheme, from Literature Review to Interviews and final themes

Source: Created by author

The categories and subcategories are organized by clusters defined by the broader second order themes. Primary categories are directly connected to the second order theme by arrows, while subcategories are adjacent to their related categories. As illustrated by two dotted lines, some categories and subcategories across clusters are related, but the full extent of potential connections identified by the author was omitted for the sake of simplicity in interpreting the categorical data

The author conceived the broader second order themes after the interview data categorization and defined them based on his experience with the codes he identified during the literature review. As mentioned, the themes themselves do not directly explain the phenomenon as they are broader classifications that encompass both challenges and potentials, but they form part of the emergent theory presented later in this chapter that describes Oberalp's context.

4.3 The potential to upcycle production leftovers

The first step in understanding Oberalp's potential to upcycle apparel production waste is to identify the waste streams it has knowledge of. As indicated in Section 4.1, Oberalp only gets information from its 1st-tier supplier, the GPs, and they only track and share information on the leftover fabric roll ends. These unused fabrics are of high quality and are stored at the GPs' facilities for indefinite periods of time, making these leftovers the only ones under consideration for potential upcycling. Oberalp's Sustainability Manager (2019) highlights roll ends as the company's sustainability priority for the time being:

> This pristine leftover is *the most worrying* source of waste because it is the one nobody has an idea of what to do about. This is perfect fabric where we could make garments, pouches, travel bags, but nobody wants to buy them at the moment. We would need to create a need for them. But we should also tackle another important source of leftover: cutoffs originated by complicated design.

The Purchasing Specialist (2019) even mentioned that she does not consider these roll ends as waste, which was later confirmed by the other interviewees, but as "potential resources to hopefully be used as carryover fabric for a subsequent season or to be used creatively for something else" (translated from Italian). In collaboration with the brands internally, she tries to ensure that these leftovers are used later in subsequent seasons by having the designers incorporate them into new collections. From this growing interest in addressing production waste, the Oberalp Group has launched a few small-scale upcycling projects (see Appendix F) where a few of their brands collaborated with partners to make upcycled products. One of its brands, Salewa, investigated the potential of its material offcuts and created a line of gloves and a smartphone insulator, while another brand, Wild Country, used high-performance leftover fabric from Salewa to create a technical mountain jacket. In examples of collaborating with external brands, Pomoca (another Oberalp brand) partnered with smaller companies to make accessories and slippers from ski skin production waste. These small-scale upcycling projects demonstrate the internal initiatives and creativity that have allowed for thinking outside the box and taking greater steps towards closing the loop. In addition to tracking the data on fabric leftovers throughout the supply chain and the coordination across brands and product groups to think in a circular manner, these small-scale upcycling projects testify to the Oberalp Group's potential in addressing the greater problem of production waste in the long term.

From the multiple rounds of interviews, the author determined three general pathways, or recycling routes, for the leftover fabric roll ends to be potentially upcycled. Figure 4-3 shows the simplified recycling routes to include in-house upcycling at GP, 3rd party recycling, and a broader collaboration with a network of producers and recyclers. These opportunities will be illustrated below.

4.3.1 Industry Value Chain: Relationships and Capabilities

Oberalp has a global network of circa 30 GPs that are highly specialized in making certain garments of high quality. The company has maintained long-lasting relationships with many of its suppliers and has built collaborative business models with several of them to have special arrangements to create small upcycling projects like those mentioned in Appendix F. These GPs range in size and capabilities, with many of them serving other large global brands.

Regarding leftover roll ends, GPs do Oberalp the courtesy of tracking and storing the leftovers with the intention of using the fabric in the future. By storing these roll ends, GPs are making themselves available to further developing their partnership to realize the mutual value of the existing fabric. These shared values of maximizing the use of the resource and being flexible to collaborate and create something new are fundamental in the GP-buyer relationship if upcycling is to occur.

As Figure 4-3 illustrates, in-house upcycling can be a potential option as it does not require the fabrics to be moved elsewhere. From the interviews, collaborating with GPs on utilizing the fabrics requires a clear idea of the final product before. In order for this potential to be untapped however, one must begin at the design stage and be aware of the existing and projected fabric stocks (this will be discussed in a later section).

According to both the Special Project Manager and the Purchasing Specialist (2019), there should be "dedicated individuals at both Oberalp *and* the respective GPs that track the production waste and specialize in coordinating between actors to develop projects". At present, only the Purchasing Specialist at Oberalp collects this data from the GPs and attempts to engage the Oberalp brands and design teams. Having a specialized counterpart at these GPs to help coordinate this task and foster collaboration on dynamic projects would be beneficial to both parties.

Aside from considering the aligned values and willingness to collaborate, Oberalp must also consider the capacity of GPs to create something new with the fabric. In order for such in-house upcycling projects to occur, GPs "must be willing and able to be on board with this kind of project. For example, [GPs] could produce something for us in their low season when they have the time to collaborate" (Purchasing Specialist, 2019). Some FPs and GPs have the capacity (those that are vertically integrated) to do in-line recycling of production waste, such as offcuts (Fabrics Sourcing and R&D Specialist, 2019). Certain firms can also be more flexible with deploying internal resources to accommodate Oberalp's requests to handle fabric waste and collaborate on a new product, such as "in-house laboratories" and market placement specialists[21]. Oberalp must consider the firms' ability to handle delivery times, its technical expertise (what kinds of upcycled products it could make from the leftovers), and the relationship it has with the GP. Therefore, when considering what GP partners to work with on addressing production leftovers, Oberalp must not only consider qualities of the fabric that are present, but also the capacity of and relationship with said GP.

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[21] Marker placement involves placing the garment design outlines on a roll of fabric to do cuttings. As demonstrated in Figure 2-9, cutting waste can reach up to 25% of textile used in garment production. Placement specialists work to maximize efficiency and minimize waste in the garment making process (Sustainability Manager, 2019).

Certain potential upcycling examples using leftover fabric rolls were mentioned during the interviews. As jackets and other complex garments typically feature more than one fabric, leftover fabric could be incorporated into future seasonal collections as a secondary smaller fabric, such as in the form of inner linings or decorative accents (Purchasing Specialist, 2019). Polyester fabrics could also be converted into high quality insulation for jackets, even if this is considered closed-loop downcycling. Depending on the quantity of remaining fabric, its composition and technical features, colors, and what kind of GP it is located at, Oberalp brands could be creative with existing stocks and produce limited edition items, such as the example of the upcycled Wild Country technical jacket (See Appendix F).

Upcycling collaboration does not simply have to happen with the immediate GP, but also with another local producer with sufficient capabilities, but more importantly "similar values and local channels" (Special Project Manager, 2019). Interviewees reiterated the importance of having a clear idea of what to do with the stock material (which begins at design) before sending the material anywhere else. Regarding the concept of industrial clusters (such as in the Turkey case study of Altun, 2012), the Special Project Manager believed that "the best solution [to upcycle leftovers] would be to have a local network around the [GP] if you take the material out, or use the channels available to make something new". She also mentioned the importance of building a supply chain that is "as short and efficient as possible, even if they are far away", suggesting that collaborative networks between local firms would provide the greatest potential.

This type of collaboration beyond the 1st tier supplier to include industry partners seems to have great potential to Oberalp in the long term, as they see "partnerships and sharing intent [closing the loop]" as part of the future. Oberalp is already a part of a few industry associations, such as the European Outdoor Group and the Sustainability Manager mentioned that she is regularly in touch with counterparts at competitors to discuss "issues of shared value…we have factories in common, we source the same materials, we have a lot of the same issues…we ask each other 'Are you a part of that research group? Are you also collaborating in the project? What are you doing about this issue?". This intra-industry collaboration is an important step in addressing a common problem that exists along shared supply chains.

Some of Oberalp's suppliers have begun to adopt the Higg Index and it has asked others to begin to do so as well. Greater intent to participate in a platform that helps standardize the tracking of production waste and sharing the information across the value chain also reinforces the future potential for increased waste upcycling of more streams, beyond simply roll ends. Interviewees expressed interest in addressing other waste streams in their value chains attributed to their practices, such as offcuts, as recycling technologies develop and greater "collaboration with GPs could offer opportunities for reinserting these materials in remanufacturing processes (in-line recycling)" (Special Project Manager, 2019). For now, offcuts are not something considered as part of a larger scale strategy as their information is not tracked and they have more limited upcycling potential, being more suited for direct recycling.

Building upon the author's background research, the interviewees mentioned their knowledge of a growing network of textile recyclers in East Asia. By the time of the first round of interviews (August 2019), Oberalp had been in contact with representatives from the RENU™ Project (See Appendix E for more information on other recycling stakeholders), an initiative by Japanese recycler Itochu Corporation, about the possibility of recycling its polyester production roll ends. This initiative has a GRS certification and does fiber-to-fiber recycling, effectively extending the material life cycle. As textile recycling technologies improve and scale to accommodate textile waste along the value chain, 3rd party recycling has growing potential to provide a viable solution addressing production waste streams (See Figure 4-3).

Each of the three broadly identified recycling routes have varying potential in being able to close the material loop by making different uses of the fabric roll ends. Interviewees see the varying potential of each of these recycling routes but have generally looked at a combination of in-house upcycling and finding local external channels or networks as the most viable immediate option, despite some of the challenges described in a later section.

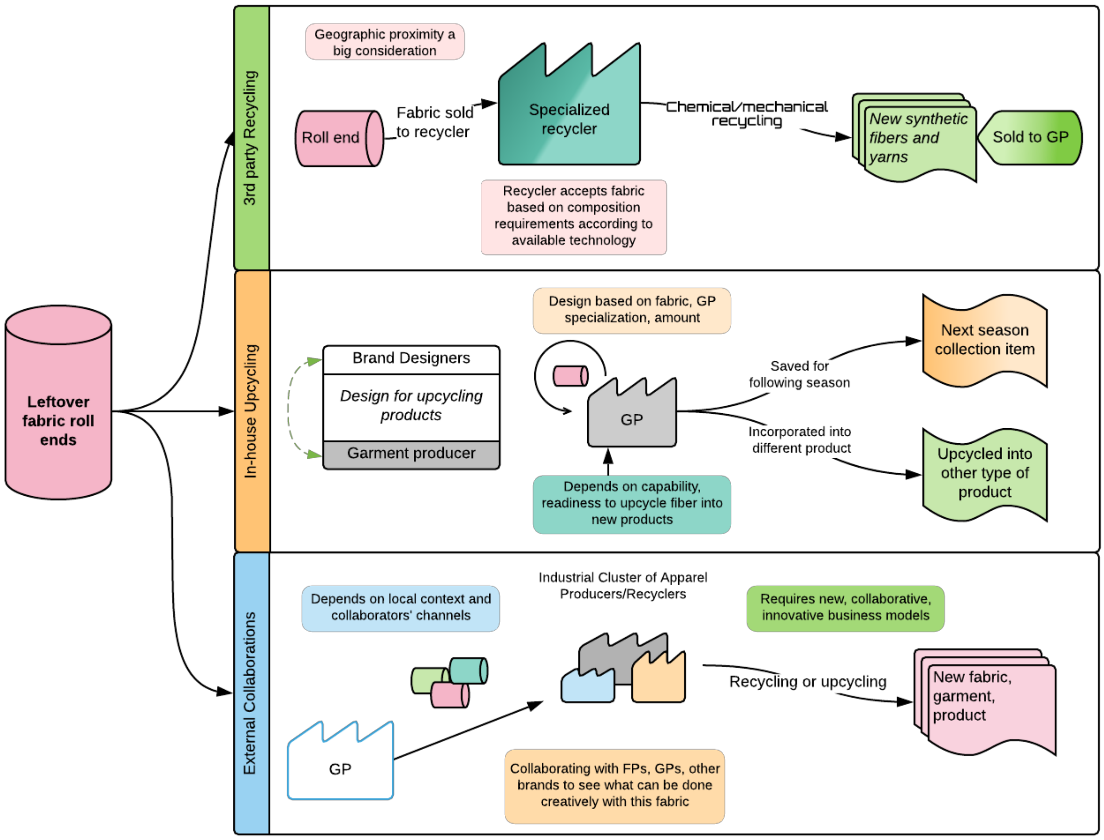

Figure 4-4 Possible Recycling Routes for Oberalp's Fabric Roll Ends

Source: Created by author

4.3.2 Innovation in Product Design and Business Models

The subject of design and a shift in business model occurred repeatedly throughout the interviews and emerged as a key element of the potential for greater material circularity. All interviewees viewed circular design strategies from Oberalp's brands as a major starting point for devising solutions for using leftover roll ends.

The Special Project Manager had many ideas about how a new company culture of valuing resources differently and thinking about circularity from a design perspective was fundamental in unlocking the potential for the organization to dedicate resources to closing the material loop. She sees innovation potential as needing to come from a culture of thinking differently about the leftover materials from design to disposal. She insisted that Oberalp and its brands needed to be innovative in their design approach and that they needed to rethink their use of materials and colors in their collections. Designers could think about what materials could be more versatile and used in different types of products, the colors that follow the seasonal market trends and which can carry over longer, and the capacity of the supplier to accommodate ad hoc product requests based on design ideas. The Sourcing Specialist and the Special Projects Manager both mentioned certain GPs' abilities to create ad hoc product lines from remaining fabric, but that they would require "a clear vision of the final product…and to research the fabric and coordinate with designers". Therefore, material experimentation would need to happen both within Oberalp and in conjunction with others in the value chain to realize the upcycling potential of certain fabrics to new products. The Special Projects Manager mentioned the innovative possibility of experimenting with new products from recycled materials using yarns from Oberalp's most used synthetic fabrics.

As referenced in Table 2-2 about the differences between the traditional and upcycled garment processes, innovation for upcycling needs to think more holistically than traditional business models of production. The Sustainability Manager specifically mentioned the potential that fabric tracking can also have with changing the business model of how to collaborate with patented fabric producers[22], who are already offering a range of recycled fabrics in their collection and therefore have a supply chain in place, by making a case about waste associated with their fabrics. She mentioned possible questions such as "can we make a different business model with the waste we generate with *your* fabrics, and do you have existing partners that we could work with?", suggesting a fabric-specific strategy. Referring back to the Purchasing Specialist's fabric tracking and coordinating with designers to think about existing stock when designing subsequent collections, knowledge of where in the supply chain this fabric exists was also mentioned as important with circular design thinking.

When applying circular thinking in designing for future collections, the Sourcing Specialist mentioned the possibility of reducing the amount of eventual leftovers by reducing the number of fabric types and colors used. With less complex and heterogenous leftover stock, designers can more easily incorporate the stock into new season collections. This would require a concerted change in thinking about the brands' competitive advantage and moving away from trying to continuously offer a variety of color and fabrics. As will be discussed later, this easier said than done.

Oberalp's brands have already created a few upcycling projects that still fit within their image of being outdoor-oriented brands. Designing these innovative products from leftover fabric also requires demand from consumers.

> If you create it, you need to be able to sell it… as every unit must have a return, it must be efficient. This requires a different business model approach about value and the impact of fabric waste in terms of lost money. The return for this added [upcycling] effort could be the storytelling behind the product. (Special Projects Manager, 2019)

These new kinds of products have the potential to create a niche in the market for more sustainable products and help reinforce the perception of recycled or upcycled products being of good quality.

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[22] The name of the patented fabric was omitted for non-disclosure purposes.

The Special Projects Manager had the idea of creating a more comprehensive start-up unit within the company that could collectively deal with the Group's leftovers apply more circular design strategies in making use of it. This would be a step above the aforementioned dedicated staff that coordinates the leftovers with GPs.

4.4 Challenges hindering greater upcycling at Oberalp

The interviews confirmed many of the industry-wide challenges to production leftover upcycling uncovered during the literature review, but also revealed unexpected challenges particularly affecting the Oberalp context. The research coding scheme in Figure 4-1 displays the 1st order categories identified as challenges, most of which were related to value chain and internal dimensions, fabric features and available technology for recycling. The following section will present the overarching challenges identified in the interviews.

4.4.1 Nature of the Fabric and its Value Chain

As a group of outdoor brands selling high performance apparel, Oberalp's fabrics themselves were an intrinsic obstacle for potential upcycling. Table 4-1 presents a small sample of the fabric types used by Oberalp's brands for its apparel production. There is a tremendous variety of fabric blends ranging from monofibers such as pure polyester to highly complex fibers that include nylon, wool and elastane. These fabric leftover roll ends are not evenly distributed across Oberalp's global (though mostly based in Asia) GPs and they occur in varying amounts, season after season, and come in different colors. The Purchasing Specialist plainly said, "we are a business of colors…and we seek to have a collection of colors from season to season", with the Sourcing Specialist implying that having this diverse color portfolio for the brands' product lines gives the company a competitive advantage. The Sourcing Specialist also pointed out that the complexity of the fabric blends used originates from the design stage, as product designers for the respective brands develop the products and have certain specifications related to the features they want, such as durability, being water/wind-proof, and being elastic.

Regarding in-house upcycling to create a new product or incorporate the leftover fabric into other collections, the variety of fabrics and their features, in addition to their location in the value chain, makes it very challenging to coordinate across design teams to come up with ad hoc solutions. This challenge comes from the predominant garment manufacturing paradigm that focuses on large-scale production. This will be discussed in the following section.

Fabric blend varieties are a big issue for circularity not only because of the need for specialized design to incorporate into new collections, but primarily because of the limited capabilities of existing recycling. Existing chemical and mechanical recyclers cannot accept certain blends that to not meet their criteria, which can often be very restrictive and severely limit the fabrics that a brand or GP can send to recycle. According to the Sourcing Specialist, the company is currently not aware of what recyclers are available where the GPs produce that would accept their different blends, a task that is compounded by the variety of blends that exist across Oberalp's GPs.

In reference to the Special Project Manager's idea of experimenting with recycled fibers, she also mentioned that there are current market features that hinder this from taking place at a larger scale. "You have to consider the margins…the final prices of the input materials. [Recycled] yarn is still more expensive than virgin", making it currently too expensive to incorporate more recycled fibers from partner recyclers into upcycling production of leftover fabrics.

The market value of synthetic materials plays a role in the efforts behind upcycling certain materials as well. Oberalp developed the Sarner Jacket (See Appendix B) using yarns from recycled wool jumpers from recycling partners in Italy. The author confirmed with the Special Project Manager that this product example is unique because of the high value of wool in conjunction with the availability of a more locally developed network of wool recyclers in Italy. When asked about the potential with synthetics, the Special Project Manager said "You could do the same [upcycle used fibers], but we consider polyester [and synthetics] so poor as a material that it is not considered worthwhile. We go back to the origin of the resource, that it is considered so cheap". As synthetics represent an overwhelming majority of fibers used in Oberalp's clothing and that they are produced in complex global supply chains, one can understand the challenging circumstances Oberalp has when considering to recycle or upcycle this material.

4.4.2 Apparel Industry Status Quo

The interviews with the Oberalp personnel revealed some deeper insights behind the obstacles to upcycling, not only within the company itself, but also in how apparel industry fundamentally operates.

4.4.2.1.1 Purchase Order Minimums

While getting a broader picture of the apparel industry purchasing process and material flows, three different interviewees discussed the significance of supplier minimums in generating leftover fabric rolls. Both FPs and GPs have minimum quantity requirements when they fulfill an order request. For example, when a product techsheet is being compiled, the GP determines the amount of varying fabrics necessary to fulfill the garment order "based on the calculations they make for materials they'll need…based on their production order quantity" (Purchasing Specialist, 2019). According to the Sustainability Manager, a big reason for the common GP practice of ordering excess fabric is "to avoid shortages in production, or [to consider the possibility] that they can get defect fabric". A single GP can order excess of a single fabric type and color (ex: purple nylon/elastane blend) that may be used in multiple styles, each of which can be made of multiple types of fabrics (such as a jacket with multiple technical layers and colors). Often times, this fabric excess can be circa +3% of the actual needs based on the orders received, and FPs for each of the requested fabrics also have their own order minimums, the price of which is passed down to the buyer (Oberalp). Therefore, in order to create a single product style, there are multiple levels of minimum order requirements involving several actors within a value chain that can result in the fabric leftovers at the GP. If one adds the complexity of an individual style order from single buyer to the myriad of other orders a GP must handle, one can understand how the problem of leftover fabric becomes magnified in a value chain.

4.4.2.1.2 Supplier Capacity

While purchase order minimums are the main reason for these leftover fabrics, they are indicative of the current model of industrialization and can reflect the GPs' technical capabilities. Based on the interviews, a GPs upcycling capacity can be related to its specialization, size, auxiliary resources (intellectual and technical), existing industry channels (such as networks of other producers and recyclers), and its fundamental company values and circularity mindset.

As aforementioned, GPs' readiness and willingness to take on an ad hoc upcycling or recycling project can be a big determinant of the potential to make use of leftover fabrics. The author mentioned the concept of buyer negotiating power when deciding how to overcome some of the obstacles, but the Sourcing Specialist said the negotiating power varies between suppliers (FPs and GPs), as some are more flexible than others.

> We are not a relatively big buyer for many of our suppliers, so we have less negotiating power in many circumstances…and must accept the quantity minimums. Our business is fragmented with fabrics in many different colors, which limits our negotiating power. Our business of different colors makes the leftovers much more difficult to deal with. (Sourcing Specialist, 2019).

Referring to the availability of a GP to participate in an upcycling project, some GPs are big, have many different buyers and short low seasons, sometimes making them unavailable to participate in a creative project. "On an industrial level, this small-scale production [individual projects with particular materials] is harder to manage and can be costly" (Sourcing Specialist, 2019), considering the extra materials and expertise needed to accommodate this. As the Sourcing Specialist explained:

> If you want to make new clothes with the leftover, you need to know how much you have, what colors are available, you might need to buy extra materials to make the finished product, and then you need to consider meeting their new purchasing minimums [for added materials necessary to make the upcycled product]. This means an added cost for us.

This relates back to tracking the complex stock that is available and at what GP, then considering if said GP is flexible enough and ready to collaborate on a new project. This includes the GP's manufacturing specialization, such as whether a GP makes simple or complicated and technical garments. This can also restrict the possibility of upcycling projects, or at least the types of products that can result from them.

Although the scope of this project focuses the challenges to upcycling excess fabric, some current challenges in the value chain can hinder the potential for future upcycling of other material streams. All interviewees confirmed that they are unaware of other waste streams associated with their apparel production in their value chain as their suppliers do not provide them with this information. This means that information on offcuts and other material waste in the value chain is not available, which typically represents a significantly larger portion of production waste (See Figures 2-3 and 2-8). Though the vast majority of their value chain complies with social sustainability certification schemes, less is known on how many follow environmentally oriented schemes that consider waste management and reporting standards. Conforming to compliance standards can be costly for a supplier, as the Sourcing Specialist mentioned. "Large suppliers can afford to put resources into becoming certified usually they already are, but smaller ones need more time since they need to understand if it is worth their investment" (Sourcing Specialist, 2019). A lack of comprehensive transparency throughout the supply chain via information standards could limit Oberalp's potential material circularity strategies in the future.

4.4.2.1.3 Limited Recycling Capacity and Network

Sending the leftover fabric that has little potential for upcycling to a recycler would be the easiest solution to making use of the resource, as was deduced from multiple interviews, since this would require the least amount of coordination and creativity. But the option to do fiber-to-fiber recycling is much more complicated than to simply send the waste to available recyclers. As identified in the literature, existing fiber-to-fiber recycling technology is currently limited to specific fabric types and blends with minimum fiber thresholds (Le, 2018; Muthu,

2017) and many of Oberalp's complex fabrics do not fit the criteria. There are fabric recyclers that exclusively accept post-industrial waste and partner with producers, but as per the Special Project Manager's knowledge, many of these recyclers are at capacity and cannot accept any more waste. This suggests that there is an issue with limited capacity in textile recycling networks to accept the rapidly growing supply of textile waste. Additionally, the more advanced recycling technologies that have a wider fabric threshold do not appear to be as widely available to the massive networks of textile producers in East and South Asia. The Special Project Manager conveyed the interest in keeping solutions more local to avoid the logistical transport costs from a network of GPs to recycling facilities in distant locations. With a limited network of recyclers that can accept complex blends, this poses a big challenge in the scaling of Oberalp's upcycling efforts.

4.4.2.1.4 Internal Business Model and Product Design

Interviewees recognized certain structural attributes within Oberalp itself as being barriers to greater upcycling. They were mostly related to the company's prevailing business model that influenced many other factors.

One source of a large amount of fabric leftovers at GPs is the production of garment samples, which is a standard industry practice. Sample orders are usually meant to demonstrate the quality and workmanship of a product to the buyer, serve as a basis for revisions in bulk orders and to determine the estimated costs of production ("Sampling Process in Apparel Industry," n.d.). As explained by the Purchasing Specialist (2019), Oberalp uses sample orders to:

> present new season products in a variety of colors at brand meetings…to show what colors and styles are new. These small batches [typically 30-50 units per garment] can be sent to stores to sell and essentially test their viability in the market.

While these batches are small, they must still comply with FP and GP order minimums. When considering that Oberalp "is a business of colors" and creates samples of new garments in a variety of different colors for display, this results in a motley of leftover fabric ordered simply for sample production. Table 4-1 featuring the different types of Oberalp's leftover fabric shows the order type as bulk or sample. A closer examination of the whole document reveals that a significant number of these fabrics are from samples and that they relate to color variety. As explained earlier, the variety of colors in small fabric quantities makes it difficult to devise ad hoc upcycling designs, making this color phenomenon directly related to a design choice rooted in the business model.

In speaking with the Sourcing Specialist about life cycle thinking and design, he mentioned that brands within Oberalp think very differently about circularity and this reflects in the eco-design and upcycling initiatives they have respectively pursued. Essentially, these various brands have different cultures and mentalities about designing their products, and subsequently how to handle their production waste.

> Every season we get different demands for colors [fiber types to a lesser degree] from the brands…the lack of predictability of what new design demands are can be challenging when trying to plan to use the leftover stock in a following seasonal collection…some brands use more complicated designs that result in more complicated leftover stocks. From the point of view of design, they [the less circular-minded brands] are less ready [to initiate upcycling projects] (Sourcing Specialist, 2019).

Those brands that think in a more circular manner are more flexible and consider their leftover fabrics more and engage with their suppliers differently. Despite this potential with some brands to take on the challenge of upcycling, a gap remains within the greater organization.

Beyond having a circular mentality within certain design teams, the Special Project Manager asserted that the current organizational business model needed to change and that a cultural shift throughout the organization regarding material and value was necessary, and potentially the most difficult obstacle to greater material circularity.

> The first challenge is the business model. Then it is the internal learning, because everyone that is part of the chain…from the idea, to the product, to the price, to the selling…every part needs to be aligned and needs to consider it [circularity] as the right thing to do. If we solve this internally, then it is a lot easier to realize [upcycling]. Then things start to roll. Even if you look for solutions externally with your partners, [if the initiative comes from Oberalp] then your partners are willing to innovate and do something creative with you (Special Project Manager, 2019)

Coordinating such upcycling projects with suppliers would require extra work by specialized individuals or a unit (as mentioned in the section on potential), and it would be likely that this investment does not pay back financially for the business but would make use of the material. The Sourcing Specialist (2019) also mentioned that the nature of small-scale upcycling projects, "due to the small quantities, the complexities, and the added costs of labor and inputs… you are not competitive when doing this." When the author asked if this effort would be worthwhile, the Special Project Manager (2019) reiterated that the business model itself needed to change, "or to work with channels that work with approaches that are different to ours…to think creatively with materials and see them as having more value."

This internal shift would require greater expertise that specializes in circular design and thinking, expertise that is still fragmented and in its early stages at Oberalp.

Therefore, product design, starting with a cultural shift towards prioritizing circular thinking, is an important strategy to not only reduce the amount of leftovers produced, but also thinking about how to facilitate the upcycling of inevitable leftovers in later stages and how partners could be a part of that process. Appendix B can help illustrate some examples of how a shifted business model can potentially change how different aspects of the organization operate regarding upcycling, from product concept and design to production.

4.5 The Emergent Theory

The seven second-order themes that emerged from the findings (see Figure 4-3) using GT method encompass both potential and challenges highlighted by the Oberalp interviewees. Collectively, these themes build upon the theory that broadly describes the Oberalp phenomemon.

Upcycing of leftover fabric end rolls in the Oberalp Group is determined by internal and external factors. The company's internal context acts as the biggest obstacle to greater circularity with its existing business model at its core, influencing a cascade of other factors. The features of the fabric itself, and its ability to be upcycled, is determined by product design, which relates directly back to the company's internal context. External factors involve collaborating with key stakeholders in the value chain, namely the GP, by aligning values, exploring different local channels, and thinking innovatively to find solutions to create upcycled products from the leftover fabric. Certain barriers such as existing recycling technologies limit the use of one recycling route, but the capacity of GPs with their local context and expertise can be pivotal for a focal company like Oberalp to begin engaging in innovative solutions.

5 Discussion

Following the presentation of findings from the multiple rounds of interviews with Oberalp employees, this section will discuss some of the unexpected outcomes from the research as well as how it contributes to literature, to industry practice and limitations to the project as a whole. It will also provide the author's insight into how Oberalp can review its current business model for the future.

5.1 Expectations from the research

The literature review gave the author significant background on the apparel industry and upcycling prior to meeting with the Oberalp interviewees. During the semi-structured interviews, several topics were discussed and confirmed the greater body of literature.

Concepts such as eco-design and LCT were mentioned repeatedly during the interviews as pivotal in influencing leftovers and how to innovate with them upstream. Transparency as an issue in the supply chain was also discussed, as the company does not have general knowledge on the waste generated by its supply chain nor what it was doing with it.

Interviews confirmed that large scale recycling of polyester blends was challenging because the technology was still not sufficiently developed, and consequently limiting that as an option. Of the options that were available, the were simply not geographically available and the logistics of transporting the fabrics there is an added barrier, as literature confirmed (GreenBlue, 2017; Nikolakopoulos et al., 2017)

There were several surprise findings during this research project. While the author was generally aware of the fact that blends of certain synthetic fibers render certain desired physical properties of technical clothing, he was left very surprised at incredible variety of fabric blends and colors used in the company's portfolio. The Purchasing Specialist's document (sample in Figure 4-1) presented an exhaustive list of different leftover fabrics (both patented and generic) and combinations of colors that existed in various quantities across the Group's globally dispersed GPs. One look at this list made the author realize the magnitude of the problem when it came to coordinating between design teams and GPs to devise solutions to handle this waste. What was also surprising from multiple interviews was the emphasis they placed on seasonal colors dictating the potential for fabrics to be reused in a subsequent season and determining how much leftover could occur.

Also of interest was the idea from multiple interviewees expressing the need to have dedicated personnel within the organization that can manage the fabric leftovers for all the brands and coordinate between design teams and key people at the respective suppliers to lead upcycling projects.

Finally, the discrepancy of circularity thinking and design innovation between brands of the company was quite a surprise to the author, as certain brands pioneered their own upcycling initiatives and thought in a more circular way, while others did not think about the implications of their designs in the same way. It demonstrates that the cultural mentality mentioned by the Special Project Manager was not centralized.

5.2 Propositions for Oberalp going forward

The interviewees at Oberalp are cognisant of the organization's potential and challenges to managing its leftover fabric and they recognize the need for considerable change in their current status quo. The propositions provided below reflect an analysis of the interview findings supported by the literature and are not meant to be professional, consultative suggestions, but rather a reflective review.

The cultural shift and change of business model would need to begin centrally, bringing together different teams across the organization to share perspectives, ideas and best practices internally. Brands' design expertise and organizational values regarding material circularity and collaborative innovation should be harmonized, driving strategy for the whole organization while allowing brands their flexibility to maintain their own image. This would be important to have brands think differently about the number colors they use from season to season. This rethinking of fabrics could also prompt research into fabric blends that can meet the desired properties meant for high technical performance while being recyclable according to existing technological capability and broader availability. The rethinking of fabrics can also have the possibility for future upcycling as a focus when thinking about designing future season collections. The Sourcing Specialist (2019) mentioned that "solutions are very material specific", requiring an approach that considers the properties, its recyclability, and ability to be incorporated into new products. The example of the Sarner Jacket (See Appendix F) demonstrates a material-oriented solution that involved working with a network of recyclers to develp a product of a highly valued material.

Beyond Oberalp's internal realignment, the company can also work towards increasing traceability and transparency in its supply chain to include environmental performance and waste generation dimensions. This is where getting suppliers to conform to specific TSIs such as the Higg Index can generate greater information flows throughout the value chain. While Oberalp's current priority is to address leftover fabric roll ends, as recycling technologies improve and capacities increase, greater information on other waste streams can help Oberalp form strategies about how to handle those waste streams in a circular manner. Information on offcuts[23] could be useful for a design team if they and the respective suppliers are ready to innovate on upcycling projects with this material. With better information sharing between Oberalp and its suppliers, in combination with organization-wide LCT, collaboration and innovation can flourish.

Oberalp's greater participation in TSIs can also serve to strengthen its reputation externally. A label like GRS can strengthen the customer's perception on the quality of an upcycled product (Meier, 2013; Textile Exchange, 2017) or one that uses recycled fibers. It can "help tell a story" about the product that incorporates recycled or upcycled materials, as the Special Project Manager (2019) explained. This is where Oberalp can build its competitive advantage (discussed later) as a shift away from relying as heavily on garment color varieties.

As Muthu (2015) explains that a firm's size is indicative of its resouces and capabilities, Oberalp could focus on bringing its smaller suppliers into compliance with the aforementioned environmental schemes. These smaller producers are also the ones that are considered more flexible to take on upcycling projects (Sourcing Specialist, 2019), providing Oberalp and other buyers a reason to reconsider their role in addressing sustainability issues in circularity.

While Oberalp is already aware of the importance of industry collaborations, it could consider joining the SAC, where other big competitors participate. As the leading international group

[23] These are currently not reported to Oberalp by any of its GPs. Literature in this thesis has demonstrated that it is one of the largest forms of production waste.

within the industry, SAC serves as the biggest source of knowledge-sharing and benchmarking across the textile industry (Muthu, 2015; Poldner, 2013). Seeing that production waste is a common problem and that many big global brands share suppliers, being at the center of the industry conversation to share best practices and find innovative solutions should be a priority for Oberalp.

5.3 Contribution to Literature

This research project primarily serves as an exploratory case study that helps uncover some of the systemic issues facing an apparel company in addressing its predominantly synthetic fabric leftovers. Oberalp's position in the apparel industry as a company that is starting to take on this challenge addresses Sung's (2015) call for contributing to the evolving field of upcycling through more industry-specific case studies. While fabric roll ends are only a fraction of the waste generated from garment production (Altun, 2012; Ellen Macarthur Foundation, 2017; Runnel et al., 2017), this report's niche focus still contributes to the greater literature on closing the loop upstream in the supply chain. It reveals the complexity that a focal company faces when deciding how to tackle this waste stream based on the inherent features of the fabrics in question and the textile industry status quo.

While most upcycling research has focused on post-consumer waste and small-scale projects (Cassidy & Han, 2013; Cumming, 2016; Han et al., 2017; Muthu, 2017), this report specifically looks at a company trying to address its own production leftovers in a systemic way. From the start, this report aims to keep the term "upcycling" as broad as possible so as to include multiple pathways that make the greatest use possible of a material. In this manner, the research and findings from Oberalp included multiple recycling routes to make use of the material, including the possibility of sending it to 3rd party recyclers when in-house upcycling with a GP is not feasible. It contributes to the field of SSCM by underpinning the importance of innovative collaboration with partners and knowing their capacity to realize projects that are of mutual value.

This report reinforces the importance of circular design thinking in order to reduce waste (Bocken, de Pauw, Bakker, & van der Grinten, 2016; Goldsworthy & Ellams, 2019), but also to think broadly of the impact that design can have on the downstream potential to eventually upcycle inevitable leftovers. Eco-design typically focuses on reducing impacts within the supply chain and making the final garment recyclable after use. This research's contributions to the importance of design focuses on another dimension of the product life cycle, specifically the ability to upcycle leftovers in production. It highlights the impact that color, fiber type, quantity, and where in the supply chain the leftover occurs can have on the material's ability to be converted into something of similar value that can be put on the market.

A company's business model is fundamental in how it operates and creates value. The findings of this research confirm that innovative and collaborative business models must reevaluate how the focal company values material resources and the responsibility it holds in influencing the behavior of its value chain (Chizaryfard & Samie, 2016; Dargusch & Ward, 2010; Larsson et al., 2013).

Using niche upcycled fashion examples (as pictured in Appendices A and F) as a basis for innovation in using production leftovers, this report confirms the prevailing capacity of smaller producers as opportunity hubs for upcycling as smaller-scale production is still the most viable option. It reinforces the factors behind why upcycling is still small-scale and not a more mainstream practice among larger producers. More importantly, it proves that these kinds of projects require innovative and collaborative business models to engage with the capable partners.

5.4 Contributions to Practice

The insight to how Oberalp could review its business model can also broadly apply to other brands in the apparel industry, not simply ones that are already making moves towards circularity. A shift in cultural mindset within an organization appears to be the first step to engage teams internally in LCT and how they value their materials. Brands can reevaluate how they create their competitive advantage and focus on developing special capabilities that prioritize greater LCT in their products. A brand's competitive advantage does not simply hinge on having the latest styles each season, but also in adopting strategic CSR approaches that consider the broader life cycle impacts of its production and its innovative capabilities, investments that can pay off in the longer term (Muthu, 2015).

This research has also demonstrated the problem with the limited capacity of recycling of both post-industrial and post-consumer waste to seriously address the needs of the apparel industry. As companies become more conscious of the impacts of their production and seek recycling solutions, they will become more aware of the potential and challenges they have within their own supply chains to achieve greater circularity. Brands must consider the recyclability of their fabrics and garments and better inform themselves of the state-of-the-art recycling technologies available and take advantage of the existing local channels at their suppliers.

This case study on Oberalp showcases a company that is already thinking about addressing the production waste that it currently tracks. Transparency and traceability are not only important for good external CSR, but also for developing priorities and strategies to address circularity issues in the value chain. With the development of supply chain information technologies such as blockchain, brands can better collaborate with their partners on a variety of projects to improve sustainability performance (El Messiry & El Messiry, 2018). This improved information could help facilitate the production of smaller-scale, ad hoc upcycling projects with partners that are willing and on board to engage (Han et al., 2017). As the Purchasing Specialist (2019) suggested, improved information flows between the entire value chain could unlock the possibility of responding to individual retail store needs through individualized small-scale upcycled projects using leftover frabric.

This research shows that the internal cultural shift towards LCT is potentially the most important challenge for a company. When a company is able to align values across its expertise groups, it can then focus on working with its partners and value chains to find common solutions. As the Special Project Manager (2019) explained, the company's intent was important not only to find other like-minded partners, but to engage others in shifting their own thinking. This "readiness" can exist more commonly than some brands may be inclinded to believe.

Upcycling of production leftovers in a global value chain is both a global as it is a local problem. It is important to first seek solutions with a supplier's local channels as a priority, as often times suppliers may be in proximity of a network that takes greater advantage of industrial symbiosis, like the case in Turkey (Altun, 2012). It may be the brand's responsibility to build some channels, either locally or regionally, to handle the leftovers and connect the suppliers with other important actors.

This research demonstrates the leading role that a focal firm can play, from making internal changes and LCT in creative design, to participating in TSI's and engaging with suppliers to think innovatively in devising upcycling solutions.

5.5 Limitations

The greatest limitation to this work was the inability to interview key suppliers, preferably ones that had successfully collaborated with Oberalp to create the upcycling projects featured in Appendix F. This dramatically limited the primary data sources to the four key personnel at Oberalp that were able to discuss the topic with the author. For that reason, the breadth of data collected, and ultimately the perspectives taken into consideration in this project were limited. Without the perspective of these key suppliers to understand the potential they believe exists to cooperate with leftover upcycling and what obstacles they perceive to hinder the latter, the findings of this research should not be taken at face value. Furthermore, the author did not have the opportunity to interview personnel that worked in other departments nor represented the design teams of individual brands to get a more holistic picture of the organizational culture. Seeing as the circular mindset varied between brands within the company, this could have been an added dimension of complexity to discern when evaluating the capacity of the company as a whole.

When using a single company as a case study to make a generalization of the industry itself, one should use caution with the conclusions that arise. Oberalp is a unique example as it operates in a sector (outdoor apparel) that is already known for its sustainability initiatives (Outdoor Industry Association, 2018), has global supply chains, and uses primarily synthetic fibers in its apparel (which, as we know from earlier sections, can be highly recyclable but is considered a cheap fabric). Therefore, companies with different profiles could experience a different reality regarding the potential and challenges to upcycling production leftovers. With this being said, a case study of any kind may be subject to biases or a narrow focus on nuanced problems. This study on Oberalp still contributes insight to an emerging field and can set the path for future research.

6 Conclusion

The textile industry is one of the most polluting industries in the world and faces numerous and complex sustainability challenges as demand for textiles continues to grow (Ellen Macarthur Foundation, 2017). With a highly fragmented global supply network, coordinating across actors and devising solutions to change the linear business model paradigm is increasingly difficult. Focal companies are become more aware of sustainability impacts along their supply chains as they take responsibility for the actions and impacts associated with their production. The Oberalp Group has embraced sustainability principles and is concerned with closing its material loop and making use of its production leftover fabric in its supply chain by innovating upcycling projects. This research project sought to answer the following two research questions to contribute to the body of literature with Oberalp as a case study:

RQ 1: What is the potential for upcycling of apparel production waste in an outdoor apparel company like the Oberalp Group?

Oberalp's garment purchasing process and immediate value chain was highlighted, revealing that the 1st-tier supplier, the garment producer (GP), conducts most of the material transactions and is the only player that tracks post-industrial waste in Oberalp's value chain. Of the tracked material, Oberalp only received data on leftover fabric roll ends, making them Oberalp's priority for material circularity as they are high quality material. Having already done a few smaller upcycling projects with production leftovers in conjunction with some partners, Oberalp's potential strategic directions and supply chain capacities are the center of being able to realize larger scale upcycling. The company recognises multiple recycling strategies as potential opportunities to handle these leftovers. It could send the material to undergo fiber-to-fiber recycling by a third party. However, a greater priority is to collaborate with ready and capable GPs with similar values to innovate and produce new garments from the leftover fabric. The company sees life cycle thinking and design strategies as integral in making this a reality while engaging with other like-minded partners across the industry and with local channels around their producers to create innovative solutions.

RQ 2: What challenges does the Oberalp Group face that hinder its ability to upcycle more of its upstream production waste?

Oberalp faces several internal and external obstacles that make upcycling its leftover fabric a challenge. The most encompassing obstacle is the organization's current business model and company culture that does not place a high enough value on its fabric leftovers nor on material circularity. This obstacle has downstream effects on designing principles that dictate the materials and colors chosen and potential for those fabrics to get reincorporated into a value chain. External obstacles include the limited recycling capacity to accept blended fibers, the limited capability of GPs to engage in these projects, and the nature of the textile industrial status quo that requires purchase order minimums. This generates leftovers to begin with and subsequently requires more inputs to generate ad hoc upcycling projects. The nature of upcycling itself is a challenge as it requires specific expertise, special collaboration, and ultimately a clear idea of what the final product must be like in order to scale it with GP partners.

Suggestions for further research:

This thesis project exposed multiple issue areas that could be researched and contribute to various fields including industrial symbiosis, eco-design, supply chain management, and industry collaboration. A few suggestions identified by the author throughout his research include:

- The desirability of ad-hoc upcycled products, how they can affect the reputation of a brand
- Industrial symbiosis around textile production clusters and how they can foster greater material circularity.
- What role international focal companies play knudging their suppliers to upcycle production waste.
- Designing for recyclability, with a focus on materials and season-to-season carryover.
- Further case studies on the internal cultural shift and how to engage different expertise groups in life cycle design thinking

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8 Appendix

8.1 Appendix A: Examples of upcycling brands and apparel

Reet Aus, based in Estonia, makes its garments from several kinds of production leftovers, including offcuts of various sizes and roll ends. The design thinking starts with the available fabrics and the styles are dynamic and change from season to season.

Figure 8-1 Shirt made by Reet Aus from leftover fabrics

(Source: https://thisisedvin.com/eco-lifestyle/reuse-remake-10-upcycle-fashion-brands)

Zero Waste Daniel, based in New York City, uses closed-loop production system to make small collections and one-off garments, making use of post-industrial leftovers from bigger producers.

Figure 8-2 Pullover and Trousers made by Zero Waste Daniel

(Source: https://thisisedvin.com/eco-lifestyle/reuse-remake-10-upcycle-fashion-brands)

REMADE Studio, based in London, uses surplus fabrics in its designs from its own production and other fashion houses and considers both innovative style and functionality when making its pieces.

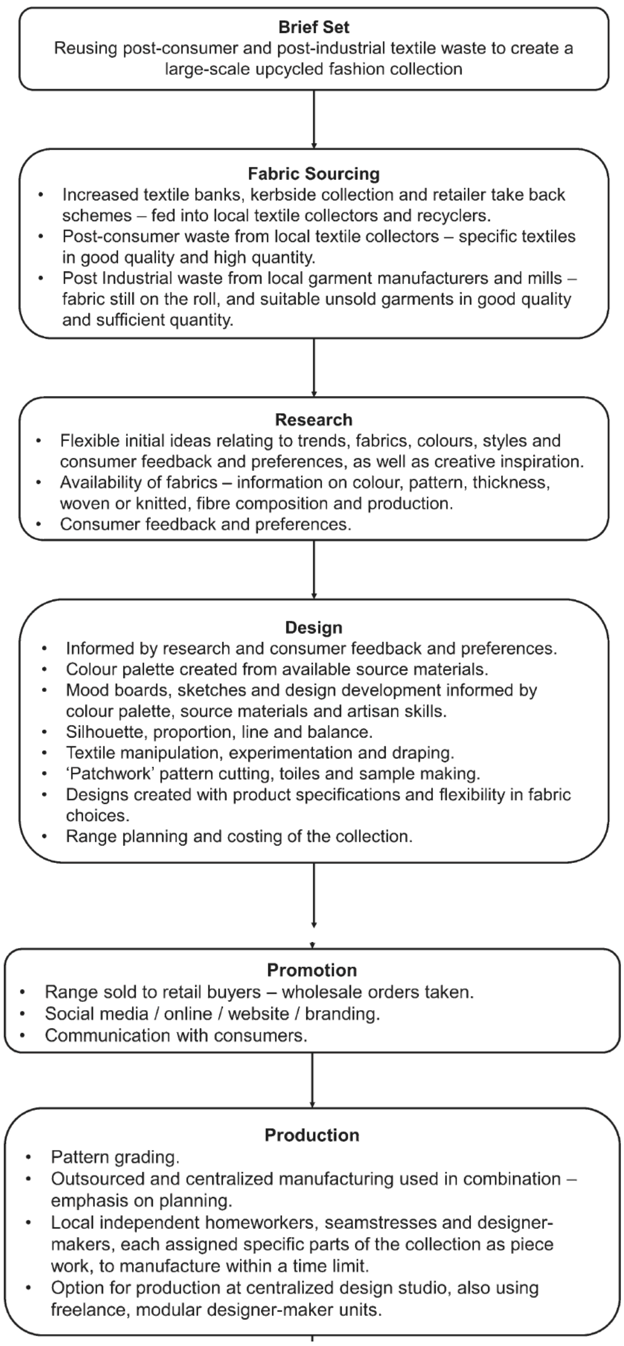
Figure 8-3 Sport jacket and shorts made by REMADE Studio

(Source: https://thisisedvin.com/eco-lifestyle/reuse-remake-10-upcycle-fashion-brands)

8.2 Appendix B: Upcycled Fashion Design and Production Process Model

Figure 8-4 Upcycled Fashion Design and Production Process Model

Source: (Han et al., 2017)



8.3 Appendix C: Overview of Textile Recycling Routes

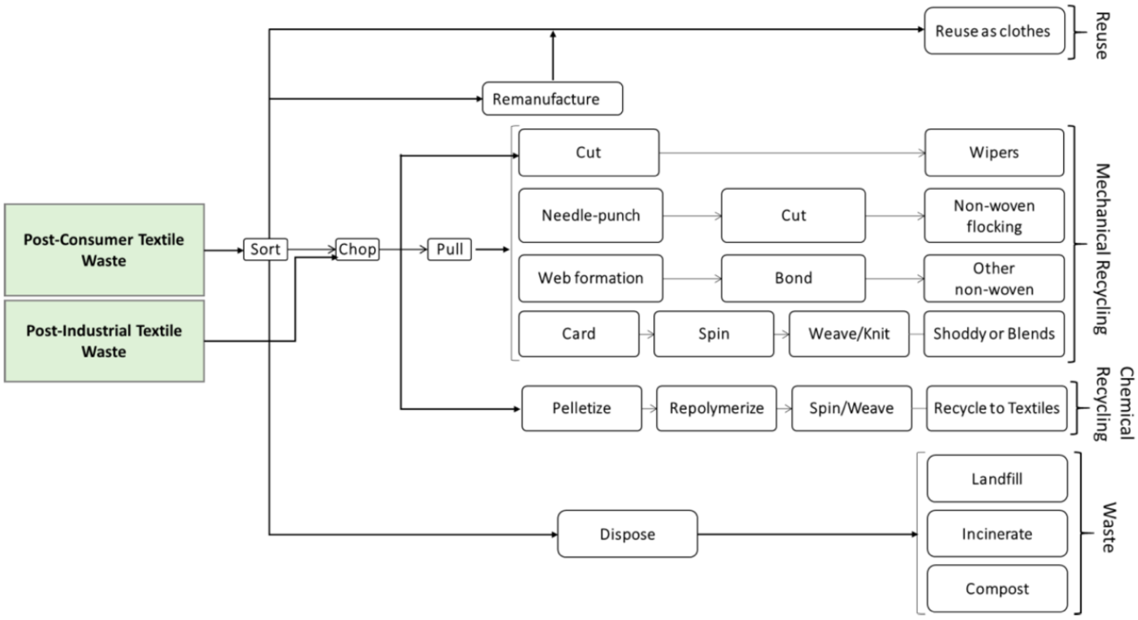


Figure 8-5 Overview of possible post-industrial and post-consumer textile waste flows

Source: (Le, 2018)

8.4 Appendix D: Mechanical and Chemical Recycling

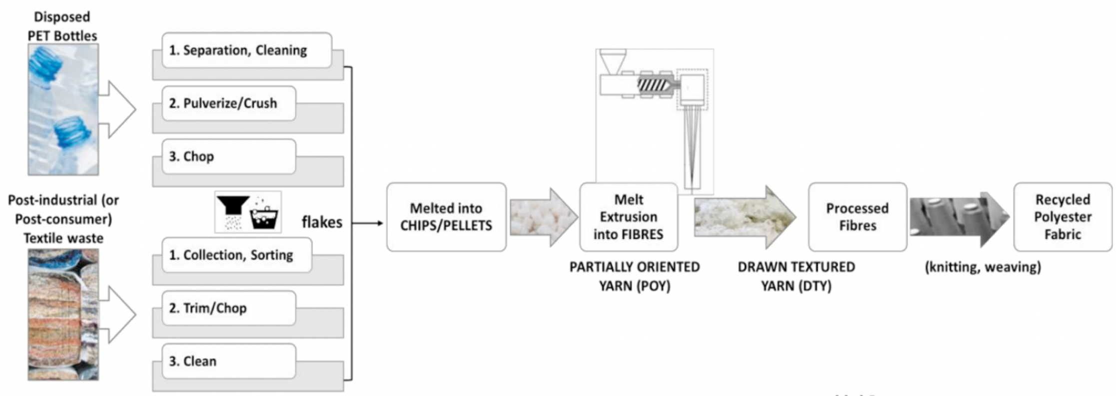


Figure 8-6 General route for mechanical recycling of polyester

Source: (Le, 2018)

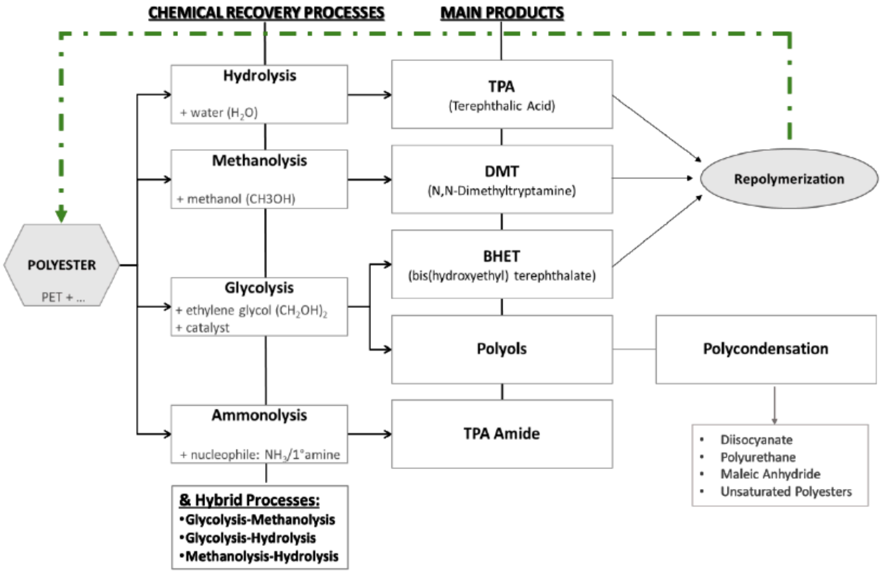


Figure 8-7 Overview of different chemical processes used to depolymerize polyester for fiber-to-fiber recycling

Source: (Le, 2018)

8.5 Appendix E: A Sample of Some Mechanical and Chemical Polyester Recyclers

Table 8-1 Mechanical Recycling Actors

Source: (Le, 2018)

Company	Feedstock/Input, Requirements	Product/Output	Description or Processes
Hyosung (South Korea)	Post-consumer PET bottles	Regen™ polyester yarn, 100% recycled	Mechanical recycling
Polylana (USA)	Recycled polyester (rPET) materials (i.e. rPET flakes made from bottles)	Polylana® staple fibre (patent pending)	Polylana® modified polyester pellets mixed with rPET flakes, proprietary staple fibre created, spun into yarn. The fibre blend can be dyed at low temperatures, blended with various natural and synthetic fibre materials.
RadiciGroup (Italy)	Post-consumer PET bottles	r-Radyarn® r-Starlight® yarns	r-Radyarn®: continuous PET filament, with dope dyed, bacteriostatic, UV stabilized versions
Seaqual (Spain)	Waste recovered from the ocean weekly (boats and fisherman from the Spanish Mediterranean Coast involved in project)	100% recycled polyester thread	From the ocean waste collected, PET plastic is collected for conversion, while other waste materials are sent to their respective recycling chains The output recycled fibres can be blended with fibres from other brands.
Sinterama (Italy)	Post-consumer PET bottles	NEWLIFE™ polyester yarn, 100% recycled	Dyeable from 98°C (low temperature) with standard polyester dyestuff, along with different fibres while maintaining mechanical properties.

Stein Fibres (USA)	Post-consumer PET bottles, post-industrial textile waste	Infinity Polyester, 100% recycled polyester fiber. 2 Streams: Gold (100% post-consumer PET bottle flake) and Silver (at least 30% post-consumer bottle flake, remainder is post-industrial reclaimed PET)	Largest producers of polyester fibrefill and non-woven fibres in North America. Distribution (relevant to Canada): Charlotte-Toronto, and Montreal-Vancouver
Teijin (Japan)	Post-consumer PET bottles	ECOPET™ staple fibre, spun yarn, fibre product	Mechanical recycling
Toray (Japan)	Post-consumer PET bottles, post-industrial textile waste	ECOUSE™ fabrics	Mechanical process blends recycled PET pellets with cotton, to spin to thread for ECOUSE™ products.
Unifi (USA)	Post-consumer PET bottles, post-industrial textile waste	Repreve® yarns (wide product range): staple and filament fibres Flake and resin products	Mechanical recycling 80/20 post-industrial/post-consumer waste.

Table 8-2 Chemical Recycling Actors

Source: (Le, 2018)

Company	Feedstock/Input, Requirements	Product/Output	Description or Processes
Far Eastern New Century Corporation (FENC) 46,47 (Taiwan)	Post-consumer PET bottles	TopGreen® recycled fibre	Chemical recycling, back-to-oligomer. Depolymerization by glycolysis of PET to BHET oligomer, which is filtered and repolymerized into PET (96% material efficiency). The polymer is spun into filament fibre. Process solid waste disposed in incineration facility with electricity recovery (43% recovery rate).47
Ioniqa 48 (The Netherlands)	Post-consumer PET bottles, textiles, carpets	PET raw material	Chemical recycling process that allows for impurity and colour removal from plastic feedstock, as well as chemical recovery.
Jeplan 49 (Japan)	Post-consumer PET bottles, textile waste	BHET flake, PET resin, yarn, fabric	Subsidiary company: PET Refine Technology Non-PET clothing or materials separated and sent for recycling by other technologies. Depolymerization to recover BHET (likely glycolysis), decolourization, and polymerization to PET.
Loop™ Industries 50 (Canada)	Post-consumer PET waste (any)	Loop™-Branded PET plastic	Patented zero energy depolymerization technology. Waste is converted to constituent monomers: PTA and MEG without heat or pressure. Purification step: dyes, additives, and impurities are removed. Repolymerization of monomers to Loop™ plastic.
Moral Fiber 51 (formerly Ambercycle) (USA)	PET bottles, post-consumer textiles	PET raw material/feedstock (PTA), PET fibre	Chemical/Biological Process: Engineered microbes to metabolize plastic waste material to generate PTA as feedstock for polyester production.
Polygenta 52 (India)	Post-consumer PET bottles	Filament yarn (50-300 denier), chips	ReNew™ patented technology. Chemical process (glycolysis) converts waste to liquid esters (recycled esters equivalent to virgin), glycol is also recovered. Proprietary decolourization process is performed to remove impurities.
Teijin 53 (Japan)	Post-consumer apparel material accepted from their Eco Circle program. Minimum: 80/20 PET/cotton, 90/10 PET/nylon, and 80/20 PET/rayon blends36	ECO CIRCLE™ fibres, textiles (apparel, interiors, household goods, industrial materials)	ECO CIRCLE™ recovery system comprises a chemical process to recover DMT, and decolourization process (heat and solvent) to remove dyes and impurities.

8.6 Appendix F: Examples of Oberalp's Upcycled Initiatives

Visual examples of small-scale upcycling

Figure 8-8 Pomobuk Slippers

(Photo source: https://www.baabuk.com/products/pomobuk)

Swiss ski gear brand Baabuk and Pomoca (an Oberalp brand) collaborated in this limited-edition upcycling project to use the manufacturing offcuts from freeride and ski mountaineering skins on the sole, while the upper part is made from New Zealand wool.

Figure 8-9 Wild Country's Curbar Jacket

(Photo source: https://www.wildcountry.com/en-gb/curbar-mens-insulated-jacket-40-0000095104?number=)

The Curbar Jacket is composed of high-performance upcycled leftover material that renders the product waterproof, windproof and very breathable.

Figure 8-10 Sarner Jacket

Photo Source: https://www.salewa.com/sarner-2-layers-wool-full-zip-womens-hoody-00-0000026163

The Sarner Jacket is made from a blend of upcycled Italian wool and other synthetic fibers.

Figure 8-11 Sarner Wool Gloves and Smartphone Insulator

These gloves are made from upcycled offcuts from the Sarner hoody production while the smartphone insulator is mate from leftovers from upcycled polyester insulation and reflective material used in other sports gear.