Is It Possible for Fast Fashion to Be Environmentally Sustainable?

Lindsay Bartol

TC 660H
Plan II Honors Program
The University of Texas at Austin

May 2, 2023

[redacted]
Jennifer L. Wilson, Ph.D.
Division of Textiles and Apparel
Supervising Professor

[redacted]
Lucy Atkinson, Ph.D.
Stan Richards School of Advertising & PR
Second Reader

Abstract

Author: Lindsay Bartol

Title: Is It Possible for Fast Fashion to Be Environmentally Sustainable?

Supervising Professor: Jennifer L. Wilson, Ph.D.

Fast fashion has been proven to have detrimental effects on the environment, largely in terms of carbon emissions, water usage, harmful chemicals, and textile waste. However, despite growing awareness of the negative impacts, consumer purchasing behavior is not shifting away from fast fashion in the near future. In result, it is important to evaluate whether or not fast fashion itself can become more environmentally sustainable.

To evaluate the ability of fast fashion to be environmentally sustainable, I outlined the current effects of fast fashion before summarizing what an ideal sustainable fashion economy would look like. Then, I defined what it means to be environmentally sustainable in the context of this paper in terms of carbon emissions, water usage, and harmful chemicals. After that, I researched what innovations are currently available that can be applied to the fast fashion business model to make it more environmentally sustainable. Finally, I evaluated whether or not these innovations have the ability to make fast fashion into a sustainable business model.

In conclusion, I found that fast fashion has the potential to become environmentally sustainable in terms of carbon emissions and water usage, reducing impact by 79.1% and 29.6%, respectively. Additionally, at least 81% of harmful chemicals can be eliminated.

Further considerations that should be taken into account when considering sustainability as a whole include other environmental factors such as plastic waste and impact on biodiversity as well as non-environmental factors such as animal welfare and treatment of workers in the supply chain.

Table of Contents

Abstract **2**
Introduction **4**
Fast Fashion and the Linear Economy **5**
The Emergence of Fast Fashion 6
Impacts of Fast Fashion and the Linear Economy 7
Production Phase 8
Consumption Phase 17
Post-Consumption Phase 18
Consumer Purchasing Behavior 22
Growth and Future Projections of Fast Fashion Companies 24
A Sustainable Fashion Economy **25**
What is a Sustainable Fashion Economy? 26
Production Phase 26
Consumption Phase 28
Post-Consumption Phase 30
Can Fast Fashion Be Sustainable? **31**
Definition of “Sustainable” 32
Carbon Emissions 33
Water Usage 34
Harmful Chemicals 35
Strategies to Reduce Environmental Impacts 36
Production 37
Consumption 47
Post-Consumption 47
Evaluation of Impact Reduction 48
Carbon Emissions 48
Water Usage 52
Harmful Chemicals 55
Other Considerations **56**
Other Environmental Factors 56
Animal Welfare 57
Treatment of Workers 58
Conclusions **59**
References **61**
Biography **67**

Introduction

In recent history, our global system of production and consumption has been largely based upon a “take, make, use, throwaway” system, in which production focuses on efficiency over impact and products are used for a short time period and then tossed into a landfill. However, as the climate crisis continues to worsen, it becomes more and more apparent that this system will not remain viable for much longer, as it results in the depletion of natural resources, changes in global temperature due to greenhouse gas emissions, and the overproduction of waste (Ki, Chong, & Ha-Brookshire, 2020).

Unfortunately, the fashion and apparel industry has become deeply entrenched in this damaging model. This is becoming a growing concern due to the size of the industry, as it is worth $1.9 trillion and employs over 300 million people throughout its value chain (Ellen MacArthur Foundation, 2017). Overall, the industry produces about 92 million tons of waste each year (Mishra, Jain, & Malhotra, 2020), and this number is only growing with demand, which is estimated to triple by 2050 (Ellen MacArthur Foundation, 2021).

This growing demand and waste is, in part, due to shorter trend cycles and the growth of fast fashion, a business model for apparel production that focuses on low cost of inputs, short lead times, and high volume of sales. As a result, utilization periods, or the time for which an item of clothing is worn, have decreased drastically. In the past 15 years, utilization has gone down by about 36%, and it is now estimated that about 50% of fast fashion products are disposed of within a year. Additionally, at the end of a product’s lifetime, there are little efforts towards recycling, as it is estimated that less than 1% of clothing is recycled and made into new apparel products, whereas 85% ends up incinerated or in landfills, which results in textile waste making up 7.7% of all landfill waste (Ellen MacArthur Foundation, 2017).

Despite these detrimental effects, the growth of fast fashion is showing no signs of slowing down, as consumers lack motivation to shift their shopping habits. Ultimately, as long as sales continue to grow, fast fashion companies will continue to thrive with little to no change, as the ultimate goal of these large corporations is to produce a profit. As a result, it is unlikely that fast fashion will be eliminated in the near future, and so until fast fashion shows signs of slowing down, it is important to research whether or not fast fashion can become more sustainable without fundamentally changing its value chain.

Throughout this paper, I will be evaluating the theoretical ability of fast fashion to become environmentally sustainable utilizing existing technologies and processes that do not inherently change the fast fashion business model. I will begin by summarizing what the current impacts of fast fashion and the linear economy are throughout the product lifecycle. Then, I will outline what a sustainable fashion economy would look like in its entirety. Next, I will define what it means to be environmentally sustainable in the context of this paper and evaluate what technologies and processes are currently available that can realistically be applied to the fast fashion business model in order to decrease its environmental impact and increase sustainability. After that, I will analyze whether or not these available innovations are enough to transform fast fashion into a sustainable process. Lastly, I will outline other considerations that should be taken into account when analyzing the overall sustainability of fast fashion before I summarize my conclusions.

Fast Fashion and the Linear Economy

In this section, I will begin with a brief background on the origins of fast fashion before conducting an in-depth review of the impacts of the product lifecycle of clothing in the linear economy. After that, I will summarize consumer attitudes and behaviors toward fast fashion versus sustainable fashion, and lastly, I will outline the business perspective by looking at past and projected growth trends for the industry as a whole.

The Emergence of Fast Fashion

Fast fashion is a business model for apparel production that is categorized by quick response times, frequent assortment changes, and trendy apparel at low prices (Caro, 2015). This style of production first gained its title at the very beginning of the 1990s, after the New York Times published an article about the brands Zara and Express opening stores in New York City for the first time. The piece reported how new styles would hit the stores every three weeks, stating that "the emphasis [was] on fast fashion" (Schiro, 1989).

For the majority of the 20th century, the trend cycle followed the same speed and calendar of fabric exhibitions, fashion shows, and trade fairs, where new pieces were presented around four times a year for the Spring/Summer, Pre-Fall, Autumn/Winter, and Resort collections. However, as the information age arose, access to these shows was granted to the public. The adoption of the internet coupled with changing lifestyles, especially for women, during this time led to a new demand for a broader range of styles at much quicker paces and lower prices. As a result, seasons in retail stores increased in the 1980s, with a total of about six to eight seasons, rather than four, becoming the norm. Companies shifted their focus from forecasting demand and trends to decreasing production costs and the time it took to get new styles on the market (Bhardwaj & Fairhurst, 2010).

One of the most prominent ways that fast fashion companies cut costs was by moving production overseas to developing countries like Vietnam, Cambodia, Bangladesh, or Indonesia. More specifically, production was moved to low and middle-income countries or communities. In these areas, regulations were much less stringent, inputs were cheaper, and wages to factory workers were lower, bringing the price of production down significantly. However, while these countries became the main sources for clothing production, the United States and the European Union remained the primary consumers (Bick, Halsey, & Ekenga, 2018).

As time progressed, this trend of higher demand and a higher number of seasons only further increased. With the growth of access to personal computers and the introduction of the smartphone, the ability to view trends has become easier through social media, allowing content and trends to cycle at an unmatched pace in today's world. Additionally, with the rise of online retailers, consumers can now purchase new styles from any location with the touch of a button. As a result of this ease of access to view, buy, and consume, the fast fashion industry has boomed in the 21st century.

Now, fashion seasons have become a thing of the past for fast fashion companies, as they have moved their focus to quickly churning out trends rather than creating pieces for long-term wear. For example, fast fashion brands like H&M and Zara are now introducing new clothing items every week, which makes for 52 seasons in the year, causing the past increase from four to eight seasons to seem inconsequential. This increase in seasons caused the number of garments produced to double between 2000 and 2014, with more than 100 billion items of clothing being made in the latter year. Furthermore, garment use time has dropped 36% since 2005, and in the US, the average consumer purchases a new piece of clothing every 5.5 days. Ultimately, fast fashion has overtaken the apparel industry, and unfortunately, this model that favors quick and low-cost production comes at a huge cost to the environment (Niinimäki et al., 2020).

Impacts of Fast Fashion and the Linear Economy

The linear economy is an economic cycle that follows a pattern of 'take, make, use, and throwaway.' In this model, raw materials are collected, products are made, consumers use the products, and then the product's lifetime ends. Ultimately, this model does not take into account the environmental impacts of its mechanisms. Likewise, fast fashion is based on speeding up the phases of the linear economy in the apparel industry. The goal of this business model is simply to produce and sell the highest volume of apparel possible, but unfortunately, this high volume of production has detrimental effects on the environment.

In this section, I will outline the effects of the apparel industry on the environment by breaking down the linear system into three stages: the production phase, the consumption phase, and the post-consumption phase. Throughout the linear system, the main environmental effects include carbon emissions, water usage, harmful chemicals, and textile waste. My focus will largely remain on these categories where they are relevant, but I will outline other considerations as needed as well. In total, the linear fashion economy has a huge impact on these four environmental categories, for it is estimated that the apparel sector produces about 10% of all carbon emissions, consumes 79 trillion liters of water per year, creates 92 million tonnes of waste each year, and utilizes over 15,000 different chemicals that negatively impact the environment and human health (Niinimäki et al., 2020).

Production Phase

The production phase of the product lifecycle encompasses everything that contributes to the making and handling of a garment before it falls into the hands of the consumer. This includes agricultural or chemical production processes, yarn spinning, textile weaving, garment manufacturing, and retail distribution. Each of these steps within the complicated supply chain presents its own environmental challenges, and unfortunately, not all of the effects are tracked and quantified. However, I will outline the impacts where data is available, and when there is a lack of data, I will outline considerations that should be taken into account.

Fiber Production. While there are a wide variety of fibers that textiles can be made out of, the majority of all fiber production can be attributed to polyester and cotton. Other fibers such as nylon, viscose, and elastane are popular within the fast fashion industry, but ultimately, polyester and cotton make up over 75% of all fiber production. Furthermore, there is significantly more research available on polyester and cotton. In consequence, I will focus on these two fibers.

First, polyester is the most widely used fiber, largely because of its versatility, durability, and low cost of production; in 2021, polyester made up 54% of all fiber production and 80% of synthetic fiber production (Textile Exchange, 2022). The main environmental impacts of polyester production are carbon emissions, water usage, and chemical usage. The production of polyester fiber results in a relatively high amount of CO_2 emissions—around 3.3 kg of CO_2 per kg of fiber produced (Niinimäki et al., 2020), but estimates range from 1.7 to 4.5 kg of CO_2 per kg (Sandin, Roos, & Johansson 2019). In 2021, it is estimated that 61 billion kg of polyester fiber was produced, putting total CO_2 emissions anywhere between 103.7 billion kg to 274.5 billion kg (Textile Exchange, 2022). However, some believe that this number could be even larger, as an estimate in 2015 put emissions at 282 billion kg (The Council of Fashion Designers of America [CFDA], n.d.b). Overall, polyester is an energy-intensive fiber to create.

In terms of water usage, polyester requires significantly less water to produce than other fibers, but it still demands 21 liters per kg produced. However, even though it does not use a relatively high volume of water, the microplastics from the fiber have been found polluting freshwater. Furthermore, production chemicals like antimony, cobalt, manganese salts, sodium bromide, and titanium dioxide can also find their way from the production system into the bodies of water if factories do not have effective wastewater systems in place. Lastly, the fact that polyester is made from a non-renewable resource—petroleum—should also be considered, for it is estimated that 342 million barrels of oil are used to produce plastic-based fibers every year (Ellen MacArthur Foundation, 2017). As summarized in Table 1, for every one kg of polyester fiber produced, 1.7 to 4.5 kg of CO_2 is produced, 21 liters of water are consumed, and a number of potentially harmful chemicals are utilized.

Cotton is the second most popular fiber, making up 22% of the fiber market (Textile Exchange, 2022). The cellulose-based fiber has found popularity due to its lightweight and comfortable qualities. The main environmental impacts of cotton production come from carbon emissions, water usage, and chemical usage. While the production of cotton results in lower carbon emissions than polyester, it is still estimated that 2.2 kg of CO_2 is produced for each kg of cotton fiber (Niinimäki et al., 2020). It is estimated that about 25 million tonnes of cotton were produced in 2021 (Textile Exchange, 2022), and about 64% of cotton is used for apparel production (Voora, V., Larrea, C., Bermúdez, S., & Baliño, S., 2020). This is equivalent to 25 billion kg of cotton, which means that about 16 billion kg of cotton is produced every year for apparel, resulting in 34.5 billion tons of CO_2 emissions related to apparel production.

However, cotton's largest impact comes from the amount of water it needs for production, which raises large concerns due to increasingly scarce water resources around the globe. Furthermore, the cultivation of cotton often takes place in water-scarce countries like China, India, and the United States, which can result in detrimental effects on community resources. Ultimately, production demands 1,559 liters of water for each kg of cotton produced (Niinimäki et al., 2020). This would put yearly water consumption for cotton used for apparel at about 38.2 trillion liters. However, estimations on the water footprint can range much higher, as some believe that the global average amount of water used for cotton production reaches 3,644 cubic meters per ton (CFDA, n.d.a), which equates to an estimation of about 63 trillion liters of water.

In addition to high water consumption, cotton production also utilizes significant amounts of harmful chemicals through the extensive use of pesticides and insecticides. While cotton uses about 2.5% of the world's arable land, it accounts for 16.5% of all pesticide use. Overall, as shown in Table 1, the cultivation of one kg of cotton fiber results in the production of 2.2 kg of CO_2, the consumption of 1559 liters of water, and the use of insecticides and pesticides.

Yarn Manufacturing. Once the fibers are produced, the next step in the supply chain is yarn manufacturing. In this stage, fibers go through the spinning process in order to create yarn. The main impacts of yarn manufacturing come from carbon emissions and fiber waste. There are two main types of spinning processes: staple and continuous filament yarns, the latter of which is usually utilized for manufactured fibers. Both processes tend to consume large amounts of energy as well as generate significant waste.

While there is not a large amount of quantified research on the yarn manufacturing stage, it has been estimated that 1 kg of CO_2 emissions are produced for about every 70 grams of cotton yarn spun in Bangladesh, largely due to the energy requirements of yarn spinning factories. Furthermore, in terms of textile waste, it is estimated that 15% of fibers used in cotton yarn production in Bangladesh become waste. In total, as noted in Table 1, every one kg of yarn spun results in the production of 14.3 kg of CO_2 and .18 kg of textile waste (Amin, Mahmud, & Anannya, 2022).

Textile Manufacturing. After the yarn is produced, the next stage is textile manufacturing, where yarn is knit or woven into fabric. Wet processes like dyeing, printing, or bleaching often occur at this stage as well. Lastly, different types of fabrics can also have different finishing processes. For example, polyester fabric will likely receive treatments like scouring and heat-setting, and cotton fabrics will receive treatments like singeing, de-sizing, scouring, and mercerizing. While this is not an exhaustive list of treatments in the finishing process, it summarizes the most popular treatments utilized. The main impacts from the textile manufacturing stage come from carbon emissions, water usage, chemical usage, and yarn waste.

Carbon emissions throughout the process can vary significantly, depending on what type of energy source is utilized. However, for cotton knitting in Bangladesh, it is estimated that 1 kg of CO_2 emissions are produced for every 1200 to 1620 grams of fabric made. That means that about .62 to .83 kg of CO_2 emissions are produced per kg of fabric. For dyeing, chemical finishing, and wastewater treatment, it is estimated that about 9.8 kg of CO_2 emissions are produced for every kg of fabric. This results in a total of 10.4 to 10.6 kg of CO_2 emission per kg of fabric (Amin et al., 2022).

However, the main environmental issue with this stage of production is the water consumption that is used in the dyeing and finishing processes. The average textile mill uses about 1.6 million liters of water per day to produce about 800 kg of fabric. That's 200 liters of water for every kg of fabric. About 16% of this consumption is utilized in the dyeing process, and about 8% is used for printing. More specifically, about 30-50 liters of water are used up in order to dye one kilogram of fabric. It should also be noted that while dyeing often occurs at this stage, it can also happen during the previous stage, right after yarn is manufactured. Yarn dyeing utilizes even more water, as it is estimated that 60 liters of water are needed to dye 1 kg of yarn on average. For the purpose of this study, it is assumed that dyeing occurs here in the textile manufacturing stage, as this is most common.

Furthermore, a large number of chemicals are utilized in the dyeing and finishing process, which often results in water pollution in areas where textile mills are present. About 72 different toxic chemicals attributed to textile dying have been found polluting water supplies. 30 of these 72 chemicals are unable to be removed from the supply, even with wastewater treatment (Kant, 2012). Some of the most concerning chemicals that are used within apparel production include flame retardants, AZO dyes, heavy metals, polyfluorinated substances, perfluorinated chemicals, and formaldehyde (Green America, n.d.).

Lastly, in terms of textile waste, it is estimated that about 2% of yarn is wasted in the process of kitting textiles, meaning that for every kilogram of fabric produced, .02 kg of yarn is wasted. While this number is small, in the context of how large the textile industry is, it should still be taken into consideration. As summarized in Table 1, the manufacturing of one kg of fabric results in the production of 10.4 to 10.6 kg of CO2, the consumption 200 liters of water, the use of a significant number of harmful chemicals, and the generation of .02 kg of yarn waste.

Garment Manufacturing. After textiles are woven and finished, they move to garment manufacturers, where the fabrics are cut, sewn, and finished to produce a completed item of clothing. At this stage, trims, such as buttons, zippers, lace, and other pieces, are also added to the garment. This process tends to be highly labor-intensive, therefore sourcing decisions are usually based on the lowest cost. The main impacts of garment manufacturing are carbon emissions and textile waste.

Carbon emissions tend to be lower at this stage, and the amount of emissions also depends on the type of garment being created. However, is estimated that for every 1 kg of garments created, .84 to 1.4 kg of CO2 emissions are produced (Amin et al., 2022). Water usage is not very high in the garment manufacturing stage unless dyeing and other wet processes are delayed until this stage. Besides wet processes, water would really only be used in significant amounts if machine washing is used for potential stain removal in the finishing process. Because the assumption for this study is that wet processes occur at the textile manufacturing stage, the water usage at this stage is negligible.

The main environmental impact at this step in the supply chain is the amount of textile waste that is produced from cutting the fabric. There are a number of different estimates of how much fabric is wasted for different types of garments. Some research suggests that about 10% of the fabric is wasted to produce a pair of jeans, while over 10% is wasted in the making of a blouse. Other more generalized estimates range from 15% to 25-30% of fabric being discarded in the garment manufacturing process. Ultimately, the amount of fabric wasted is dependent on a number of factors, such as the type of garment, the fabric width, the fabric design, and the design of the garment pattern (Niinimäki et al., 2020). Overall, as shown in Table 1, every one kg of garments created results in the production of .84 to 1.4 kg of CO_2 and the generation of .11 to .43 kg of textile waste.

Distribution. Lastly, after the garment is manufactured, it must be distributed to a touch point for consumers. The garment is shipped to a retail distribution center, where it will then be either delivered to a brick-and-mortar store or delivered straight to the consumer through an e-commerce model. The main environmental impact at this stage is the carbon emissions that are produced from the transportation of the garment, as most garments are made in developing countries but are then bought and consumed in the U.K., the European Union, or the United States.

While there are no quantified summary statistics on distribution emissions, it is estimated that this stage accounts for approximately 5% of emissions throughout the product lifecycle.

Furthermore, the amount of emissions is highly dependent on what type of transportation is used. Often, in traditional retail shopping, garments are transported by container boats. However, many e-commerce and fast fashion companies are utilizing air transport in order to shorten delivery times. Unfortunately, air transport has a much higher carbon footprint than container boats. For example, it is estimated that a 1% increase in air transport from ship transport for apparel could result in a 35% increase in transportation emissions (Niinimäki et al., 2020).

Another critical consideration for the distribution stage is plastic waste used in packaging. While a deep analysis of plastic waste is outside the scope of this analysis, it should be noted that plastic waste is a growing concern for the e-commerce sector of the apparel industry, as plastic packaging is often used for clothing that is directly shipped to the consumer. Plastic waste will be further discussed in the "Other Considerations" section at the end of this paper. However, for this study, the main impact of the distribution stage is the carbon footprint that compromises 5% of total emissions throughout the product life cycle.

Other Considerations and Impact Summary. One last aspect of the production process that must be acknowledged is the major ethical concerns related to working conditions for those involved in the production supply chain. In order for a business to be truly sustainable, it must treat workers in all steps of the production process fairly. However, the treatment of workers is outside of the scope of my analysis, as I am focusing only on environmental sustainability, rather than sustainability as a whole. The subject of labor will be briefly touched upon in the "Other Considerations" section at the end of this paper.

The impacts of the production phase are summarized in Table 1. In areas where there is no impact in a specific category or where the impact is close to negligible, "N/A" is listed. In categories where data on the impacts could not be located, "Data Unavailable" is listed.

Table 1: Environmental Impacts of the Production Phase		
Polyester Fiber Production	Carbon Emissions	1.7 to 4.5 kg of CO2 per kg of fiber
	Water Usage	21 liters per kg of fiber
	Harmful Chemicals	antimony, cobalt, manganese salts, sodium bromide, titanium dioxide, and microplastics are harmful if they make their way into the water supply.
	Textile Waste	N/A
Cotton Fiber Production	Carbon Emissions	2.2 kg of CO2 per kg of fiber
	Water Usage	1559 liters per kg of fiber
	Harmful Chemicals	pesticides & insecticides
	Textile Waste	N/A
Yarn Manufacturing	Carbon Emissions	14 kg of CO2 per kg of yarn
	Water Usage	N/A
	Harmful Chemicals	N/A
	Textile Waste	.18 kg of fiber per kg of yarn
Textile Manufacturing	Carbon Emissions	10.4 to 10.6 kg of CO2 per kg of fabric
	Water Usage	200 liters per kg of fabric
	Harmful Chemicals	Large numbers of harmful chemicals are used in wet processes. Some of the most prominent include flame retardants, AZO dyes, heavy metals, polyfluorinated substances, perfluorinated chemicals, and formaldehyde.
	Textile Waste	.02 kg of yarn per kg of fabric
Garment Manufacturing	Carbon Emissions	.84 to 1.4 kg of CO2 per kg of garments
	Water Usage	N/A
	Harmful Chemicals	N/A
	Textile Waste	.11 to .43 kg of fabric per kg of garments
Distribution	Carbon Emissions	Data Unavailable
	Water Usage	N/A
	Harmful Chemicals	N/A
	Textile Waste	N/A

Consumption Phase

The consumption phase of the garment lifecycle begins when the first consumer acquires the item, and it ends when the last wearer gets rid of the item. This is also referred to as the garment's utilization period. In the linear apparel model, consumption is a very short phase that is only shrinking as time goes on. In 2017, it was estimated that over half of fast fashion garments produced were thrown out within a year, and the number of wears a garment received had decreased 36% in the previous 15 years (Ellen MacArthur Foundation, 2017). Moreover, it is estimated that the average piece of clothing is only worn seven to ten times before being thrown away (Mishra et al., 2020). However, the final impacts of these changing consumption patterns ultimately occur in the post-consumption phase, when clothing is thrown out. In contrast, the direct impacts of the consumption phase largely result from consumer laundry habits which is what I will be examining the effects of in this section.

Ultimately, washing and drying clothing utilizes large amounts of energy and water, and in some cases, harmful chemicals that can make their way into water supplies. It is estimated that washing and drying a load of laundry every two days results in 440 kg of $CO2$ every year. However, this also depends on the type of load being done. If clothes are washed at 30 degrees Celsius and air-dried, then about 0.6 kg of $CO2$ is produced per load. However, a load washed at 60 degrees Celsius and dried in a dryer can produce around 3.3 kg of $CO2$ per load. These numbers are based on a 5 kg load of laundry, meaning that for every kg of clothing washed, .12 to .66 kg of $CO2$ is produced (Berners-Lee & Clark, 2010).

Furthermore, it is estimated that about 41 gallons of water per load are used for the average residential washing machine, meaning that 31.0 liters of water are used per kg of clothing washed. Again, if a person does a load of laundry every two days, this would result in

28,324.3 liters of water being used per year for laundry (National Parks Service, 2021). Lastly, in terms of harmful chemicals, microplastics and chemicals from some laundry detergents can be detrimental to the environment. Microplastics are small pieces of plastic that are shed by synthetic fabrics like polyester (CFDA, n.d.b.). While the full effects of microplastics are still being determined, they have the potential to be highly harmful to plant, animal, and human health in the long run. As wastewater technology treatment advances, microplastics are being more successfully removed from wastewater, but not all wastewater is treated, so it is important to be mindful of these effects. Additionally, certain laundry detergents have been found to contain carcinogens, which can be highly harmful if they make their way back into the water supply.

In total, as noted in Table 2, washing and drying one kg of clothing in the consumption phase results in the production of .12 to .66 kg of CO_2, the consumption of 31 liters of water, and the possible use of harmful laundry detergents and shedding of microplastics. In the table, "N/A" signifies negligible or no impact in a specific category.

Table 2: Environmental Impacts of the Consumption Phase		
Washing and Drying Clothing	Carbon Emissions	.12 to .66 kg of CO_2 per kg of clothing
	Water Usage	31 liters of water per kg of clothing
	Harmful Chemicals	Microplastics and chemicals in laundry detergents
	Textile Waste	N/A

Post-Consumption Phase

Lastly, the post-consumption phase is defined as what happens to a garment after it is finished being worn. It begins once a garment's last wearer gets rid of the product, and it ends when the garment has been destroyed, has reached its final destination, or has become a new product. For the linear model, this is where the product lifecycle ends completely. Once an individual is finished with a product, it is simply never used again.

The main impacts of the post-consumption phase include textile waste, carbon emissions, and harmful chemicals. On average, 70 pounds, or 31.8 kg, of clothing per consumer is thrown away every year in the United States (McAllister, 2016). Furthermore, about 85% of clothing that is disposed of in the United States ends up in landfills or is incinerated. Unfortunately, not all of this waste comes from individuals throwing away clothing, but it also comes from apparel companies throwing away surplus inventory—clothes that were never even worn at all. For example, in 2017, it was revealed that H&M had been burning around 60 tons of unsold inventory every year (Lieber, 2018).

While the exact portion of clothing that is sent to landfills over incineration is not generally reported on, it is known that significantly more clothing waste goes to landfills. Furthermore, quantified reports on the emissions and other impacts of incineration of textile waste are not widely available. As a result, I will focus on the impact of landfill disposal for my analysis. In 2018, landfills in the US received 11.3 million tons of textile waste, which accounted for 7.7% of municipal solid waste (Environmental Protection Agency, 2022).

When waste in landfills decomposes, it releases what is referred to as landfill gas, which is about 50% CO2 and 50% methane. The release of this much methane is concerning, as methane has significantly stronger warming qualities than CO2. To estimate the amount of methane emissions that are produced by clothing in landfills in a year, there are two main methods developed by the IPCC: the default method and the first order decay model. The default method does not reflect the time that waste takes to decay, whereas the first order decay model does. For my analysis, I am utilizing the default method of calculating landfill gas methane emissions, for this method allows for a direct calculation of a singular total for emissions over the entire process of decomposition. Additionally, while different fibers vary in the time they take to decompose, this method allows for the ability to disregard the time difference and find an overall sum for textile landfill gas. The equation is as follows:

$$\text{Methane emissions (Gg/yr)} = (MSW_T \bullet MSW_F \bullet MCF \bullet DOC \bullet DOC_F \bullet F \bullet 16/12\text{-}R) \bullet (1\text{-}OX)$$

In this equation, MSW_T is the total municipal solid waste generated, MSW_F is the fraction of municipal solid waste disposed to solid waste disposal sites, MCF is methane correction factor, DOC is degradable organic carbon, DOC_F is the fraction DOC dissimilated, F is the fraction of CH4 in landfill gas, 16/12 is the conversion of C to CH4, R is recovered CH4 (Gg/yr), and OX is oxidation factor.

Here, $MSW_T \bullet MSW_F$ will be the 11.3 million tons of clothing waste sent to landfills in the US, which is 10,251.19 Gg, The suggested default MCF when site conditions are unknown is 0.6. For textiles and paper, the DOC is estimated to be 40%. The DOC_F can range from .42 to .98, depending on the temperature of the atmosphere. Once again, I will utilize both of these numbers to calculate a range of possible emissions. The IPCC default for F is 0.5. Here, I will set R to zero, as I am aiming to calculate the total emissions produced instead of the total emissions that make it into the atmosphere. Lastly, the IPCC default for OX is 0 (Jensen & Pipatti, 2000).

This equation shows that methane emissions from clothing in landfills in the US in 2018 produced anywhere from 688.88 to 1607.39 Gg. Utilizing the conversion rate of 1 kg of methane emissions being equal to about 25 kg of CO2 emissions, somewhere between 17.22 billion kg and 40.18 billion kg of CO2e were produced from clothing that went to landfills in the US in 2018. This is equivalent to 1.68 kg to 3.92 kg of CO2e per kg of clothing. However, this is only from methane, which is only half of landfill gas.

Unfortunately, the IPCC does not provide an equation that allows for the specific calculation of CO2 emissions from landfill gas. In result, I will use the methane equation as a proxy, but I will remove the methane correction factor and replace 16/12 with 44/12, as this is the conversion of C to CO2. This results in an estimation of 3157.37 Gg to 7367.19 Gg of CO2 emissions, or 0.31 kg to 0.72 kg of CO2 per kg of clothing. Combined with CO2e from methane emissions, this results in a range of 1.99 kg to 4.64 kg of CO2e per kg of clothing.

In terms of harmful chemicals, when garments sit in landfills, chemicals from the items are released in the soil, water, and air. The harmful chemicals are the same ones that are used in the production process, often in the wet processes of bleaching, dyeing, and finishing textiles. This can be especially detrimental to the water supply near landfills, specifically for those that rely on groundwater for drinking water. As summarized in Table 3, landfill disposal of apparel results in the production of 1.99 kg to 4.64 kg of CO2e per kg of clothing, the runoff of harmful chemicals into important ecosystems, and the buildup of 37 kg of textile waste per US consumer per year.

Table 3: Environmental Impacts of the Post-Consumption Phase		
Landfill Disposal	Carbon Emissions	1.73 kg to 6.73 kg of CO2e per kg of clothing
	Water Usage	N/A
	Harmful Chemicals	Large numbers of harmful chemicals are used in garment production. Some of the most prominent include flame retardants, AZO dyes, heavy metals, polyfluorinated substances, perfluorinated chemicals, and formaldehyde.
	Textile Waste	37 kg of clothing per US consumer per year

Overall, fast fashion and the linear economy have significant negative impacts on the environment. From production to consumption to post-consumption, this model is not sustainable in the long term, and eventually, it needs to be transformed completely. Unfortunately, research on consumer behavior and the fast fashion industry shows that, in the short term, this business model is not going anywhere, which I will discuss in the following two sections.

Consumer Purchasing Behavior

Here, I examine the trends in consumer opinions and purchasing behavior as related to fast fashion versus sustainable fashion. Ultimately, despite the negative effects of the linear fashion economy on the environment, there is not a large trend of consumers shifting towards more ethical purchasing behaviors in regard to apparel.

Ultimately, there are three main reasons for this. First, some consumers are simply unaware of the effects of the linear fashion economy on the environment. Second, for some consumers, ethics are not a priority when it comes to clothes shopping. Instead, factors like price, convenience, and style take precedence. The last—and most prominent—reason is that although there is a growing awareness of the negative impact of fast fashion, consumers who believe that it is better to shop sustainably do not necessarily act in accordance with their beliefs. Unfortunately, there is a gap in the attitudes and behaviors of consumers, as many that hold ethical concerns still do not shop ethically (Wiederhold & Martinez 2018).

Multiple studies provide evidence for the prominence of this last reason. For example, one study found that positive attitudes toward sustainable clothing only explained 11.5% of the variance in purchase behavior, meaning that attitudes and beliefs are a weak predictor of actual shopping habits (Jacobs, Petersen, Hörisch, & Battenfeld, 2018). In another study conducted in the UK, it was found that 78.12% of those polled in a sample population reported that they were informed on environmental issues from the fast fashion industry. Additionally, on average, participants reported feeling disgusted by the negative environmental impacts of fast fashion and being interested in brands that promote sustainability. However, about a third of the same participants reported that they believed less than 10% of their purchases were sustainable. In fact, only around 20% of participants believed that over 30% of their purchases were sustainable (Zhang, Zhang, & Zhou, 2021). Lastly, another study based on an online survey found a direct link between perceptions of social responsibility of a brand and consumer attitudes toward that clothing brand. However, no link was found between consumer attitudes and purchase behavior (Neumann, Martinez, & Martinez, 2021). Ultimately, although awareness seems to be widespread, and consumers seem to be interested in sustainability, their purchasing behavior does not match their attitudes.

Because there is no significant consumer shift away from unethical shopping behaviors, it is unlikely that consumers will lower their rate of purchasing in the near future or shift their shopping habits away from fast fashion companies. Because of this, low prices and a high volume of sales will remain a prominent business strategy in the fashion industry. However, the change in consumer attitudes that favor sustainability has the potential to influence fast fashion companies to shift to more sustainable practices, as long as it does not come at too great of a cost. As a result, instead of attempting to eradicate the fast fashion model completely, it is necessary to look at whether or not the fast fashion industry can be environmentally sustainable, for sustainable fast fashion is likely a more realistic goal than instilling sustainable shopping habits in consumers in the near future.

In conclusion, the lack of consumer motivation to transform purchasing patterns will result in the staying-power of the fast fashion industry, at least in the short-term, for in the end, as long as consumers purchase their products, fast fashion companies will continue to produce them. As a result, transformation on the business side, as long as the core fast fashion business model remains unchanged, will be more realistic than transformation on the consumer side.

Growth and Future Projections of Fast Fashion Companies

In addition to the disconnect between consumer sentiment and actions, the past growth and future projections of fast fashion companies and the industry as a whole can be examined in order to see that the expansion of the fast fashion business model is unlikely to slow down.

For example, from 2016 to 2021, the market size for fast fashion grew at a rate of 1.69% per year, reaching a total value over $91 million in 2021. Going forward, the market is expected to grow at a much higher average rate of 13.8% per year for the next five years from 2021 to 2026, ultimately reaching a value over $173 million in 2026 (The Business Research Company, 2023).

To better understand what fast fashion's growth has looked like in reality, I have summarized the sales growth and growth rates of two of the largest publicly traded fast fashion companies—Inditex and H&M Group—over the past ten years in Table 4. Inditex owns seven brands: Zara, Pull&Bear, Massimo Dutti, Bershka, Stradivarius, Oysho, & Zara Home. H&M Group owns eight brands: H&M, COS, Monki, Weekday, & Other Stories, Cheap Monday, H&M Home, and ARKET.

Table 4: Sales Growth of Inditex and H&M Group

Year	Inditex Sales (M)	Inditex Sales Growth	H&M Group Sales (M)	H&M Group Sales Growth
2013	$17,727	-	$12,213	-

2014	$19,204	8.33%	$14,385	17.78%
2015	$22,154	15.36%	$17,182	19.44%
2016	$24,710	11.54%	$18,265	6.31%
2017	$26,856	8.69%	$19,000	4.02%
2018	$27,714	3.19%	$19,988	5.20%
2019	$29,983	8.19%	$22,112	10.63%
2020	$21,626	-27.87%	$17,768	-19.64%
2021	$29,379	35.85%	$18,902	6.38%
2022	$34,523	17.51%	$21,239	12.37%

The large drop from 2019 to 2021 is likely due to macroeconomic factors that can be attributed to the global pandemic. This is likely why the growth rate of the fast fashion market from 2016 to 2021 seemed so much smaller than future projected rates. In comparison, in the average year before the pandemic, growth rates ranged from 3.19% to 15.36% for Inditex and 4.02% to 19.44% for H&M. As a result, a 13.8% growth rate over the next five years does not seem unreasonable, especially as the number of purchases per year increase and the utilization periods for clothing decrease (Inditex, 2023; H&M Group, 2023).

Ultimately, the market for fast fashion shows no signs of slowing down, as shown by market predictions and historical data from the largest public fast fashion corporations. Again, this demonstrates that moving towards more sustainable fast fashion is likely a more realistic goal than shifting away from fast fashion as a whole.

A Sustainable Fashion Economy

In this section, I will give a brief definition of what a sustainable fashion economy is, and then I will summarize what a sustainable fashion economy would ideally look like throughout the product lifecycle. It is important to note that not all principles and mechanisms of a sustainable fashion economy will be able to be applied to the fast fashion industry. However, I would like to outline the entirety of an optimal sustainable fashion economy in order to show what the ultimate goal beyond fast fashion would look like.

What is a Sustainable Fashion Economy?

A sustainable fashion economy is based on three main principles: reducing environmental impacts, lengthening the product lifecycle, and closing the loop to turn the linear fashion economy into a circle. As discussed in depth in the following sections, the production phase would focus on lessening environmental impacts and designing clothing to be reused and recycled, the consumption phase would focus on increasing the utilization period of a garment and decreasing rates of consumption, and the post-consumption phase would focus on rerouting garments that have reached the end of their lives to re-enter the lifecycle as a new product through recycling.

Production Phase

As stated above, a sustainable production phase would focus on utilizing inputs and designing a supply chain that has the lowest possible impacts on the planet, as well as designing products to be reused and recycled. As outlined in the linear fashion economy section of this paper, the steps within the production phase supply chain include fiber production, yarn manufacturing, fabric weaving, garment manufacturing, and distribution. I will also add a design stage at the beginning of the process, in order to address how sustainable design can be accomplished.

Design. First, in the design stage, the two main considerations should be the durability of the garment and the ability of the garment to be recycled at the end of its lifetime. The durability of a garment has two components: physical durability and emotional durability. Physical durability is simply the ability of a garment to remain intact over time, whereas emotional durability focuses on the style and look of the garment and its ability to stay relevant over a long period of time, as opposed to garments that follow quick trend cycles. Designing a garment to be recycled considers the materials that a garment is made out of and how easily it could be disassembled. For example, different fibers can be more difficult to recycle, and fiber blends are more difficult to recycle than pure fibers, as the fibers often have to be mechanically separated (Ellen MacArthur Foundation, 2020).

Fiber Production. In the fiber production phase, the focus would be on utilizing fibers that have the lowest impact on the environment. Some of the most sustainable fibers include recycled fibers, organic plant-based fibers, or fiber innovations from new materials. Recycled fibers usually have the lowest impact, as no new materials are produced. However, this is dependent on how much energy is required to recycle the previous items into new fibers. Examples of recycled materials include recycled cotton, recycled polyester, and recycled wool. Organic fibers follow a certain set of standards in their production that reduces water usage as well as pesticides and insecticides. Some organic fibers include organic cotton, organic hemp, and organic linen. Lastly, there are also new fiber innovations emerging, such as ECONYL, which is made from recycled synthetic waste, and Bananatex, which is made purely from banana plants (Rauturier, 2022).

Yarn Manufacturing. In the next phase of yarn spinning, the sustainable effort would surround attempts to reduce carbon emissions from energy usage in this phase, as well as the reduction of waste. Ultimately, utilizing clean energy sources and implementing management practices to reduce waste and recycle it would make this stage more sustainable.

Textile Manufacturing. The textile manufacturing stage would resemble the yarn spinning process in its attempts to reduce emissions and waste, with a focus on clean energy and better management practices. Additionally, this stage would focus on eliminating harmful chemicals that are often used in the wet processes of dyeing, bleaching, and finishing fabrics. Hazardous substances can be defined as compounds with intrinsically negative properties, such as being persistent, bioaccumulative and toxic, very persistent and very bioaccumulative, mutagenic and toxic for reproduction, carcinogenic, or endocrine disruptors, as outlined by the ZDHC Knowledge Base, where a full list of harmful substances can be found (Ellen MacArthur Foundation, 2020). Efforts in the textile manufacturing stage should also focus on reducing the consumption of water and ensuring that wastewater that is being produced is also being properly treated.

Garment Manufacturing. Next, in the garment manufacturing stage, a shift toward clean energy is needed in order to reduce carbon emissions. Additionally, creative pattern design that utilizes as much of a piece of fabric as possible would result in higher fabric utilization rates. Lastly, fabric waste should be properly disposed of and recycled so that it can reenter the supply chain instead of being sent to a landfill.

Distribution. Lastly, the distribution phase should focus on reducing carbon emissions in transportation and utilizing sustainable materials for packaging. To reduce carbon emissions, lower energy transportation should be utilized, such as water transport instead of air transport. Additionally, taking the shortest routes and ensuring a high utilization rate of transport vehicles can also help to rescue impact. In terms of packaging, plastic packaging should be minimized, and biodegradable packaging and/or packaging made out of recycled materials should be implemented.

Consumption Phase

To create a more sustainable consumption phase, the utilization period of a garment should increase and the rate of consumption should decrease. To achieve these goals, there are two mechanisms that can be adjusted—that of the consumer and that of the seller. Additionally, individuals should also work to reduce the impacts of taking care of their clothing.

To extend the utilization period on the consumer's side, the obvious strategy is to buy less clothing and to keep clothing items for a longer period of time. To achieve longer utilization, consumers can work to discover their personal style and avoid buying garments simply because they are trendy. Additionally, to extend a garment's lifetime, damaged garments should be repaired rather than thrown out. Lastly, once an individual is done with a garment, they can still increase its utilization by giving an item away or reselling the item instead of throwing it away.

On the other hand, clothing companies can adopt new business models that encourage longer utilization of clothing. The main business models are resale and rental. Similar to the consumer side, more businesses can also adopt resale strategies. Some sites for re-selling garments have already become popular, such as TheRealReal, which allows people to buy used designer clothing. Similarly, some companies offer the opportunity to buy used garments from their brand. Levi's is one example, as they list vintage Levi's products on their site in addition to their new products.

In the rental business model, clothes are sent to individuals for a specified amount of time so that they can wear an item just a few times before returning it so that it can be worn by someone else. There are a few different formats of this model. For example, renting one item to wear one time, instead of buying an item to wear once or twice, is a model that is growing in popularity. This is especially useful for formalwear or special occasions, as these items get very few wears when bought by an individual. Another format of the rental model is offering a subscription to receive multiple items every month. With this model, an individual receives a few items of clothing at the beginning of the month that they then can wear and return at the end of the month. These rental models can be especially useful in accommodating increasing trend cycles and changes in taste, for it allows people to change out their wardrobe at a very quick pace without having to buy and throw out new items (Ellen MacArthur Foundation, 2021).

Another important aspect of the consumption phase is reducing the environmental impact of maintaining clothing. Washing and drying clothing uses high amounts of energy and water. As a result, consumers should minimize the amount they wash their clothing, ensure that they are doing full loads of laundry, and air dry clothing rather than use an electric dryer as much as possible. Overall, in order to make the consumption phase of the product lifecycle as sustainable as possible, both consumers and businesses must engage in the process and change their actions, both in terms of selling and purchasing tactics as well as in clothing maintenance and care.

Post-Consumption Phase

The post-consumption phase in a sustainable fashion economy focuses on recycling garments so that, instead of being sent to landfills, their materials can be reused in new products. There are three main categories of recycling: upcycling without full deconstruction, upcycling with full deconstruction, and downcycling.

Upcycling is a type of recycling where an item is made into a new product that is of the same value or of greater value. In the apparel industry, this would mean that the materials are remade into a new garment. Upcycling without full reconstruction can take many different forms, as a garment could simply be dyed a new color, or it could be cut apart and resewn into a new piece of clothing. This type of recycling is the most sustainable, as it requires the least amount of energy.

When an item of clothing is upcycled with full deconstruction, it is broken down into its smallest components, which then re-enter the supply chain at the beginning. The three main mechanisms for this type of recycling include fiber recycling, polymer recycling, and chemical monomer recycling. With fiber recycling garments are sorted by color and material and then shredded back into fibers. In contrast, polymer recycling destroys the fibers but instead keeps the chemical structure of the material intact by way of melting or extruding fabrics. Lastly, chemical monomer recycling goes a step further and breaks the polymers down into monomers that can then be remade into polymers with the same quality as virgin materials.

Lastly, downcycling is when an item is recycled into a new product that is of lesser value than the original product. This type of recycling is less sustainable, for it moves down into a different product lifecycle rather than fully closing the loop and re-entering the same sector. Examples of this type of recycling include utilizing textiles as cleaning ranges or as stuffing for furniture or dog beds.

Overall, the idea of a sustainable fashion economy is constantly evolving as research on the subject continues to grow, and hopefully, this research will eventually be put into practice on a large scale. By reducing emissions, water consumption, and chemical use throughout the product lifecycle; elongating the lifetime of a garment; and working to close the loop and create a circular fashion economy, the apparel industry has the potential to be sustainable in the long run.

Can Fast Fashion Be Sustainable?

Despite fast fashion having detrimental effects on the environment, it is showing no signs of slowing down. While the best option for the environment would be to eradicate fast fashion completely and shift towards a completely sustainable fashion economy, this is ultimately an unreasonable hope for the near future. As a result, it is important to ask whether or not fast fashion itself can be sustainable.

In this section, I will start by outlining the criteria for what it means to be sustainable in the context of this paper. Then, I will outline the potential changes that can be made in the fast fashion business model by applying concepts and strategies from the sustainable fashion economy. I will be assessing the change possible only from the actions of the industry, rather than the consumer. The assumption is that there will be no change in consumer behavior and that sales will continue at the same rate and will continue to grow at expected rates. However, I will still consider the impacts that fast fashion has throughout the entire product life cycle, including production, consumption, and post-consumption. I will simply examine reduction tactics that focus on the phases that a company can control—the entirety of the production phase and a portion of the post-consumption phase. As a result, to be sustainable, the efforts within the production and post-consumption phases must also offset the environmental impact of the consumer in the consumption and post-consumption phases that a company's products are linked to generating.

After summarizing the potential changes that could be made in the fast fashion business model, I will provide an overall evaluation of how these changes could reduce the impacts of the value chain in its entirety and if the reductions are enough to make the fast fashion business model sustainable. The final evaluation will also include a sensitivity analysis in order to consider the uncertainty of the effects of different practices.

Definition of "Sustainable"

To answer the question of whether or not fast fashion can be sustainable, I first need to define what it means to be sustainable. For this study, I will focus on three of the four main categories of environmental impacts that I examined when outlining the impacts of fast fashion and the linear economy: carbon emissions, water usage, and harmful chemicals. The fourth category of textile waste will be integrated into carbon emissions and harmful chemicals in the final evaluation, as the main environmental effects of textile waste are the emissions and chemical runoff that occur when disposed of in landfills. In each of the sections below, I will outline why the effects of each category are important, as related to the environment; then, I will outline how I will define sustainability for apparel companies.

Carbon Emissions

Over the past 150 years, ever since the Industrial Revolution, greenhouse gas emissions have increased immensely, causing the concentration of carbon dioxide to reach an average of 410 parts per million since 2011 (IPCC 2021). In 2020 alone, carbon emissions reached 34.8 billion metric tons worldwide (Tiseo, 2021). Since 1981, the earth has warmed about .18 degrees Celsius per decade, which is about twice as fast as the average increase since 1880. As a result, the greenhouse gas effect has caused global temperatures to steadily increase, reaching .87 degrees Celsius above pre-industrial levels in the decade 2006-2015. Now, it is estimated that temperatures have increased 1 degree above pre-industrial levels (IPCC, n.d.). In order to combat extreme climate risks, 193 countries have signed The Paris Agreement to limit temperature increases to below 2 degrees Celsius above pre-industrial levels, and preferably below 1.5 degrees Celsius above pre-industrial levels. Ultimately, if the earth were to warm more than 1.5 degrees, it would result in unstable weather conditions, detrimental effects on ecosystems and biodiversity, and a dangerous increase in sea levels (Erdenesanaa, n.d.).

In order for a clothing company to be sustainable in regard to carbon emissions, it must be reducing its emissions in line with the 1.5-degree pathway outlined by the Paris Agreement. Ultimately, in order to remain in line with the 1.5-degree pathway, emissions need to be reduced by 45% by the year 2030, and they must reach net zero by the year 2050 (United Nations, n.d.b). For the purpose of this paper, I will define sustainability for carbon emissions in the short term, and I will explore whether or not it is reasonably possible for the fast fashion life cycle to reduce its emissions by 45%. I am choosing to utilize the shorter-term metric, for it is likely that significant innovations, like large-scale carbon removal technology, will be needed in order to achieve net zero emissions. While planning for this stage should begin now, the scope of this paper focuses on the current capabilities of fast fashion companies and their potential ability to be sustainable in the present.

Water Usage

As climate change continues to cause the planet to warm, the effects are observed throughout the water cycle. With rising temperatures, the earth sees higher rates of evaporation causing higher demand for water in agriculture and natural environments. Additionally, extreme weather has become more common as storms and flooding increase and droughts become more severe. With this heightened uncertainty regarding water patterns, it is more important than ever to increase protection of the water supply, for water insecurity is increasing. This issue will only be exacerbated with the predicted population increase of the earth. As a result, freshwater, which makes up only 3% of the planet's water, needs to be used as efficiently and sparingly as possible in order to ensure a proper water supply for the planet's population (International Union for Conservation of Nature, 2015).

In order to be sustainable in terms of water usage, a company must align with the United Nations' Sustainable Development Goal (SDG) 6 of ensuring the availability and sustainable management of water for all as it relates to their business practices. The main targets of SDG 6 that relate to the clothing industry include ensuring safe drinking water for all, ensuring equitable sanitation for all, and increasing efficiency in water usage. As a result, for a company to be considered sustainable in terms of water, it must align with three main goals. First, a company must replenish all of the water that it utilizes in water-scarce areas. Second, it must ensure that all wastewater used in production is being treated so that it may be reused. Lastly, it must make an effort to reduce overall water usage in production (United Nations, n.d.a).

Harmful Chemicals

Over 15,000 chemicals are used in the textile production process, and many of them have adverse effects on the environment. One of the main concerns of chemical use in the apparel industry is that many of the chemicals are used in wet processes, and often, untreated effluent is discharged back into the environment, further contributing to the scarcity of freshwater supplies. Additionally, the presence of effluent in water significantly decreases the oxygen concentration, which is highly harmful to underwater ecosystems and biodiversity. However, chemicals used in the production process do not only affect water quality but air quality as well. They can evaporate into the air, where they can be breathed in or absorbed into the skin, resulting in negative effects on human health (Khan & Malik, 2014). Some of the most concerning chemicals that are used within apparel production include flame retardants, AZO dyes, heavy metals, polyfluorinated substances, perfluorinated chemicals, and formaldehyde (Green America, n.d.).

Because so many chemicals are utilized throughout the apparel production process, it is outside the scope of this paper to evaluate sustainability based on the use of each individual chemical. Instead, I will look to the assessment of the Zero Discharge of Hazardous Chemicals (ZDHC) Foundation and its approved partners. The ZDHC Foundation has established the Roadmap to Zero Programme, which assists stakeholders in the apparel value chain in eliminating dangerous chemicals and creating a more sustainable and environmentally friendly process. The ZDHC Foundation approves third-party certification bodies to assess those in the apparel supply chain and certify their ZDHC Manufacturing Restricted Substances List (MRSL) Conformance (ZDHC, 2022).

Ultimately, in order for an apparel company to be considered sustainable in terms of chemical use, its entire supply chain must uphold ZDHC MRSL Conformance, as approved by an official third-party certifier. Not only should each stage in the supply chain avoid harmful chemicals, but they should also have proper waste management systems in place in order to treat wastewater and dispose of solid waste that has been utilized in the chemical treatment process, for even if the most harmful chemicals are avoided, there are still a large number of chemicals that are less threatening but still impactful.

Strategies to Reduce Environmental Impacts

In this section, I will gather information on current technology and process innovations for the apparel value chain and summarize the potential impacts that these changes could have on carbon emissions, water consumption, the use of harmful chemicals, and textile waste.

As stated, I will assess the change possible only from the actions of the industry, not the consumer. My analysis of the possible tactics will follow the product life cycle, starting with the production phase and ending with the post-consumption phase. The main focus will be on the production phase, as this is the phase that a company has the most control over. I will summarize the potential impacts of each stage at the end of each section, and then I will finish with an overall evaluation of how these changes could reduce the impacts of the value chain in its entirety and if the reductions are enough to make the fast fashion business model sustainable. The final evaluation will also include a sensitivity analysis in order to consider the uncertainty of the effects of different practices.

As much as possible, I will only utilize and recommend sustainability strategies that do not fundamentally alter the fast fashion business model. To do so, the strategies that I will consider should not slow the process and should remain in line with maintaining low costs of production, high volume of sales, and quick turnaround times. However, in many cases, the pricing on large-scale inputs and technologies is not publicly available. As a result, I will take cost into consideration to the best of my ability, and I will specify what information is available on pricing, but ultimately, more research will likely be needed on the cost structures of the strategies.

Production

Fiber Production. The first step in the production phase is the cultivation of the fibers. Here, I will be focusing on polyester and cotton, as these are the two most common fibers used in apparel production. As outlined in the section "A Sustainable Fashion Economy," more sustainable versions of polyester and cotton already exist.

For polyester, the two available options include recycled polyester and bio-polyester. Bio-polyester is a new fiber that is still in development and its impacts have not yet been properly quantified. However, the use of recycled polyester is currently a very viable option for apparel companies. The main issue is that, while recycled polyester is more developed than bio-polyester, the effects are also still not fully agreed upon. One study estimated that recycled polyester can reduce emissions by up to 79%. A different study specified reduction based on the type of recycling used; it is estimated that mechanically recycled polyester reduces emissions by 76%, semi-mechanical recycling reduces emissions by 54%, and chemical recycling reduces emissions by 24% to 36%, depending on the type (Periyasamy & Militky, 2020). However, another recent study estimated that the production of recycled polyester fiber might produce up to three times the CO2 emissions of virgin polyester (Qian, Ji, Xu, & Wang, 2021).

Another aspect to keep in mind is the fact that the majority of recycled polyester is made from plastic bottles, not polyester textiles. By recycling the bottles into polyester rather than new bottles, the lifecycle of the materials is likely to be shortened, as apparel is less likely to be recycled at the end of its lifetime.

An additional factor to be considered is that recycled polyester is slightly more expensive than virgin polyester. When comparing the costs of producing pillows with virgin and recycled polyester, it was estimated that using recycled polyester increased costs of production anywhere between .12% to 1.36%. As a result, utilizing recycled polyester over virgin polyester would be possible for a fast fashion company, but it would raise variable costs, lowering profit margins.

In terms of water usage, there is not a good estimate of what the reduction in total water consumption is. However, it is estimated that the water footprint, or the impact of freshwater consumption on the water shortage, is reduced by 59% (Qian et al., 2021). In terms of harmful chemicals, recycled polyester has the same chemical composition as virgin polyester. As a result, it is necessary that any wastewater produced from the process is properly disposed of and treated. As summarized in Table 5, in the best-case scenario, if a company utilized 100% recycled polyester fiber, it could reduce CO2 emissions in the polyester fiber production stage by 79%, but in the worst-case scenario, it would increase emissions by 300%. Additionally, it reduces the impact on water scarcity by 59% and can reduce the impact of chemical usage if proper wastewater management is put in place.

The second most utilized fiber is cotton. More sustainable options for cotton include recycled cotton, organic cotton, or Better Cotton. For recycled cotton, CO2 emissions for production are estimated to be higher than for virgin cotton. This is largely because of the energy needed for the industrial procedures of shredding and breaking down recycled yarn or fabric. In contrast, agricultural processes do not require as much energy. Ultimately, the production of recycled cotton fiber is estimated to increase emissions by about 50%. However, the main environmental savings from recycled cotton is not in regards to emissions, but water. Because there is no need to grow new crops for recycled cotton fibers, water consumption is reduced significantly. Ultimately, it is estimated that the use of recycled cotton can reduce water consumption anywhere from 25% to 80% (Wu et al., 2015). Lastly, there is a reduction in the use of harmful chemicals as well, as there is no longer a need for insecticides and pesticides in the production process. Furthermore, one study estimated that recycled cotton prices were 18% lower than virgin cotton prices in 2019, making the more sustainable option more affordable as well (Fidan, Aydoğan, & Uzal, 2021).

However, as demand for recycled cotton rises, the price will likely rise as well, for accessibility is limited to the amount of cotton yarn, fabric, and products that are recycled and available to be remade. As a result, other options, like organic cotton and Better Cotton are necessary as well. Organic cotton is a type of virgin cotton that is grown with the goal of reducing its impact on the environment. It is estimated that the production of organic cotton produces about 60% less CO2 emissions than standard virgin cotton. Additionally, organic cotton uses about 28% less water to cultivate. Lastly, organic cotton is grown without the use of pesticides, reducing harmful chemicals in the process as well. However, one issue with organic cotton is that it tends to produce lower yields than conventional cotton. This can increase the impact of production per kg of fiber produced, and it can hurt the profits of farmers producing cotton. However, it still reduces environmental impacts overall.

Better Cotton, which meets a standard set by the non-profit of the same name, is similar to organic cotton in that it aims to reduce the impact of cotton on the environment. The main difference is that it doesn't completely eliminate the use of pesticides, but instead attempts to use them judiciously and sparingly. The production of Better Cotton is estimated to reduce CO2 emissions by about 40% and water consumption by about 39%. As previously stated, Better Cotton also reduces the use of pesticides, even though it does not eliminate them completely. Furthermore, Better Cotton yields tend to be higher than that of organic cotton. (Shah, Bansal, & Singh, 2018). In terms of pricing, both organic cotton and Better Cotton are priced about 5% higher than standard cotton, with an increase between USD 0.01 per kg to USD 0.03 per kg (Voora, Bermúdez, Farrell, Larrea, & Luna, 2023). Overall, as shown in Table 5, by utilizing cotton alternatives, CO2 emissions could be reduced up to 60% or could increase by 50%, water usage could be reduced between 25% and 80%, and harmful chemicals could be reduced by the elimination of the use of pesticides and insecticides.

Yarn Manufacturing. The next step in the production process is spinning the fibers into yarn. As previously stated, the main impact of this stage is CO2 emissions from the energy use of spinning factories as well as fiber waste that is produced in the process. To reduce CO2 emissions, cleaner energy sources are necessary. Clean energy sources include solar, wind, hydroelectricity, geothermal, and biomass. Ultimately, if energy inputs were completely switched to renewable sources, CO_2 emissions could be reduced by 100%. While switching from fossil fuels to renewable energy sources might require an upfront investment, it could also save money in the long term, as renewable energy sources are currently the cheapest sources of energy, according to the International Renewable Energy Agency. It is estimated that investments in renewables in 2021 allowed the United States to save $55 billion in energy costs in 2022 (International Renewable Energy Agency, 2022). This is largely due to this sharp increase in fossil fuel prices in the past two years. Even if fossil fuel prices drop, they could remain unstable. Not only is solar power currently cheaper, but it could offer greater stability and predictability of pricing, allowing companies to better estimate future costs.

Furthermore, the shift to renewable energy is not only happening in the United States but also in countries where fast fashion production is prominent. For example, in 2020, the Jai Bhawani women's cooperative textile mill announced that it would become Asia's first solar-powered textile mill. It was estimated that the project would cost Rs 100 crore, which is equivalent to about 122k USD (Nair, 2020). Moreover, this transformation is not an isolated event. In May of 2022, South Asia's biggest textile and apparel manufacturer, MAS Holdings, announced that two of its factories in Indonesia had converted to renewable electricity, making these factories 100% powered by green energy (Glover, 2022).

In terms of fiber waste, as long as the waste is properly tracked and collected, it can then be recycled so that it can re-enter the supply chain rather than being disposed of. It should be noted that cotton is the only fiber for which large-scale fiber-to-fiber recycling is available. However, other fiber could be recycled through open-loop recycling to make stuffing. In total, as noted in Table 5, these strategies could allow CO_2 emissions and fiber waste to be reduced by 100%.

Textile Manufacturing. After the yarn is spun, it is then woven into fabric. In this stage, the focus is on reducing CO2 emissions from energy usage in factories, reducing water consumption in wet processes, minimizing yarn waste, and getting rid of the use of harmful chemicals in the dyeing and finishing processes. Similar to spinning mills, textile manufacturers can also make the switch to clean energy sources in order to reduce CO2 emissions. Again, if a complete switch is made, this could reduce emissions by 100%.

Next, to reduce water consumption in the wet processes, there are two main strategies—conservation through the reduction of consumption in the processes and conservation through wastewater treatment and reuse. Overall, research on new techniques to reduce water usage is growing, but many of the emerging technologies are still new and as a result, are unreliable or unadaptable on a large scale. For example, ozone bleaching, an alternative form of bleaching, results in high water savings, but the technique is not yet able to produce consistent levels of whiteness that match traditional bleaching techniques.

However, two new dyeing innovations that are more realistically applicable include the use of low-liquor ratio machines and supercritical fluid dyeing. When dyeing fabric, the liquor ratio refers to how much water is utilized to dye a textile. For example, a liquor ratio of 1:10 means that 1 kg of fabric is dyed in 10 liters of water. The purpose of low-liquor ratio machines is to reduce the amount of water utilized in the dyeing process. It is estimated that if the liquor ratio is lowered from 1:10 to 1:8, water consumption will be reduced by 20%, and a cost savings of 15% can be achieved (Hussain & Wahab, 2018). However, while cost savings is possible, it should be noted that a large upfront capital investment would be needed to implement the machinery that makes this process possible. Currently, not enough information is available to me to make a proper estimation of the potential cost of this investment.

Supercritical fluid dyeing utilizes supercritical fluids, usually CO2, instead of water in order to dye fabrics. Supercritical fluids are materials that can be categorized as either liquids or gases formed by a combination of high temperatures and high pressure, giving them special properties. This technique is new, but it is promising for the use of dyeing synthetic fabrics, like polyester. However, it is still being developed for the use of dyeing other types of fibers. After dyeing, the supercritical CO2 can be recycled, so that no extra emissions are produced. This technique reduces water consumption by 100%, as no water is needed for the process. Furthermore, the use of this technique results in cost savings for the future, as the process is cheaper than the traditional dyeing process. However, similar to low-liquor ratio machines, there would be a significant upfront investment to implement the machinery needed for this process, and it could only be utilized on fully synthetic fabrics (Hussain & Wahab, 2018).

In addition to new dyeing techniques to save water, good management and water-saving washing techniques can also be utilized. Good management practices include process monitoring, special staff training, and maintenance programs. It is estimated that these strategies can result in water savings of 5-10% in the fabric production process. To further reduce the water footprint of this phase of production, wastewater treatment and reuse can also be implemented. In this process, wastewater that has been used in the wet processes is treated in then reused in the wet processes again. It is estimated that this usage can reduce water consumption in this phase by 30-50% (Ozturk, Karaboyacı, Yetis, Yigit, & Kitis, 2015). Finally, at the end of the process, effective wastewater treatment should be put in place so that no effluent makes its way back into the water supply. In terms of textile waste, the solution is similar to that of the spinning stage. Once again, waste should be tracked and collected, and as a result, cotton yarn can be recycled into new textiles and other yarns can be recycled into stuffing.

Lastly, in terms of chemical usage, there needs to be an increase in monitoring and control over what types of chemicals are used throughout this process to ensure that no harmful chemicals from the ZDHC Manufacturing Restricted Substances List are utilized in the dyeing, bleaching, and finishing processes of this stage. Fortunately, the ZDHC not only provides an MRSL but also offers a number of resources to assist companies in the journey to increase transparency and work to reduce harmful chemicals throughout manufacturing in order to achieve full compliance.

Overall, as summarized in Table 5, through the application of new technologies and better management in the textile production stage, CO2 emissions can be reduced by up to 100%, and water consumption can be reduced by up to 100% in the dyeing process of fully synthetic fabrics or 20% for all fabrics. Furthermore, all water usage in this stage can be reduced by 35-60% through good management practices and water treatment and reuse, and textile waste can be reduced by up to 100%. Finally, through close management of wet processes, the use of harmful chemicals can also be eliminated.

Garment Manufacturing. After the fabric is produced, the garment is then manufactured. In the garment manufacturing stage, CO2 emissions from energy usage need to be reduced, and fabric waste from assembling a garment needs to be minimized. Just like in the yarn spinning and fabric weaving phases, clean energy sources can be utilized to reduce the CO2 emissions of garment factories by up to 100%.

To reduce fabric waste in this stage of the production phase, the main strategy is to use thoughtful design that will allow for maximum use of a piece of fabric based on how the pieces are cut for the pattern. However, the savings that this strategy allows is highly dependent on the garment that is being made. Furthermore, this strategy can restrict freedom in the design process.

It could be utilized to a certain extent in fast fashion production, but it is unlikely to be highly implemented, as a key component of fast fashion is being able to create trendy pieces. Therefore, a strategy that controls the design process is unlikely to be implemented.

However, while it is impossible to completely eradicate fabric waste from the cutting process of garment manufacturing, there is control over what is done with this waste. Again, the only large-scale textile recycling that is available is for cotton through Renewcell, and textiles used for recycling must be at least 95% cotton. However, other textiles can again be downcycled into stuffing. By rerouting the waste back into the production cycle, it no longer ends up in landfills, where it would be doing damage. Ultimately, as shown in Table 5, CO_2 emissions and fabric waste could be reduced by up to 100%.

Distribution. The final stage of the production process is distribution, in which the garment is delivered either to a retail store or directly to the consumer. The main concern in this stage is CO_2 emissions that are produced by transportation. Unfortunately, as stated in previous sections, there is little research on the amount of CO_2 emissions that apparel distribution creates. In consequence, there is also little research on methods to reduce emissions in this stage. Furthermore, it would likely be difficult to decrease emissions during distribution, as quick distribution is a hallmark of fast fashion, and many attempts to reduce emissions would likely increase the amount of time it takes to transport a product.

However, one method that could be implemented is the optimization of distribution paths, so that garments do not travel unnecessary distances. Additionally, because I previously acknowledged the issue of plastic waste when outlining the effects of distribution, I would like to mention realistic alternatives, even though non-fabric waste is not considered in my overall evaluation. Two of the main alternatives include recycled plastic and biodegradable plastic.

These options will be further discussed in the “Other Considerations” section at the end of this paper.

Table 5: Capacity for Reduction of Impact in the Production Phase		
Polyester Fiber Production	CO2 Emissions	79% Reduction to 300% Increase
	Water Usage	59% Reduction in Water Footprint
	Harmful Chemicals	No change in chemical usage, but if proper wastewater treatment plants are in place, then the impact of harmful chemicals can be avoided.
	Textile Waste	N/A
Cotton Fiber Production	CO2 Emissions	60% reduction to 50% increase
	Water Usage	25% to 80% Reduction
	Harmful Chemicals	Potential elimination of pesticides and insecticides
	Textile Waste	N/A
Yarn Manufacturing	CO2 Emissions	Up to 100%
	Water Usage	N/A
	Harmful Chemicals	N/A
	Textile Waste	Up to 100%
Textile Manufacturing	CO2 Emissions	Up to 100%
	Water Usage	Up to 100% reduction in the dyeing process of fully synthetic fabrics; up to 20% reduction for the dyeing of all fabrics. Furthermore, all water usage in this stage can be reduced by 35-60% through good management practices and water treatment and reuse.
	Harmful Chemicals	The use of harmful chemicals can be fully eliminated.
	Textile Waste	Up to 100%
Garment Manufacturing	CO2 Emissions	Up to 100%
	Water Usage	N/A
	Harmful Chemicals	N/A
	Textile Waste	Up to 100%
Distribution	CO2 Emissions	Data Unavailable
	Water Usage	N/A

	Harmful Chemicals	N/A
	Textile Waste	N/A

Consumption

Because the consumption phase begins when a garment is purchased by the consumer, it is difficult for companies to influence this phase of the product life cycle. There are some strategies that companies could introduce in order to elongate the utilization period. For example, a brand could offer repair services for its items, it could host a resale platform, or it could spread awareness for the impact of the apparel industry.

Repair services might include offering to mend damages to a brand's garment that a customer has previously bought. However, this would impose an extra cost upon a company with no clear form of profit from the service. It also works directly in opposition to the business model of fast fashion, which aims to sell large volumes of clothing to consumers. A resale platform for the brand clothing might be a viable option, as a company would receive a portion of the profits from the resale. However, many fast fashion items are not made with a high enough quality to retain value for a second sale. This may not be true in all cases, but because it is not a useable strategy for all fast fashion companies, I will conclude that resale is not a viable strategy. Lastly, a company could work to raise awareness of the effects of high rates of consumption, but similarly to repair services, this works in opposition to the strategy of fast fashion companies with no clear form of profit. Furthermore, even if a brand did work to raise awareness, the effects are largely unquantifiable, as it would be difficult to measure the impact that a campaign like this would actually have on consumers. As a result, for this study, I will assume that there is no change in the consumption phase.

Post-Consumption

In the post-consumption phase, the main impact is fabric waste from the quick consumption of clothing that is sent to landfills after being used. The main strategy for reducing this fabric waste is the introduction of textile recycling so that clothing that has reached the end of its lifecycle can be reused. One of the main issues with increasing recycling is that it requires consumer participation, as the consumer is the one to dispose of the product. As a result, I will assume that consumers continue to donate and recycle clothing at the same rates that they currently do so. As previously discussed, 85% of discarded clothing goes to landfill, while about 15% is donated or sent to other collections. However, it is estimated that 4% of this 15% ends up in landfills anyway. The other portion is either resold, made into industrial rags, used for stuffing, or fiber recycling. However, under 1% of the 15% is used for fiber recycling. Ultimately, for the post-consumption phase, 85.6% of fast fashion products are sent to landfill (Schumacher & Forster, 2022).

Overall, there exists a large number of attainable strategies that fast fashion companies can implement to make their business model much more sustainable. By utilizing recycled or organic fibers, implementing clean energy sources, establishing best practices for water management, and eradicating harmful chemicals, the fast fashion industry can significantly reduce its negative impact on the environment.

Evaluation of Impact Reduction

In this section, I will evaluate whether or not it is possible for fast fashion to be sustainable, under the definition outlined in this paper, by utilizing the strategies summarized in the previous section. I will start by evaluating the carbon emissions, then water usage, and finally, harmful chemicals.

Carbon Emissions

As outlined in the section "Definition of Sustainable," for a company to be sustainable in terms of carbon emissions, it must remain in line with the 1.5-degree pathway goals for the short term, meaning that emissions must be reduced by 45% by 2030. Here, I will summarize the impact of 1 kg of clothing and then analyze whether or not the tactics outlined in the previous sections are able to result in a 45% decline in carbon emissions for clothing across its lifetime.

For the fiber content of this 1 kg of clothing, I will assume that 22% is cotton, in line with fiber's share of the market, and I will attribute the rest to polyester. While polyester only makes up 52% of the fiber market, the fast fashion industry heavily relies on synthetic fabrics, so it is safe to conclude that polyester would make up a higher percentage of fibers in the fast fashion industry. While assuming the last 78% is polyester is not fully accurate, the other types of fiber that are popular in the fast fashion industry are other synthetic fabrics like elastane and nylon, and their impacts on the environment are very similar to that of polyester, so using polyester as a placeholder will not significantly offset results.

To begin, I worked backward from the garment manufacturing stage in Table 6 to find the amount of fiber, yarn, and fabric needed to produce 1 kg of clothing while accounting for the amount of textile waste that is produced over each stage of production. In order to do so, I have utilized the average amount of waste produced at each stage.

Table 6: Inputs Needed to Produce 1 kg of Clothing		
Stage	Average Waste	Output
Fiber Production	N/A	1.5 kg of fiber
Yarn Manufacturing	15% of fiber	1.28 kg of yarn
Textile Manufacturing	2% of yarn	1.25 kg of fabric
Garment Manufacturing	20% of fabric	1 kg of clothing

If 30% of this is cotton, then .33 kg of cotton is needed, and if 78% is polyester, then 1.17 kg of polyester is needed. Under the current fast fashion model, the production of .33 kg of cotton results in .73 kg of CO2 emissions, and the production of 1.17 kg of polyester results in the production of 3.63 kg of CO2 emissions, utilizing the average of the range of potential emissions. The production of 1.28 kg of yarn results in 18.3 kg of CO2 emissions. Next, the production of 1.25 kg of fabric results in the production of 13.1 kg of CO2 emissions, again utilizing the average of the range of emissions estimations. After that, garment manufacturing creates an average of 1.12 kg of emissions for every 1 kg produced. In terms of the distribution phase, no fully quantified estimates are available to break emissions down to the amount produced per kg of clothing. However, it is approximated that 5% of emissions from the product lifetime come from the distribution phase. Because I am concluding that there will be no change in the distribution phase, this will not interfere with the reduction calculations. Next in the consumption phase, the average amount of CO2 emissions per wash for 1 kg of clothing is 0.39 kg. Because the average item of clothing is worn seven times before it is thrown out, the consumption phase creates 2.73 kg of CO2 emissions, assuming that a garment is washed after each wear. Lastly, in the post-consumption phase, 1 kg of clothing results in an average of 3.32 kg of CO2 equivalent emissions from landfill gas. However, only 85.6% of discarded clothing ends up in landfill, so the landfill emissions for 1 kg of clothing purchased would be 2.84 kg. These calculations as well as total emissions from the lifecycle of 1 kg of clothing are summarized in Table 7.

Table 7: Carbon Emissions from 1 kg of Clothing (kg CO2e)		
Production	Polyester Fiber Production	3.63
	Cotton Fiber Production	0.73
	Yarn Manufacturing	18.3
	Textile Manufacturing	13.1

	Garment Manufacturing	1.12
	Distribution	5% of total emissions
Consumption	Washing & Drying	2.73
Post-Consumption	Landfill Disposal	2.84
Total		44.68

Next, I will evaluate the best case scenario if a company were to implement all of the strategies that I recommended with the ideal outcomes. Emissions from polyester fiber production would be reduced by 79%, putting emissions down to .76 kg if all virgin polyester is replaced with recycled polyester. Emissions from cotton could be reduced by 60% if all organic cotton is used, bringing production of CO2 emissions down to .29 kg. Next, for yarn manufacturing, textile manufacturing, and garment manufacturing, emissions can be reduced to zero if clean energy is used to power manufacturing plants. Lastly, I am estimating that distribution, consumption, and post-consumption emissions remain the same, as distribution needs to remain timely for the fast fashion business model, and the consumption and post-consumption phases are ultimately dictated by consumer behavior. The best-case scenario emissions are illustrated in Table 8.

Table 8: Best Case Scenario Carbon Emissions from 1 kg of Clothing (kg CO2e)		
Production	Polyester Fiber Production	0.76
	Cotton Fiber Production	0.29
	Yarn Manufacturing	0
	Textile Manufacturing	0
	Garment Manufacturing	0
	Distribution	2.23
Consumption	Washing & Drying	2.73
Post-Consumption	Landfill Disposal	2.84
Total		9.32

Overall, in an optimal situation, a 79.1% reduction in carbon emissions from the product lifecycle is possible. This reduction is an ideal and would be difficult in reality, but this shows that it is theoretically possible for fast fashion companies to reduce their emissions within line of the 1.5-degree pathway without fundamentally changing their business model. In practice, factors that would need to be taken into consideration are the fact that brands do not have full control of the supply chain, and so energy sources of manufacturing plants are not in their immediate jurisdiction; they would either need to specifically find factories that use clean energy or partner with factories to help invest in clean energy. Additionally, organic cotton is slightly more expensive than regular cotton, meaning that it would increase the variable costs of producing clothing. Lastly, it is unlikely that enough recycled polyester is available to completely replace virgin polyester.

Water Usage

To be sustainable in terms of water usage, a company must make a notable effort to reduce overall water usage, replenish all of the water it uses in water-scarce areas, and ensure all wastewater is sent to wastewater treatment plants.

First, I will examine what water savings are possible through existing process innovations in the product lifecycle. To calculate how much water is used throughout the lifecycle of 1 kg of clothing, I will utilize the calculations regarding how much fiber, yarn, and fabric is needed from the previous section. The production of .33 kg of cotton uses 514.47 liters of water, and the production of 1.17 kg of polyester uses 24.57 liters of water. In the yarn production stage, water use is negligible. After that, the production of 1.25 kg of fabric utilizes 250 liters of water. Next, the garment manufacturing stage again uses a negligible amount of water. Lastly in the production phase, distribution uses no water. In the consumption phase, washing clothing uses 31 liters of water per kg of clothing. Again assuming that each item is worn seven times and washed in between each wear, the total water usage in this phase is 217 liters. Lastly, in the post-consumption phase, no water is used. However, it should be noted that clothes sitting in landfills may result in chemicals making their way into nearby water supplies. The total water usage throughout the lifetime of 1 kg of clothing is shown in Table 9.

Table 9: Water Usage from 1 kg of Clothing (liters)		
Production	Polyester Fiber Production	24.57
	Cotton Fiber Production	514.47
	Yarn Manufacturing	N/A
	Textile Manufacturing	250
	Garment Manufacturing	N/A
	Distribution	N/A
Consumption	Washing & Drying	217
Post-Consumption	Landfill Disposal	N/A
Total		1006.04

In the best case scenario for water reduction, 100% recycled polyester would be used, reducing water consumption by 59% to 10.07 liters. Additionally, in the optimal case, 100% recycled cotton would be used. However, the estimates for water reduction fall into a wide range—from 25% to 80%. Furthermore, in the CO2 analysis, I analyzed the reduction if all organic cotton is used. In consequence, I will utilize the organic cotton reduction estimate of 28% to remain consistent. With this reduction, water usage would fall to 370.42 liters. In the textile manufacturing stage, there are two main options for reducing water use in textiles—low liquor ratio machines and supercritical fluid dyeing. Because supercritical fluid dyeing is currently only effective on synthetic fabrics, I will analyze the option of implementing low-liquor ratio machines, as this technique would work on all fabrics and blends. This would result in a 20% reduction down to 200 liters. Furthermore, good management processes can save

5-10% of water. Using the average, a second reduction of 7.5% would bring water usage down to 185 liters. Lastly, treating and reusing wastewater in the wet processes would result in another reduction of 30% to 50%. Again utilizing the average, a final 40% reduction would bring water consumption down to 111 liters. Next, for the consumption phase, I will again expect that there is no change. The results of these reductions are summarized in Table 10.

Table 10: Best Case Scenario Water Usage from 1 kg of Clothing (liters)		
Production	Polyester Fiber Production	10.07
	Cotton Fiber Production	370.42
	Yarn Manufacturing	N/A
	Textile Manufacturing	111
	Garment Manufacturing	N/A
	Distribution	N/A
Consumption	Washing & Drying	217
Post-Consumption	Landfill Disposal	N/A
Total		708.49

Overall, implementing these practices would result in a 29.6% reduction in water consumption throughout the product lifecycle. This shows that it is theoretically possible for fast fashion companies to significantly reduce water consumption throughout the product life cycle in the short-term future. However, while possible, there are challenges to implementing these strategies in reality. Similarly to the issues with reducing CO2 emissions, the production portion of the life cycle is largely controlled by supply chain partners, not apparel brands themselves. This would make it difficult to ensure changes within the textile manufacturing phase. Furthermore, organic cotton is slightly more expensive than traditional cotton, meaning that companies would see a reduction in profit margins if it replaces traditional cotton.

Moreover, this reduction is not enough to be considered sustainable. A company must also replenish all of the water it uses in water-scarce areas and ensure all wastewater is treated at wastewater plants. Unfortunately, the majority of production happens in countries that are very water scarce. For example, India contains 18% of the world's population, but only 4% of the world's water resources, and there is a lack of water management infrastructure in place, resulting in persistent water contamination issues. To ensure replenishment, companies will need to treat all wastewater and then partner with non-profits in order to make up for the discrepancies between water used and water replenished from treatment. With current technologies and initiatives available, this goal is attainable, but once again, it will require a capital investment that will not return a profit for the company. As a result, this may only be attainable for larger corporations that have more available capital to allocate towards these goals.

Harmful Chemicals

To be sustainable in terms of harmful chemicals, a company's entire supply chain must comply with the ZDHC MRSL. The most critical stage in which changes need to be made is the textile manufacturing stage in the production phase, as this is where wet processes that utilize high levels of chemicals occur. There are already fast fashion brands that have committed to compliance with ZDHC's goals. Because it is outside the scope of this paper to evaluate each individual chemical, I will examine the progress of fast fashion companies that have committed to ZDHC's goals. According to the list of brands on ZDHC's website, ASOS, H&M, Inditex, and River Island have all joined the non-profit's initiative. Of these companies, H&M is the only company to report its progress on compliance with the MRSL. Throughout its entire supply chain, the company has achieved 81% compliance and is working to continuously increase this percentage. While there is no proof that a fast fashion company can reach full compliance with the MRSL, 81% is a substantial start toward this goal. However, this means that complete sustainability in terms of harmful chemicals is unlikely to be possible for fast fashion companies in the short term.

Ultimately, it is promising to see that fast fashion has the potential to become sustainable in terms of carbon emissions and water usage in the short term. In regard to harmful chemicals, while it is not yet proven that 100% compliance with the ZDHC's MRSL is possible, there are still significant strides that can be made, as 81% compliance can still be achieved. In the end, this outlines an optimistic short-term alternative to abandoning the fast fashion business model as a whole.

Other Considerations

In this section, I will outline considerations that were outside of the scope of my analysis that should also be taken into account when analyzing the overall sustainability of a fast fashion company and the product lifecycle of apparel. First, I will summarize other environmental factors before touching on animal welfare and the treatment of workers throughout the apparel supply chain.

Other Environmental Factors

Two other environmental considerations for the apparel industry include plastic waste as well as biodiversity and land use. I briefly mentioned plastic waste in the "Impacts of Fast Fashion and the Linear Economy" section when discussing the distribution stage of the production phase. Overall, In the United States alone, it is estimated that packaging waste amounted to 82.2 million tons in 2018. Furthermore, only about 9% of plastic waste worldwide is recycled, while about 50% of it ends up in landfills (Jestratijevic & Vrabič-Brodnjak, 2022). This becomes more concerning with the growth of the e-commerce sector. As of right now, e-commerce is estimated to account for 37% of all apparel sales across the world, and this number is only expected to increase. Two of the main alternatives to conventional plastic include recycled plastic and biodegradable plastic. Recycled plastic is an ideal option, as it utilizes no new inputs. However, as only 14% of plastic is recycled, it is unrealistic for all traditional plastic to be replaced by recycled plastic. In this case, other alternatives include biodegradable plastics like PLA plastic or PBAT plastic (Ibrahim et al., 2022). By using recycled materials, plastic waste can be revitalized, and by using biodegradable materials, the impact on the environment is lessened, as these plastics will not be sitting in landfills and further contributing to landfill gas emissions.

The second environmental consideration is biodiversity and land use. These topics have been briefly mentioned in this paper, as carbon emissions and chemical runoff directly affect biodiversity, but here, I will summarize this issue in more depth. Biodiversity is defined as the variety of life in an ecosystem, and it is crucial to the environment, as proper biodiversity maintains the balance of the earth's natural resources. Unfortunately, biodiversity is declining at a faster rate than ever, with 12 to 20% of species on the brink of extinction. Furthermore, the fast fashion supply chain can have a significant impact on the biodiversity of different ecosystems. For example, cotton agriculture can result in soil degradation and habitat loss; high carbon emissions contribute to global warming, which changes the natural equilibrium of ecosystems; chemical runoff from wet processes damages the health of plant and animal life; the shedding of microplastics can poison marine life; and man-made cellulose fibers, which are often made from wood, can contribute to deforestation. Ultimately, this re-emphasizes the importance of proper fiber sourcing, emissions reduction strategies, water management tactics, and reduction of harmful chemical usage (Granskog, Laizet, Lobis, & Sawers, 2020).

Animal Welfare

In addition to other environmental factors, animal welfare should also be considered in the production stage of the product lifecycle. In my analysis, I only discussed the two most common fibers—cotton and polyester, which fall into the plant-based and synthetic fiber categories, respectively. As a result, I did not discuss the third fiber category: animal-based fibers. Textiles like leather, wool, down, and silk all fall into this category. Leather is directly made from animal skins, and often, the animals used to produce leather are factory-farmed in terrible conditions. Wool comes from the coats of sheep, which are sheared and spun into yarn. However, mistreatment of sheep that are used to produce wool is not uncommon. For example, mulesing is a fairly common practice of cutting the skin around the buttox of sheep in order to prevent infection, but this can be very painful, as it is often performed with no anesthesia. Down is the feathers from geese or ducks that are close to the skin, and it can be utilized to stuff jackets for a very effective insulation quality. Unfortunately, due to high demand, most down is collected through live plucking, which is an incredibly painful process for the animals. Lastly, silk is made from the silk fibers produced by silkworms. They are a part of the cocoons that these creatures spin for themselves, so to extract these fibers, the cocoons are boiled while the pupae are still inside. To combat this negative treatment in the textile production process, companies should consider alternatives to these fibers, especially when they require the killing of animals to create, and pay close attention to the conditions in which animals for fiber production are raised (Robertson, 2021).

Treatment of Workers

Lastly, it is important to for companies to be mindful of the labor conditions of the entirety of their supply chain, as it is not uncommon for manufacturing factories to allow unsafe working conditions, utilize child labor, or underpay their workers. The treatment of workers and the conditions they work in gained greater attention after the Rana Plaza factory collapse, where a structural failure of the clothing factory in Bangladesh resulted in the deaths of over 1100 workers. Rana Plaza had been producing garments for brands like Zara, Primark, and Mango. Furthermore, the use of child labor is not abnormal. For example, in Cambodia, the legal minimum age to work is 15 years. However, because there is a lack of oversight, girl ages 12 to 14 often drop out of school and work at textile factories in order to help support their families. Lastly, there is constant downward pressure on the salaries of workers in textile factories due to the nature of fast fashion. Ultimately, the goal of fast fashion is to produce clothing as quickly as possible at as low prices as possible, and in result, workers are regularly paid very low wages, as subcontracted factories fight to keep their prices down. Ultimately, apparel companies need to ensure that the low costs of production are not coming at the expense of the health and safety of workers throughout the supply chain (Buzzo & Abreu, 2019).

Conclusions

Overall, the pattern that the apparel industry is currently operating under is unsustainable for both the short-term and long-term future. However, the fast fashion business model will continue to grow in the short-term future. As a result, it is highly important to shift efforts toward making the fast fashion industry more environmentally sustainable by reducing carbon emissions, managing water consumption, and eradicating harmful chemicals. With technology and process innovation that is currently available today, it is possible for fast fashion companies to be sustainable in the short term as related to carbon emissions and water consumption. The main tactics for carbon reduction include utilizing recycled and organic fibers and implementing clean energy sources throughout the supply chain. By implementing these strategies, emissions throughout the entire product lifecycle can be reduced by up to 79.1%. To manage water usage, companies should use organic or recycled fibers, technology innovations for wet processes, and careful water management practices. These strategies can reduce water consumption throughout the entire product lifecycle by up to 29.6%. Furthermore, wastewater treatment technology is advanced enough to ensure that all wastewater from production activities can be purified, as long as companies make the effort to ensure that proper disposal strategies are put into place. Lastly, any additional water loss can be replenished in water-scarce areas by partnering with non-profits to ensure water security in areas of operation. In terms of harmful chemicals, only an 81% compliance with ZDHC's MRSL has shown to be possible, but this is still a promising start, and there is definitely the potential to reach 100% in the long term. However, in order to properly evaluate complete sustainability, other factors, such as plastic waste, impacts on biodiversity, animal welfare, and labor practices must also be considered.

Moreover, while fast fashion companies can become significantly more sustainable through the strategies outlined in this paper, this is not a long-term solution. The benchmarks utilized in this study are specifically for the short term. As time progresses and horizons lengthen, the definition of sustainability should become more stringent, and the goals should become loftier. Ultimately, the long-term goal is to completely eradicate fast fashion and implement a slow, circular fashion economy in its place. However, until consumer purchasing behavior shifts significantly, the sustainability initiatives outlined in this paper can act as a stepping stone toward the most sustainable end goal.

References

Amin, R., Mahmud, A., & Anannya, F. R. (2022). Assessment of Carbon Footprint of Various Cotton Knitwear Production Processes in Bangladesh. AATCC Journal of Research, 8(6), 47-57. Doi: 10.14504/ajr.8.6.6

Berners-Lee, M. & Clark, D. (2010, November 25). What's the carbon footprint of … a load of laundry?. *The Guardian*. Retrieved from https://www.theguardian.com/environment/green-living-blog/2010/nov/25/carbon-footprint-load-laundry

Bhardwaj, V. & Fairhurst, A. (2010). Fast fashion: response to changes in the fashion industry. *The International Review of Retail, Distribution and Consumer Research*, 20(1), 165-173. Doi: 10.1080/09593960903498300

Bick, R., Halsey, E., & Ekenga, C.C. (2018). The global environmental injustice of fast fashion. *Environmebtal Health*, 17(92). Doi: 10.1186/s12940-018-0433-7

Buzzo, A. & Abreu, M.J. (2019). Fast Fashion, Fashion Brands & Sustainable Consumption. In: Muthu, S. (Eds) *Fast Fashion, Fashion Brands and Sustainable Consumption*. *Textile Science and Clothing Technology*. Springer, Singapore. Doi: 10.1007/978-981-13-1268-7_1

Caro, F., Martínez-de-Albéniz, V, Agrawal, N. (Ed), & Smith, S. (Ed). (2015). Fast Fashion: Business Model Overview and Research Opportunities. *Retail Supply Chain Management*. *International Series in Operations Research & Management Science*, 223, 237-264. Boston, MA: Springer. doi:10.1007/978-1-4899-7562-1_9

Ellen MacArthur Foundation. (2017). A new textiles economy: redesigning fashion's future. Retrieved from https://ellenmacarthurfoundation.org/a-new-textiles-economy

Ellen MacArthur Foundation. (2020). Vision of a circular economy for fashion. Retrieved from https://ellenmacarthurfoundation.org/topics/fashion/overview

Ellen MacArthur Foundation. (2021). Circular business models: redefining growth for a thriving fashion industry. Retrieved from https://ellenmacarthurfoundation.org/fashion-business-models/overview

Environmental Protection Agency. (2022, December 3). Facts and Figures about Materials, Waste and Recycling. Retrieved from https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/textiles-material-specific-data

Erdenesanaa, D. (n.d.). What happens if the world warms beyond 1.5 degrees Celsius?. *Inside Climate News*. Retrieved from https://insideclimatenews.org/climate-101/what-happens-if-the-world-warms-beyond-1-5-degrees-celsius/

Fidan, F.Ş., Aydoğan, E.K., & Uzal, N. (2021). An integrated life cycle assessment approach for denim fabric production using recycled cotton fibers and combined heat and power plant. Journal of Cleaner Production, 287, Doi: 10.1016/j.jclepro.2020.125439

Glover, S. (2022, May 30). MAS factories switch to renewable energy. *Ecotextile News*. Retrieved from https://www.ecotextile.com/2022053029414/materials-production-news/mas-factories-switch-to-renewable-energy.html

Granskog, A., Laizet, F., Lobis, M., & Sawers, C. (2020, July 23). Biodiversity: The next frontier in sustainable fashion. *Mckinsey*. Retrieved from https://www.mckinsey.com/industries/retail/our-insights/biodiversity-the-next-frontier-in-sustainable-fashion

Green America. (n.d.). Tosic Textiles FAQs. *Green America Magazine.* Retrieved from https://www.greenamerica.org/toxic-textiles-faqs

H&M Group. (2023). Annual Report. Retrieved from https://hmgroup.com/about-us/corporate-governance/annual-report/

Hussain, T. & Wahab, A. (2018). A critical review of the current water conservation practices in textile wet processing. Journal of Cleaner Production, 198, 806-819, Doi: 10.1016/j.jclepro.2018.07.051

Ibrahim, I.D., Hamam, Y., Sadiku, E.R., Ndambuki, J.M., Kupolati, W.K., Jamiru, T., Eze, A.A., & Snyman, J. (2022). Need for Sustainable Packaging: An Overview. *Polymers*, 14(20). Doi: 10.3390/polym14204430

Inditex. (2023). Inditex Group Annual Report 2022. Retrieved from https://static.inditex.com/annual_report_2022/pdf/Inditex-group-annual-report-2022.pdf

International Renewable Energy Agency. (2022, July 13). Renewable Power Remains Cost-Competitive amid Fossil Fuel Crisis [Press Release]. Retrieved from: https://www.irena.org/news/pressreleases/2022/Jul/Renewable-Power-Remains-Cost-Competitive-amid-Fossil-Fuel-Crisis

International Union for Conservation of Nature. (2015, November). Issues Brief: Water and Climate Change. Retrieved from https://www.iucn.org/sites/default/files/2022-07/water_and_climate_change_issues_brief.pdf

IPCC. (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York: Cambridge University Press. Retrieved from https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

IPCC. (n.d.). FAQ Chapter 1. Retrieved from https://www.ipcc.ch/sr15/faq/faq-chapter-1/

Jacobs, K., Petersen, L., Hörisch, J., & Battenfeld, D. (2018). Green thinking but thoughtless buying? An empirical extension of the value-attitude-behaviour hierarchy in sustainable clothing. *Journal of Cleaner Production*, 203, 1155-1169. Doi: 10.1016/j.jclepro.2018.07.320.

Jensen, J. E. F. & Pipatti, R. (2000, May 1). CH4 Emissions from Solid Waste Disposal. In Penman, J., Kruger, D., Galbally, I., Hiraishi, T., Nyenzi, B., Emmanul, S., Buendia, L., Hoppaus, R., Martinsen, T., Meijer, J., Miwa K., & Tanabe, K. (Eds.), *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (pp. 419-439). IPCC.

Jestratijevic, I. & Vrabič-Brodnjak, U. (2022). Sustainable and Innovative Packaging Solutions in the Fashion Industry: Global Report. *Sustainability*, 14(20). Doi: 10.3390/su142013476

Kant, R. (2012). Textile dyeing industry an environmental hazard. *Natural Science*, 4(1), 22-26. Doi: 10.4236/ns.2012.41004

Khan, S., Malik, A. (2014). Environmental and Health Effects of Textile Industry Wastewater. In Malik, A., Grohmann, E., Akhtar, R. (Eds) *Environmental Deterioration and Human Health*. Dordrecht: Springer. https://doi.org/10.1007/978-94-007-7890-0_4

Ki, C-W., Chong, S. M., & Ha-Brookshire, J. E. (2020). How fashion can achieve sustainable development through a circular economy and stakeholder engagement: A systematic literature review. *Corporate Social Responsibility and Environmental Management*, 27(6), 2401-2424. doi: 10.1002/csr.1970

Lieber, C. (2018, September 17). Why fashion brands destroy billions' worth of their own merchandise every year. *Vox*. Retrieved from https://www.vox.com/the-goods/2018/9/17/17852294/fashion-brands-burning-merchandise-burberry-nike-h-and-m

McAllister, L. (2016, March 24). Textile Waste by the Numbers. *Vox Magazine*. Retrieved from https://www.voxmagazine.com/news/textile-waste-by-the-numbers/article_9ea228ba-f13a-11e5-8c76-5b50180f85de.html

Mishra, S., Jain, S., & Malhotra, G. (2020) The anatomy of circular economy transition in the fashion industry. Social Responsibility, 12(4), 524-542. doi:10.1108/SRJ-06-2019-0216.

Nair, S. (2020, November 18). Asia's first solar powered Textile Mill to come up in Maharashtra's Parbhani district. *Jagran Josh*. Retrieved from https://www.jagranjosh.com/current-affairs/asias-first-solar-powered-textile-mill-to-come-up-in-maharashtras-parbhani-district-1605695266-1

National Parks Service. (2021, August 11). Laundry Practices and Water Conservation. *National Parks Service*. Retrieved from https://www.nps.gov/articles/laundry.htm#:~:text=The%20average%20residential%20washing%20machine,kWh%20of%20electricity%20per%20year

Neumann, H. L., Martinez, L. M., & Martinez, L. F. (2021). Sustainability efforts in the fast fashion industry: Consumer perception, trust and purchase intention. *Sustainability Accounting, Management and Policy Journal*, 12(3), 571-590. Doi: 10.1108/SAMPJ-11-2019-0405

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*, 1, 189–200. https://doi.org/10.1038/s43017-020-0039-9

Ozturk, E., Karaboyacı, M., Yetis, U., Yigit, N. O., & Kitis, M. (2015). Evaluation of Integrated Pollution Prevention Control in a textile fiber production and dyeing mill. *Journal of Cleaner Production*, 88, 116-124. Doi: 10.1016/j.jclepro.2014.04.064

Periyasamy, A. P. & Militky J. (2020). LCA (Life Cycle Assessment) on Recycled Polyester. In S. S. Muthu (Ed.) *Environmental Footprints of Recycled Polyester*. Signapore: Springer.

Qian, W., Ji, X., Xu, P., & Wang, L. (2021). Carbon footprint and water footprint assessment of virgin and recycled polyester textiles. *Textile Research Journal*, 91(21-22), 2468-2475. doi:10.1177/00405175211006213

Rauturier, S. (2022, July 15). What Are the More Sustainable Fabrics on the Market Right Now? *Good on you*. Retrieved from https://goodonyou.eco/most-sustainable-fabrics/

Robertson, L. (2021, September 30). Fashion and Animal Welfare: Everything You Shoul Know Before You Buy. *Good on You*. Retrieved from https://goodonyou.eco/animal-welfare-fashion/

Sandin, G., Roos, S., & Johansson, M. (2019). environmental impact of textile fibers – what we know and what we don't know. *Mistra Future Fashion*. Retrieved from https://www.diva-portal.org/smash/get/diva2:1298696/FULLTEXT01.pdf

Schiro, A-M. (1989, December). Fashion; Two New Stores that Cruise Fashion's Fast Lane. *The New York Times.* Retrieved from https://www.nytimes.com/1989/12/31/style/fashion-two-new-stores-that-cruise-fashion-s-fast-lane.html

Schumacher, K. & Forster, A. L. (2022, May). Facilitating a Circular Economy for Textiles Workshop Report. *National Institute of Standards and Technology*. Retrieved from https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1500-207.pdf

Shah, P., Bansal, A., Singh, R.K. (2018). Life Cycle Assessment of Organic, BCI and Conventional Cotton: A Comparative Study of Cotton Cultivation Practices in India. In E. Benetto, K. Gericke, & M. Guiton (Eds) *Designing Sustainable Technologies, Products and Policies*. Springer, Cham. https://doi.org/10.1007/978-3-319-66981-6_8

Textile Exchange. (2021). Preferred Fiber & Materials Market Report 2021. Retrieved from https://textileexchange.org/knowledge-center/reports/preferred-fiber-materials-market-report-2021/

Textile Exchange. (2022). Preferred Fiber & Materials Market Report 2022. Retrieved from https://textileexchange.org/app/uploads/2022/10/Textile-Exchange_PFMR_2022.pdf

The Business Research Company. (2023). Fast Fashion Market 2023 – By Gender (Men's Wear, And Women's Wear), By Age (Adult Wear, Teen Wear, And Kids Wear), And By Region, Opportunities And Strategies – Global Forecast To 2032. Retrieved from https://www.thebusinessresearchcompany.com/report/fast-fashion-market#:~:text=The%20fast%20fashion%20market%20size,at%20a%20rate%20of%2013.8%25.

The Council of Fashion Designers of America. (n.d.a). Materials Index: Cotton. Retrieved from https://cfda.com/resources/materials/detail/cotton

The Council of Fashion Designers of America. (n.d.b). Materials Index: Polyester. Retrieved from https://cfda.com/resources/materials/detail/polyester

Tiseo, I. (2021, November 22). Annual global emissions of carbon dioxide 1940-2020. *Statista*. Retrieved from https://www.statista.com/statistics/276629/global-co2-emissions/

United Nations. (n.d.a). Goal 6: Ensure availability and sustainable management of water and sanitation for all. Retrieved from https://sdgs.un.org/goals/goal6

United Nations. (n.d.b). For a livable climate: Net-zero commitments must be backed by credible action. Retrieved from https://www.un.org/en/climatechange/net-zero-coalition#:~:text=What%20is%20net%20zero%3F,oceans%20and%20forests%20for%20instance.

United Nations (2022, November 1). Water Action Agenda. Retrieved from https://sdgs.un.org/sites/default/files/2022-11/Water_Action_Agenda_operations_concept_note.pdf

Voora, V., Larrea, C., Bermúdez, S., & Baliño, S. (2020). Global Market Report: Cotton. *The International Institute for Sustainable Development.* Retrieved from https://www.iisd.org/publications/report/global-market-report-cotton

Voora, V., Bermúdez, S., Farrell, J.J., Larrea, C., & Luna, E. (2023). Global Market Report: Cotton prices and sustainability. *The International Institute for Sustainable Development*. Retrieved from https://www.iisd.org/system/files/2023-01/2023-global-market-report-cotton.pdf

Wiederhold, M. & Martinez, L. F. (2018). Ethical consumer behaviour in Germany: The attitude-behaviour gap in the green apparel industry. International Journal of Consumer Studies, 42(4), 419-429. Doi: 10.1111/ijcs.12435

Wu, G. H., Wang, L. L., Ding, X. M., Wu, X., Liu, S. Q., & Cuc, S. (2015). Water footprint and carbon footprint reduction in textile's waste recycling. *Industria textilă*, 66, 85-89.

Zero Discharge of Hazardous Chemicals. (2022, November). ZDHC MRSL Conformance Guidance. Retrieved from https://downloads.roadmaptozero.com/input/ZDHC-MRSL-Conformance-Guidance

Zhang, B., Zhang, Y., & Zhou, P. (2021). Consumer Attitude towards Sustainability of Fast Fashion Products in the UK. *Sustainability*, 13(4). Doi: 10.3390/su13041646

Biography

Lindsay Bartol was born in Plano, Texas on September 8, 2000. In 2019, she began her studies at The University of Texas at Austin in the Plan II Honors Program and the Canfield Business Honors Program. In her time in college, she served in multiple leadership roles on the philanthropy committee of Alpha Chi Omega, where she became involved with the non-profit, the SAFE Alliance, which she interned at throughout her sophomore and junior year. After graduating in May of 2023, she plans to work as a Consultant for Oliver Wyman in the company's Chicago office.