Multi-Tier Supply Chain Assessment of Garment Environmental Sustainability

by

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B.S. Mechanical Engineering, Purdue University, 2012

Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering in partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration

and

Master of Science in Mechanical Engineering

In conjunction with the Leaders for Global Operations Program at the **Massachusetts Institute of Technology June 2018**

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ABSTRACT

Li & Fung is a global, leading trading firm that connects manufacturing vendors with retailers. Li & Fung is responsible for the supply of beauty products, furniture, and apparel, with the majority of sales in the apparel category. Li & Fung has developed strong relationships with a large portion of global retailers and maintains a leading market position in the global garment market. Furthermore, Li & Fung leverages a complex supply chain of over 16,000 partner factories across 40 countries. These factories employ hundreds of thousands of workers who perform the difficult work of producing a variety of garments. This large footprint of factories and employees results in an equally large environmental footprint.

Although it is well known that the environmental impact is substantial, with researchers stating that the apparel industry is one of the largest global polluters, it has been difficult to quantify the business impact as a whole, let alone the impact of a single garment. Through this internship, the objective was to quantify the environmental impact of factories and products. This quantification will enhance decision-making and arm the business with a toolset to help factories improve and drive down impact in a targeted manner. Furthermore, these quantifications are manifested in product level footprints and factory metrics calculated with the use of internally generated data and external data.

The internal data provided much of the backbone for the analysis and its collection was completed through an internally developed, proprietary tool. External data was then gathered to address information gaps in the supply chain. Together this data formed the basis for Li & Fung's Environmental Assessment Tool. This tool provides potential benefits at all levels of the supply chain. In particular, it allows designers and customers to make informed decisions about product attributes that drive environmental impact, factories to compare their environmental impact against an appropriate peer group and make educated decisions, and Li & Fung to quantify their environmental impact and take steps to address environmental hotspots.

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Acknowledgements

I would like to thank Li & Fung for the opportunity to engage in a project where I hold strong interest, their support in making available the individuals who can lend expertise and change minds within the organization, and encouragement to make the most of the internship experience inside and outside the internship work. The investment Li & Fung made in the area of sustainability will surely position the organization to become a leader in the industry and help transform factories' operations for a more environmentally sustainable future.

Within the organization, there are countless individuals who receive acknowledgement for what has been achieved throughout the internship, and although I will not list everyone, several deserve special acknowledgement. I would like to thank Pamela Mar for her guidance, patience, and support. Pamela consistently recognized the need for a more sustainable supply chain and I trust that what we have created together will continue to evolve in its ability to address environmental hotspots in the supply chain. To Leonard Lane and Joanne who hold a similar view of a more environmentally sustainable future, I thank you for allowing me to join Fung Academy and providing the vision of how the internship fits into the larger organizational agenda.

Additionally, there are several colleagues who were so important to creating an enjoyable work experience and helping me navigate the organization. Angel, thank you for your friendship, hilarious matter-of-fact sense of humor, and unending support when I faced both personal and professional challenges. Wayne, thank you for your friendship, endlessly caring attitude, your encouragement to travel the region, and coaching to push forward in the face of adversity. JP, thank you for your friendship, constantly overflowing happiness, being a phenomenal hiking buddy, and always having the time in-spite of your workload. Vasu, thank you for your friendship, technical support particularly when I ran into several modeling challenges, and learning and inquisitive attitude. To Cherry and Chelsea, thank you for your patience when supporting me with my logistical and administrative responsibilities.

Furthermore, there are many individuals in the MIT organization that were essential to the completion of this internship and in the development of this thesis. Charlie Fine provided unending guidance and support and made himself available regardless of what was on his plate. I'm not sure how Charlie does it given his many other responsibilities, but I will always be thankful to him for prioritizing my work when I really needed it. Maria Yang consistently provided the recommendations that helped me avoid pitfalls and made project deliverables that much better. Maria is an incredibly thoughtful advisor with world-class attention to detail and I am happy to call her a mentor. Additionally, thank you to Jeremy Gregory and Randy Kirchain for providing their guidance early on in the project, their investment in me helped me avoid many obstacles and provided a strong foundation for our work.

Last, but not least, thank you to my fellow classmates in the LGO class of 2018. Your friendship while abroad kept me sane. Your world-class ability challenged me to always strive for better, both in how I conduct myself and how I address business challenges. I am forever blessed to call each of you friends, and I know I will always have 48 friends who will be there encouraging me when times are difficult and challenging me when times are easy. A special thank you to Brandon Jennings and Rachel Schmidt for taking the journey with me to Hong Kong. It's impossible to put into words what your friendship has meant through the course of the internship and I am very happy I was able to share my time there with you.

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CHAPTER 1: INTRODUCTION

1.1 Problem Statement

"The clothing industry is the second largest polluter in the world ... second only to oil. It's a really nasty business ... it's a mess" stated Eileen Fisher, a leader in the clothing industry, while accepting an environmental award from Riverkeeper. [1,2] Eileen Fisher's message becomes even more tangible when the statistics surrounding the clothing industry are well understood.

The impacts of the clothing industry are clearly harmful to the environment, and this picture does not even reflect the social and economic consequences of the clothing industry. These consequences are as substantial, if not more substantial, than the environmental impact. With that stated, for the purposes of this paper, the primary focus will be the environmental impact of the materials sourced for the clothing industry, processes leveraged to turn raw material to fabric, and steps taken to turn fabric into clothing.

Li & Fung (referred to as LF throughout) is consistently committed to developing a more sustainable supply chain in the way it operates its own business and interacts with its partners. This is evident in the organization's mission statement, as well as, in the recent three-year plan. In its three-year plan, Li & Fung states:

"Consumers are demanding more transparency; they want to know how and where a product was made, where the materials come from and understand the sustainability of the products they purchase ... We are in a unique position to create the supply chain of the future for our customers to deliver solutions on speed, quality and sustainability" [3]

This mission is best manifested in a renewed ability to identify environmental improvement areas across the entire supply chain and arm partner factories with the tools to reduce their environmental impact. Furthermore, this mission can only be achieved once environmental data is collected from end-to-end across the supply chain and environmental footprints are generated that show high impact areas and targeted improvement opportunities. This internship was undertaken to accomplish end-to-end views of the supply chain's environmental impact, collect the required internal environmental data, and inform factories of their environmental performance relative to their peer group.

1.2 Hypothesis and Project Motivation

For this project, it was critical to establish a methodology and set of metrics that fully captured the impact of stakeholders across the supply chain. If the methodology were not robust enough, it would overstate or understate the relative impact of stakeholders. Furthermore, if the selected metrics were not comprehensive enough, the full environmental picture would remain unknown and factories would be limited to suboptimal decisions. It was ultimately decided to align the methodology and approach with that used by the Sustainable Apparel Coalition (SAC), which has membership from many of the largest apparel producers, including LF. Not only is the methodology and metric set comprehensive enough to fully capture apparel's environment impact, but by aligning with a widely established terminology, the education process can be streamlined. The metrics used under this approach are Climate Change (kg CO_2-equivalent), Land Occupation (m^2a), Water Depletion (m^3), Resource Depletion (kg MJ-equivalent), and Eutrophication (kg PO_4-equivalent). Each of these metrics are currently used by the SAC in their evaluation of environmental performance in garments, although the approach to data collection was augmented to enhance visibility and granularity of assessments.

Historically these metrics and the associated model have been computed with the use of third-party data as a proxy for the true, environmental impact. In this case, third party data was leveraged in combination with data collected directly from portfolio factories. Under this approach, two primary research areas were address. (1) Given the limited technology infrastructure, low levels of data collection, and unsophisticated accounting structures, is it possible to collect reliable primary data from garment factories. (2) Through a combination of primary factory data and secondary supply chain data, can products, across factories, be differentiated based on their overall environmental impact?

CHAPTER 2: COMPANY AND PROBLEM BACKGROUND

2.1 Company Background

Li & Fung was founded in 1906 as a Canton-based Chinese trader in Guangzhou, China. Over their 110 year, proud history, Li & Fung continued to evolve and went through four primary stages of business. After several decades of business, Li & Fung transitioned its business from mainland China to Hong Kong, where it would continue to operate as an exporter of Eastern goods to the Western world. In the late 1970s, Li and Fung's business evolve rapidly from a focus on exporting products to global supply chain management. In this role, Li & Fung began to manage the end-to-end supply chain for brands and multinationals in the United States and Europe. In recent years, Li & Fung continued to evolve and is now a multifaceted supply chain solutions enterprise. This most recent transformation, although more challenging than previous business model reorganizations, was made possible through implementation of technology and a focus on value creation.

Today, Li & Fung is a truly global solution provider. Not only has its 110 year history and evolution allowed it to build global connections, but it has also allowed Li & Fung to establish a truly global footprint. Currently, Li & Fung employs over 25,000 workers, operates 300+ offices in 40+ countries, works with 16,000 vendors across 60 countries, serves over 8000 customers across 100 countries, and generates nearly $19 billion in annual revenue. Below, is a visual of Li & Fung's global supply network.

Figure 1: Li & Fung Supply Chain Overview

Li & Fung's business is structured into two key areas: (1) trading and (2) logistics. Furthermore, the trading business is broken into (1) LF Sourcing, (2) LF Beauty, (3) LF Fashion, (4) LF Private Label, and (5) LF Products, while the logistics group is consolidated into LF Logistics. LF Sourcing makes up the Agency business, while LF Beauty, LF Fashion, LF Private Label, and LF Products makes up the Principal business. Given the breath of offerings and wide reach, Li & Fung offers a breadth of products to its customers, including apparel.

- Apparel Product Offerings
    - Men's, women's, maternity, children, babies
    - Woven, denim, sweater, leather
    - Tops, bottoms, dresses, outerwear, performance
- Footwear Product Offerings
    - Casual, school, costume, formal
    - Crocs, slippers, flip flops
    - Boots, functional
    - Toddlers, baby
- Accessories Product Offerings
    - Handbags, other bags, backpacks
    - Jewelry
    - Fashion accessories
    - Hair, hats, belts, socks, umbrellas, small leather, non-leather goods

To maintain this complex offering of products, while meeting its shifting customer needs, Li & Fung has developed a broad set of capabilities. These capabilities allow Li & Fung to responsibly manage its customers' supply chains, which require a high-volume of products in a short period of time. These capabilities make up an end-to-end supply chain management approach, which includes buyer planning, product design, product development, vendor compliance, factory sourcing, raw material procurement, manufacturing control, DC and transport management, freight forwarding customs clearance, hubbing and consolidation, and local transportation. Although Li & Fung maintains varying levels of ownership across these capabilities, Li & Fung is deeply embedded across all areas of the supply chain. This high degree of connection with the customer and unmatched level of capabilities has made Li & Fung a market leader, while Li & Fung understands that past success does not guarantee future success. As such, Li & Fung has set out on an aggressive strategy to reshape the business.

Li & Fung's most recent transformation is centered around digitalization of the supply chain across each of its capability areas. The goal of the digital transformation is to build a supply chain that is sustainable, flexible, visible, and quick to market. This requires a complete rethink of the supply chain across design, marketing and demand planning, sourcing and manufacturing, inbound logistics, warehousing, outbound logistics, and sales. Furthermore, innovation opportunities, leveraged, run in contrast to traditional working standards. Innovations under investigation include open source, social design platforms, predictive analytics and machine learning, real-time production optimization, digital production, smart warehousing in stock optimization, pull-based replenishment and retail allocation optimization, supply chain visibility and tracking through the blockchain, and end-to-end product and supply chain sustainability assessments (which will be the focus of this thesis).

To tactically accomplish these innovations, Li & Fung has already begun to embed digitalization initiatives across the supply chain. A sampling of the supply chain initiatives include: Optitex digital sampling, RFID tracking of products and materials, supply chain analytics, wireless sensors for environmental data, FastFit 360 embedded product development cycles, robotics and automation, data collection for social compliance, wearable technologies, and end-to-end environmental analytics. This last initiative is the focus of the remainder of this paper.

2.2 Project Background

2.2.1 Challenges to Environmental Sustainability

The textile industry is the 5th largest emitter of CO_2 in the United States, according to the US Energy Information Administration, unsurprisingly behind the primary metals, nonmetallic mineral products, petroleum, and chemicals industries. [4] Yet, the US is far from the largest producer and polluter in the global textile industry. When US production is framed in terms of annual global exports, the scale of global production and consumption becomes clear. The US ranks fourth at $14B in annual exports, behind China ($109B), the EU ($64B), and India ($17B). [5] Furthermore, it is estimated that 150 billion garments are produced annually, the equivalent of 20 new garments for every person on the planet. [1] In additional to significant production levels, the growth in production and consumption is extraordinary. For the period from 2000 to 2014, the average consumer of clothing purchased 60% more clothing and were far more likely to dispose of used clothing. [6] This increasing consumption is placing a heavy burden on water, environmental, and energy resources and contributing to ever-increasing levels of environmental toxicity and atmospheric greenhouse gases. Ongoing and increasing consumption and production levels have caused dramatic impact on local water levels, as seen in the catastrophic depletion of the Aral Sea. [7] Yet the global consequences are even more dramatic.

- To produce a single cotton shirt, 2,700 liters of water are used, or the equivalent of 2.5 years of drinking water for an individual [8]
- Cotton is also the world's largest pesticide-consuming crop and contributes 24% and 11% to the global insecticide and pesticide consumption, respectively [1]
- Polyester, one of the most common textile materials, production uses nearly 70 million barrels of oil annual, and polyester takes more than 200 years to decompose [1]
- The production of polyester in 2015 alone resulted in 706B kg in greenhouse gas emissions, the equivalent emissions of annual power generation from 185 coal-fired power plants [9]
- Production of tree-based fibers, like rayon, viscose, modal, and lyocell, has resulted in the destruction of over 70 million trees [1]
- The annual wastage of clothing for a single UK household equates to 100 pairs of jeans, their water impact from clothing is equal to 1000 bathtubs of water, and their carbon footprint from the consumption of clothing is equivalent to a car driving 6000 miles [10]
- The fashion industry is the second largest polluter of freshwater resources and consumes twenty-five percent of chemicals produced globally [1]
- In 2013 alone, approximately 25 billion kilograms of cotton were produced and contributed 107.5 million tons of CO_2 emissions – the equivalent of 25 coal-fired power plants burning for a year [11]

The problem is clearly vast and wide-ranging, and unfortunately there is not a single manufacturer, raw material, or process step that can be singled out. There must be a holistic transformation of the industry, the incentive system, and decision-making to create the lasting change that is so dearly needed.

2.2.2 Corporate Achievements in Environmental Sustainability

Apparel corporations have attempted to solve the environmental-impact problem through their own solutions, attacking specific sustainability problems. Unfortunately, approaches have not been widespread and best practices have not become the norm. Several examples of environmental sustainability focused practices are provided below, although firms are continuing to advance in their environmental initiatives over time.

- Realizing the significant environmental impact of conventional cotton production, both in the release of chemicals into the environment and level of water depletion, in 1996, Patagonia shifted supply to 100% organic cotton [12]
- Eileen Fisher plans to use 100% organic cotton and linen, use 30% bluesign® certified product, be carbon positive in US operations, and recycle one million garments by 2020 [13]
- Alternative Apparel achieves production of 80% of garments through sustainable materials and processes by leveraging G2 wash, 60% less water consumption than traditional washes, eco and organic fabrics, non-toxic dyes, and recycled polyester [14]
- United by Blue focuses material sourcing on recycled polyester, which is less energy intensive than new polyester and removes plastic waste from waterways, organic cotton, which is grown chemical fertilizer and pesticide free, and wool, which is a natural, renewable resource [15]
- For every t-shirt sold, Amour Vert plants a tree in North America through its partnership with American Forest. Currently over 150,000 trees have been planted, a significant source of natural carbon sequestration [16]

Li & Fung is in the process of implementing practices similar to those listed above for some of their brands, although initiatives are fragmented and often not standard practice. By working with institutions and certifications, Li & Fung will gain scale and better institute environmental best practices across all of its supported brands.

2.2.3 Institutional Support for Environmental Sustainability

The Sustainable Apparel Coalition, SAC, a textile industry alliance of manufacturers, supply chain coordinators, brands, and third-party groups, is at the forefront of the sustainability initiative. Their focus includes connecting all parties in the supply chain of clothing and developing frameworks and standards that can be instituted globally. They are further supported by the work of several groups, including governments, NGOs, certification institutes, and for-profit organizations. The work of the SAC, in particular the Higg Index, will be discussed in greater detail later in this paper.

Progress in sustainability has also been driven from firms focused on the ethical and sustainable manufacturing of raw materials. Two organizations at the forefront include the Better Cotton Initiative (BCI) and Cotton Made in Africa (CmiA). Both of these organizations are focused on more sustainable production and sourcing of cotton, one of the primary raw materials used in the production of clothing. In addition to taking steps to improve the sustainability of cotton growth, these initiatives provide avenues to understand best practices and sources of environmental data. This information is arrogated into the SAC databases and used by third parties to develop LCAs. Lastly, certifications from the BCI and CmiA can be used to validate the sustainability of a cotton farmer's operations and improve visibility into the sustainability of lower tier suppliers.

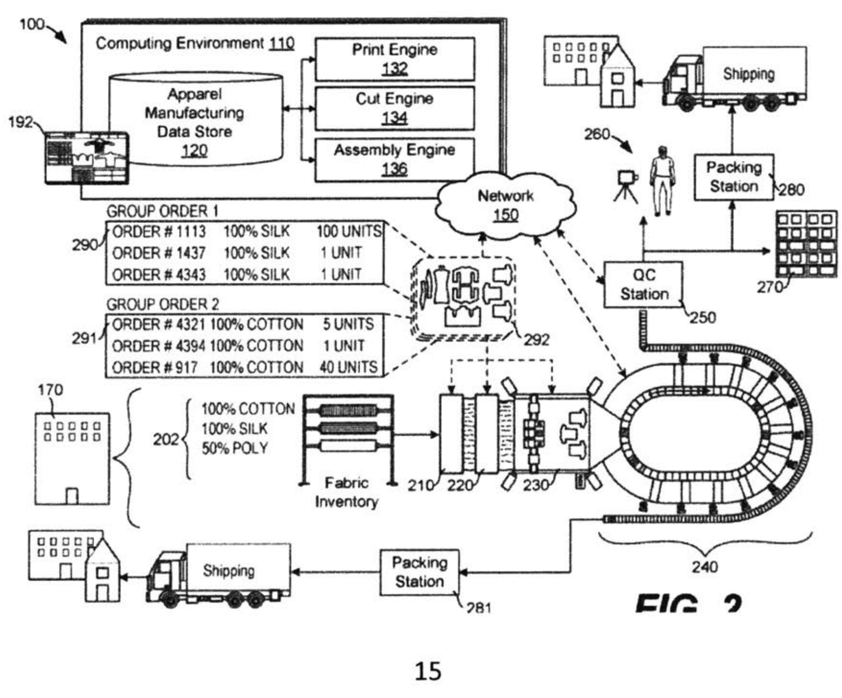
Movements, such as Fair Trade and B-Corp, although not limited to the clothing industry, have furthered the environmental sustainability agenda. These movements have influenced various supply chain players to refocus their operations on more sustainable practices and raised awareness to consumers and consumer advocates of environmentally sustainable businesses and suppliers.

2.2.4 Garment Production Processes and Market Trends

The production of garments has largely remained unchanged for hundreds of years. There have been isolated innovations, including mostly autonomous weaving or knitting, new synthetic materials, and higher yield production of organic materials, but none of these innovations have directly targeted environmental sustainability in the garment industry. These innovations have in fact reduced the manufacturing costs of clothing and driven down prices for consumers. Unfortunately, this increase in manufacturing and high growth in consumption has only increased the environmental impact of the industry. Furthermore, increasing demand and large industry growth led producers to increase production and introduce increased variety for consumers. This has often led to waste, from non-purchased products, and the use of less sustainable input materials and processes.

Many of the large sustainability innovations, moving forward, in the garment industry will come from process improvements deep in the supply chain. These improvements will pass through to the brands and consumers. These improvements include the use of green energy in production of raw materials, yield management in organic materials, renewable organic and synthetic materials. Furthermore, firms like Li & Fung will need to develop better analytics platforms to understand consumer demand and flexible supply chains that produce near just-in-time delivery. Amazon, who has recently entered the apparel space, is taking steps to develop the tools that deliver real-time consumer insights and can be leveraged for just-in-time delivery. This is demonstrated with Amazon's April 18, 2017 patent filing with the USPTO, titled "On demand apparel manufacturing". [17] An illustration of the new apparel manufacturing approach and design is demonstrated below, in a diagram from the patent application.

Figure 2: Amazon On-Demand Apparel Manufacturing [17]



2.2.5 Overview of the Li & Fung Supply Chain

As in the Amazon example, Li & Fung is equally concerned with transforming the apparel industry. In fact, earlier this year, Li & Fung released a plan to digitize the supply chain. [18] This digitization and associated supply chain transformation would drive improvement from product design through warehouse management and would drive end-to-end optimization through linkage to the end consumer. The diagram below demonstrates Li & Fung's view of the supply chain and planned areas for tactical improvement.

Figure 3: High Level View of Li & Fung Supply Chain [18]

Source: https://threeyearplan.lifung.com/downloads/playbooks_digitalization.pdf

Given the size and scope of Li & Fung's supply chain, it is critical to break improvement into several key areas. Design and pre-production, which are outside the scope of this paper, are being addressed primarily in the design team through implementation of digital tools, i.e., Optitex, which allows for digital sampling. Digital sampling allows Li & Fung and its customers to save cost through evaluation and selection of designs through a digital process rather than through procurement and distribution of thousands of physical samples. In addition to cost reduction, digital sampling will result in substantial reductions in environmental impact.

On the wholesaler, retailer, and consumer end of the supply chain, other initiatives are in process. These initiatives include improved modeling of consumer behavior, traceability of product through various ID technologies, and implementation of blockchain technology. Each of these initiatives will add value for various members of the supply chain and enhance the intelligence of Li & Fung's services. Although these initiatives are outside the scope of this paper, their implementation will drive future changes to the modeling and evaluation conducted, which led to the insights in this paper. Based on the scope and complexity of work conducted, the focus of this paper will be the evaluation of environmental sustainability for finished goods, beginning in raw material sourcing and ending in product disposal / recycling.

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CHAPTER 3: LITERATURE REVIEW

3.1 Methodology

The approach taken for product-level environmental assessments, closely resembles the work done by the Sustainable Apparel Coalition through the Higg Index and environmental firms when completing Life Cycle Assessments (LCAs). The Higg Index is an industry-recognized environmental assessment approach and has been agreed to by a majority of the industry. Leveraging this approach, where appropriate, allows for an improved ease of adoption and streamlined business education. Furthermore, use of an LCA approach provides the structure to ensure all environmental factors are considered and evaluations are consistent. Although, the Higg Index was originally intended as a performance tool to evaluate environmental strengths and weaknesses, as will be made clear, through the work completed at Li & Fung, the new intention is to drive education, collaboration, and visibility across all stakeholders in the value chain.

3.2 The Higg Index

The Higg Index was established in 2012 through the SAC, an association of more than 60 apparel stakeholders at the time. It was an extension of the evaluation tools and frameworks established by major brands at the time. The Higg Index intends to transform design, supply, manufacturing, and logistics and distribution to more sustainable practices through evaluations of performance across the full lifecycle of a product. Furthermore, primary evaluation considerations in the process include: raw materials, manufacturing processes, packaging attributes, transportation, typical use cycle, and end-of-life behavior.

The original focus of the Higg Index was to (1) quantify sustainability impacts of products in the apparel industry, (2) standardized practices for evaluating sustainability, (3) improve efficiency of supply chains and reduce risk, and (4) create the educational tools and platforms to educate suppliers on environmental performance and sustainability. To accomplish this focus, several tools have been developed, including the MSI Contributor, Higg Material Sustainability Index (MSI), and Higg Design & Development Module (DDM). The MSI contributor provides a platform for stakeholders to input their sustainability data. The Higg MSI provides a single source of data for material production impacts and educates the industry on material best practices. The Higg DDM shepherds designers along the design process of creating more sustainable apparel. Together, these tools provide an avenue for organizations, such as Li & Fung, who are involved in all aspects of the apparel supply chain to take actionable, proactive steps and mitigate environmental impact.

In this project, in line with the Higg Index, apparel products were evaluated across six key metrics. These metrics provide visibility across the range of impacts in apparel production and align with the terminology with which the industry is familiar. [19] These metrics are climate change, water depletion, resource depletion, eutrophication, land occupation, and chemistry. Below, further detail on these metrics can be found.

Climate Change

Climate Change is defined as the change in local, regional, and global climate, particularly since the beginning of the Industrial Age, attributed to increased levels of equivalent carbon dioxide in the atmosphere from fossil fuel consumption. Climate Change is based on the IPCC 2013 GWP 100a v1.00 LCIA Method and is measured in kg CO2 equivalent. [19]

Water Depletion

Water Depletion is defined as the damage to the environment in terms of human health, ecosystem quality, and resource availability measures. Water Depletion is based on the WSI Pfister et al. 2009 v1.01 LCIA Method and is measured in cubic meters. [19]

Resource Depletion

Resource depletion is defined as the consumption of abiotic resources at a rate faster than the natural replenishment of said resources. Resource Depletion is based on the CML 2013 v4.3 LCIA Method and is measured in Megajoules equivalent. [19]

Eutrophication

Eutrophication is defined as the high concentration of nutrients in a large lake or other stationary body of water, which results in dense plant-like growth, typically from algae, and the death of animal life from a lack of available nutrients. Eutrophication is based on the CML-IA baseline 2013 v3.01 LCIA Method and is measured in kg PO4 equivalent. [19]

Land Occupation

Land Occupation is defined as the area of agricultural land occupied or consumed in the production of primary raw materials for use in clothing production. Land Occupation is based on the ReCiPe v1.10 LCIA Method and is measured in annual consumption of agricultural square meters. [19]

Chemistry

Chemistry is defined as the use of chemicals in the manufacturing process. These chemicals are rated and classified based on their human, animal, and environmental toxicity. Chemistry is primarily a qualitative metric at this time, presenting the hazardous materials present in manufacturing process and identifying those materials that should be removed for the system for improved human, animal, and environmental safety. [19]

3.3 Life Cycle Assessment (LCA)

Life Cycle Assessments (**LCAs**), which have gained increased adoption in recent years, evaluate and investigate the environmental impact of a product or service through all steps of the supply chain. This is made possible through the accounting of stocks, flows, and processes. Furthermore, LCAs take an accounting of the consumption of energy and material inputs, the release of emissions and waste into the ecosystem, the impact of said consumption, waste, and emissions, and geographic and process attributes.

A study, over the course of two years, conducted by Dr. Mahapatra showed the impact of production of 1 kilogram of polyester and 1 kilogram of cotton. The research showed that the production of fabric is not an environmentally friendly process. In the production of polyester fabric, 171.5 megajoules of energy is consumed, compared to 140.1 megajoules for cotton. Polyester fabric production also consumes 1.5 kg of oil and gas compared to 0 kg for cotton grown naturally. While, polyester production does not require the use of fertilizers and pesticides, cotton, which is not grown organically, uses 457 g of fertilizer and 16 g of pesticides. Additionally, polyester production emits 3.8 kg of carbon dioxide and 0.2 g of sulfur dioxide, while cotton production emits 5.3 kg of carbon dioxide and 4 g of sulfur. Finally, polyester production depletes 1,900 liters of water, while cotton production depletes 26,700 liters of water, mostly from irrigation in arid climates. [20]

This analysis, although limited to the fabric, clearly demonstrates why a life cycle assessment is critical and begins to illustrate the complexity of assessments. Taking the analysis and approach a step further, many of the required data points, when evaluating the lifecycle environmental impact of the cotton T-shirt, or any other article of clothing, are as follows.

- Input Raw Materials
  - Energy (including regional grid portfolio)
  - Water (including green, blue, gray water)
  - Chemicals and Fertilizers
  - Land Usage and Yield (for agricultural products)
- Material Processing
  - Energy (including regional grid portfolio)
  - Water (including green, blue, gray water)
  - Chemicals, Dyes, and Bleaches
  - Scrap and Waste
- Cut & Sew Operations
  - Energy (including regional grid portfolio, localized generation)
  - Water (including green, blue, gray water)
  - Waste (fabric, chemicals, etc.)
- Packaging
  - Materials (paper, plastics, tonnage, waste)
- Transportation & Logistics
  - Energy (based on mode of transport and distance)
- Consumer Use
  - Energy (including regional grid portfolio, wash and dry behavior)
  - Water (wash behavior)
  - Chemicals (detergents and bleaches)
- Recycling and Disposal
  - Disposal (landfill impact, emissions, contamination)
  - Reuse and Recycling (proportionality and regional behavior)

As seen in the above supply chain outline, the garment supply chain is complex. Furthermore, the process of producing garments has substantial disaggregation of core activities, limited ongoing visibility, and disconnected relationships between consumers and producers. Along the production process, stakeholders often have little knowledge of their impact on the environment and intermediate steps in the product lifecycle.

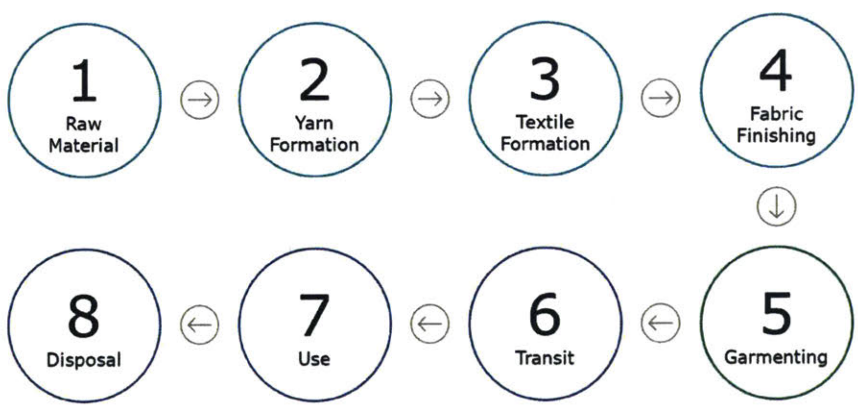
When an evaluation of product lifecycles and stakeholder impacts is conducted at each step in the process, it becomes clear how similar garment lifecycle decisions follow the engineering lifecycle-cost to change principle. Below is an illustration of the impacts on water, energy, chemical, waste, and health and safety, as extracted from the Global Fashion Agenda: Pulse of an Industry. [21]

Table 1: Overview of Supply Chain Impact Intensity [21]

	Design & Development	Raw Materials	Processing	Manufacturing	Transportation	Retail	Use	Disposal
Water	Very High	High	High	Low	Very Low	Very Low	Medium	Medium
Energy	Medium	High	Very High	Medium	Medium	Medium	High	Medium
Chemicals	High	High	Very High	Low	Very Low	Very Low	Medium	Very Low
Waste	High	Very Low	Medium	Medium	Medium	Medium	Medium	Very High
Health & Safety	Low	Medium	Very High	Very High	Low	Very Low	Very Low	Very Low

To understand the impact of the clothing industry in greater detail, why the impact is so high, what the primary drivers are, and what can be done differently from a material and clothing structure standpoint, it is critical to first present the clothing supply chain with appropriate detail. In Figure 5, below, the typical supply chain for a traditional piece of clothing is depicted. This supply chain has been simplified from that seen in Figure 3 and 4, as this supply chain represents a manageable scope and the areas where reliable data can be accurately collected. For the remainder of this paper, the supply chain and associated evaluations will be evaluated in the context of the depiction below.

Figure 4: Traditional Clothing Supply Chain



1. Raw Material: This process step includes the production and processing of natural and synthetic materials, and takes place either at a farm or plantation, in the case of natural fibers, or at chemical processing plants, in the case of synthetic fibers
2. Yarn Formation: The fibers are then transported to a yarn formation facility, either on-site or external to the raw material processing facility, where fiber is processed into yarn of varying sizes and quality
3. Textile Formation: Next, the textiles are processed into fabric by either weaving or knitting together supplied yarn at the textile formation facility
4. Fabric Finishing: The last step in the fabric production process is fabric finishing. In this process, fabrics are treated based on their future application or environmental exposure. Fabric finishing includes burling and mending, scouring, bleaching, mercerization, drying, napping and shearing,

brushing, singeing, beetling, decating, tentering, crabbing, heat-setting, calendering, creping, optical brightening, sizing, weighting, fulling, and softening [22]

5. Garmenting: Once the fabric has been formed, it is transported to the "cut and sew" factories, most of which are in the developing world, for processing. These factories cut and assemble fabric into shirts, pants, outwear, etc.
6. Transit: This step encompasses the transportation of finished goods from the garmenting factory location to the retail location, including transit to the warehouse and retail locations. A typical channel allocation of 30% trucking and 70% marine container shipping was applied. In future iterations, the modes of transit can be adjusted to reflect individual circumstances.
7. Use: Once purchased by the consumer, the product enters the use phase, and the use phase ends when the product is recycled or disposed. Typical processes in this phase include washing, drying, bleaching, etc.
8. Disposal: Most clothing today is disposed of in landfills, although increasingly consumers are willing and able to recycle unwanted clothing or give clothing to charity. Furthermore, some firms have started businesses on the upcycling of old clothing. This category takes into account user behavior in the disposal and recycling of garments.

The supply chain steps that drive the must substantial impact on the lifetime, structure, and environmental impact of a piece of clothing are the raw material, yarn formation, and textile formation steps. Although, the end-of-life steps, including washing, drying, use, and disposal have a substantial impact if consumers do not consume responsibly. Given that user activities are difficult to influence and are not influenced by the material properties of a garment, those steps are not in scope. In the next section, the raw material, yarn formation, textile formation, and fabric finishing steps will be discussed in greater detail.

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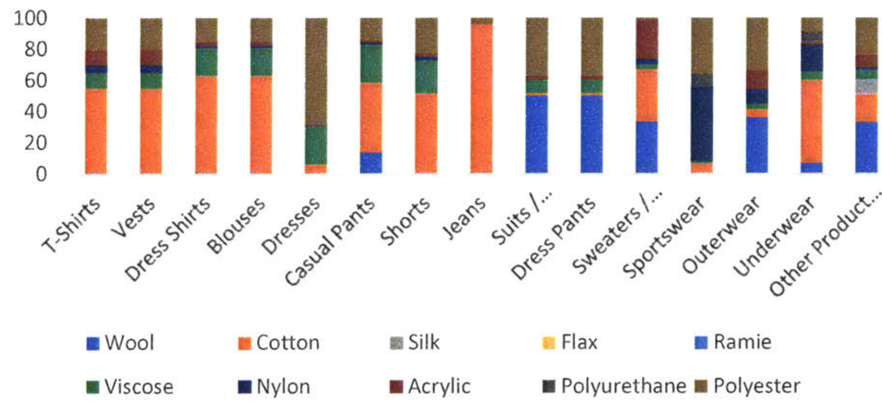
CHAPTER 4: METHODOLOGY

4.1 Raw Material Evaluation:

When designers select materials for clothing, there are many considerations that drive the final decision. Historically, decisions have been made on the basis of user experience, "feeling of quality", availability, and cost. Over time the paradigm has shifted, within some manufacturers, to include environmental sustainability as a fifth consideration. Given their advantageous material traits and/or costs, cotton, polyester, and wool have become the three most popular materials for clothing, as seen in Figure 6.

Figure 5: Material Usage by Clothing Type [23]



Cotton, polyester, and wool each have their own advantages and disadvantages when evaluated across affordability, durability, availability, user comfort, and environmental sustainability.

- Cotton is the most popular material used in clothing with some clothing categories made of more than 50% cotton. Cotton is a natural fiber made possible through the harvesting of crop.
  - Affordability: Cotton is one of the most affordable materials for clothing, with a price of roughly $1.48/kg on the open market. [24] The low price of cotton makes it increasingly popular in the production of clothing.
  - Availability: Since the growth and cultivation of cotton requires large swaths of land, cotton is primarily grown in larger countries and in locations that have readily available access to water resources. Given cotton's popularity in the clothing industry, it accounted for 22.3M tons of production in 2009 for use in clothing. [25] Over the years, the percentage of clothing made from cotton has continued to increase, but growth rates have been tempered recently by the increasing popularity of synthetic materials.
  - Comfort: Not only is cotton popular because of its widespread availability and low price, but consumers have gravitated to cotton due to its high level of comfort. Cotton is extraordinarily soft and light. Cotton is also hypoallergenic and consumers, who react negatively to other materials, rarely experience negative interactions from cotton. Unfortunately, cotton does have a drawback in that it is not a good insulator and should not be used as the primary material in cold-weather gear and outerwear. [26]
  - Durability: Cotton is a highly durable material, when used in clothing, although the durability of the end fabric is highly dependent on the fabric construction. The high

durability of cotton is attributable to its high fiber tensile strength and high degree of stretchiness. Furthermore, cotton is very heat resistant. [27]

- Sustainability: The most water intensive mass-produced material for use in the garment industry, cotton, drives 0.9946 m3 in water scarcity during the production of one kilogram of output (as seen in Table 2). This is partially caused by the high volume of water intake by cotton during growth but is also a result of the location of production. Cotton is often produced in water strained regions. Although, cotton does not perform favorably with regards to water usage, it is much more efficient than many materials in consumption of abiotic resources and emissions of greenhouse gases. On these two factors, cotton is one of the best performing materials.

- Polyester is nearly as popular as cotton, and for some product categories accounts for more than 50% of production. Polyester, unlike cotton, is a synthetic fiber manufactured through the processing of coal and oil.
  - Affordability: Although cotton has long been the industry leader for cost effective clothing, recently polyester has taken the crown. Polyester costs roughly $1.03/kg on the open market. [28] This makes polyester the most cost effective material at scale for use in mass-produced clothing. Furthermore, the mass availability of polyester and low prices of coal and oil have driven down prices, while scale has made it cheap to manufacture.
  - Availability: Facilities that produce polyester are limited by the availability of coal and oil for processing into polyester. Given the widespread availability of oil in the large oil producing countries, these countries are primary producers of polyester. In total, polyester accounted for 18.2 M tons of material used in clothing production during 2009. [25]
  - Comfort: As polyester is a synthetic polymer, similar to many plastics, consumers often associate polyester with a plasticky feel. This is quite common for poorly treated and unblended polyester fabrics. Fortunately, there are several properties that make polyester quite attractive for consumers. Polyester resists water and is non-absorptive, resists odors, and dries quickly. [27]
  - Durability: Polyester is a very flexible material and is heat resistant under normal conditions. These properties are largely a result of its hydro-carbon birth and help polyester retain shape well. Furthermore, polyester has a very high tensile strength, which prevents the material from ripping and deforming. [26]
  - Sustainability: In contrast to cotton, polyester is one of the least water-intensive materials used in clothing. Polyester production is generally the result of petroleum processing and, as such, does not consume large volumes of water during growing season. Furthermore, polyester is manufactured in large industrial facilities, which are rarely located in water-strained locales. Unfortunately, since polyester is petroleum-based and manufacturing is resource intensive, its production consumes large amounts of abiotic resources and emits significant greenhouse gas emissions. Polyester ranks as one of the worst raw materials in clothing for the consumption of abiotic resources and emission of greenhouse gases.

- Wool is much less popular than both polyester and cotton, and is primarily used in more expensive clothing types, including suits, outerwear, and dress pants, because of its insulative properties. Wool is a natural fiber made from sheep and goats' hair.
    - Affordability: Production of wool is quite expensive in comparison to cotton and polyester. Although the raising of sheep is not capital or expense intensive, the processing of sheep and goat hair into workable material is expensive. Once the hair is sheared it must be separated, through an expensive process, with only the good hair retained. Given the high cost of this processing, wool sells on the open market for roughly $14.04/kg. This is a substantial premium over cotton and polyester. [29]
    - Availability: The difficulty of production and the much more limited number of cattle farms, in comparison to industrial plants and cropland, makes wool a less plentiful material. Additionally, given its high cost, many consumers are unwilling to pay such a price premium over cotton and polyester. Given these supply and demand dynamics, annual production of wool for use in clothing was only 1.1M tons in 2009. [25]
    - Comfort: Wool is one of the best insulators available for use in mass-produced clothing. Given its superior ability to insulate, wool is often used in the manufacture of cold-weather gear and outerwear. Unfortunately, wool is incredibly absorptive which can lead to discomfort among consumers, particularly when used in sportswear. [26]
    - Durability: Wool is much less durable than its cotton and polyester alternatives, as wool has a low tensile strength and is highly sensitive to heat. When wool is exposed to heat, it easily breaks down. Breakdown also occurs when wet wool is subjected to mechanical forces. [27]
    - Sustainability: Wool in contrast to polyester and cotton is not resource intensive in its extraction or growth – it is not resource intensive to raise sheep, and other animals, for wool. Rather, the high resource intensity, higher than polyester across all categories, is driven by the processing steps. Transforming hair from sheep into quality, consistent material for clothing is very resource intensive. Emissions are more than two times higher than that from polyester and four times higher than that from cotton. Furthermore, wool has slightly higher abiotic resource depletion than polyester and three times higher abiotic resource depletion than cotton.

In Table 3, there are additional properties for cotton, polyester, and wool that should be considered by designers when selecting a material and by consumers when making purchasing decisions. Although, there are substantial interdependencies between material selection, yarn processing, fabric formation, and fabric finishing, that will drive the ultimate material properties and consumer experience.

Table 2: Environmental Sustainability by Raw Material

Process	Climate Change (kg CO2 eq)	Eutrophication (kg PO4-- eq)	Water Scarcity (m3)	Resource Depletion - FF (MJ eq)	Source Reference (Refer to References)
Cotton	3.0861	0.0095	0.9946	32.4384	[30]
Denim	3.0861	0.0095	0.9946	32.4384	[30]
Cotton made in Africa	1.2572	0.0122	0.0002	7.3442	[31]
Polyurethane	4.8524	0.0046	0.0676	89.7083	[32]
Acetate	2.5718	0.0013	0.0288	83.5656	[32]
Flax	0.3207	0.0033	0.0009	2.1237	[33]
Lyocell	6.84	0.0048	0.075	68.73	[34]
Viscose	7.5383	0.0054	0.1245	89.3542	[34]
Rayon	7.5383	0.0054	0.1245	89.3542	[34]
Down	0.5657	0.0016	0.0013	3.7578	[35]
Hemp	0.5147	0.003	0.0014	4.5828	[33]
Jute	0.5951	0.005	0.0788	5.0083	[36]
Nylon	7.7849	0.0055	0.0304	97.3574	[32]
Acrylic	8.3051	0.0038	0.0168	136.8469	[32]
PVC	9.1048	0.0023	0.031	114.7103	[32]
Polyester	6.4943	0.0054	0.067	100.3071	[37]
Wool	13.8014	0.0224	0.1095	103.61	[38]
Silk	37.2013	0.0189	0.2441	409.7045	[39]
Spandex	10.2732	0.0061	0.1011	143.8815	[40]
Leather	30.7282	0.0708	0.7355	110.7363	[41]

All values provided above are global averages and substantial variability is possible across countries (particularly in the case of natural fibers)

Table 3: Material Properties of Popular Clothing Materials

Material Property	Cotton	Polyester	Wool
Luster	Low	Semi-bright to Dull	Medium
Elongation	High	Manufacturer Specified	High
Resiliency	Low	High	High
Density	1.54 g/ccm	1.38 g/ccm	1.30-1.32 g/ccm
Moisture Absorption	High	Very Low	High
Dimensional Stability	High	Very High	Medium
Resistance to Acids	Low	Low to High	High
Resistance to Alkalies	Medium	Medium	Low
Resistance to Sunlight	Low	High	Low

4.2 Yarn Formation Evaluation:

When selecting a yarn formation process, designers must select between technologies to transform fibers into yarn and determine an appropriate yarn thickness for the application. These considerations are often interdependent with the fabric application and input raw material selection. As such, the properties of the yarn cannot be solely linked to the yarn formation equipment used. That said, designers are able to influence the breaking strength, breaking elongation, breaking work, irregularity, hairiness, tendency to snarl, energy consumption, evenness, and smoothness through the selection of appropriate yarn formation techniques for the desired application. Furthermore, designers have a large selection of yarn formation techniques to choose from, including ring spinning, rotor spinning, friction spinning, self twist spinning, electro-static spinning, vortex spinning, air jet spinning, twist-less spinning, single filament continuous spinning, and multi-filament continuous spinning. [42] Each of these techniques impart a specific property to the yarn and are responsible for the quality and price-point of the end product.

Additionally, the yarn formation process has a real, environmental impact. The environmental impact of many yarn formation techniques / attributes can be seen in Table 4. The spinning process is clearly a substantial contributor to climate change and abiotic resource depletion. Although, spinning at lower densities has a significantly higher impact than at higher densities. This difference is primarily driven by the higher energy usage needed to produce fine (vs coarse) yarn. Furthermore, fine yarn must be produced in a more delicate manner, as breakage during processing is more likely.

Table 4: Environmental Sustainability by Yarn Formation Technique

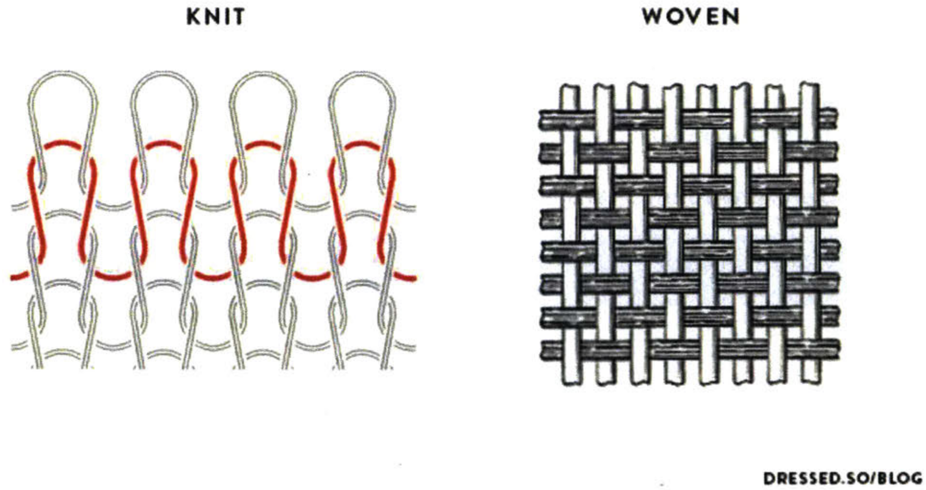
Process	Climate Change (kg CO2 eq)	Eutrophication (kg PO4-- eq)	Water Scarcity (m3)	Resource Depletion - FF (MJ eq)	Source Reference (Refer to References)
Continuous filament spinning	1.4766	0.0007	0.0031	14.4506	[43]
Extrusion and Staple fiber spinning	7.3396	0.0033	0.0157	71.828	[43]
Melt-spun (80-500 dtex),	2.3452	0.0011	0.005	22.9509	[43]
Reeling and throwing	5.863	0.0027	0.0125	57.3774	[43]
Spinning (45 dtex)	19.4564	0.0088	0.0415	190.4078	[43]
Spinning (70 dtex)	12.5077	0.0057	0.0267	122.405	[43]
Spinning (150 dtex)	5.8456	0.0026	0.0125	57.2074	[43]
Spinning (200 dtex)	4.3429	0.002	0.0093	42.5017	[43]
Spinning (300 dtex)	2.9271	0.0013	0.0062	28.6462	[43]

All values provided above are global averages and substantial variability is possible across countries (particularly in the case of natural fibers)
dtex = grams per 10,000 meters (a measure of material density)

4.3 Textile Formation Evaluation:

The primary textile formation techniques are knitting and weaving, although some clothing is nonwoven. Nonwoven makes up a small portion of global clothing sales and utilizes rather unsophisticated techniques, such as gluing, melting, or molding fibers together in a largely unstructured manner. Alternatively, textiles formed through knitting and weaving have a predictable structure and mechanical properties that make them suitable for specific applications. An example of the mechanical structures for weaves and knits can be seen in Figure 7 below, although the exact knit or weave is highly dependent on the desired application.

Figure 6: Comparison of Knit and Woven Textile [44]



Knits are created when fibers are interconnected through loops, and given that knit fibers travel multi-directionally across the face of a fabric, have the ability to stretch along all axes. The stretchiness of these interconnections in combination with the open space between loops provide knit fabrics with substantial freedom of motion. The freedom of motion also prevents knits from wrinkling. Wrinkling occurs when fibers are moved into uneven or bent positions as a result of heat and/or motion. Knits revert back to an even position and appear wrinkle-free much more easily than other fabric types. Unfortunately, knits do come with tradeoffs. Given the high flexibility of motion of yarn, abrasion is highly likely as fibers that move across each other are loosened and bunch up. Additionally, if fabric is damaged and a single fiber if broken, the damage propagates. This occurs as the fibers above and below the damaged fiber are no longer supported and will unwind.

In addition to the mechanical properties of knitted fabrics, designers are increasingly asked to consider environmental impact when making design decisions. In the case of knitted fabrics, environmental impact for the knitting process is relatively low compared to that of the yarn spinning and raw material production processes. As can be seen in Table 5, knitting utilizes low levels of abiotic resources and, as a result, emits low levels of greenhouse gases. This is achieved across all fabric densities, although it is evident that environmental impact increases with the fineness of yarn used in the textile formation process.

In contrast to knits, wovens have their own advantages and disadvantages given their structure. Given the tight perpendicular structure of interconnections and largely horizonal / vertical directions of fibers, wovens lack stretchiness and freedom of motion in the horizonal and vertical directions. Alternatively, wovens experience some, but limited, freedom of motion in diagonal directionality. The limited freedom of motion in wovens results in limited stretchiness of materials. This high degree of structure in material formation also results in a high susceptibility to wrinkling for wovens. Although the constrained structure of wovens leads to some clear disadvantages, there are also some long term benefits. Wovens are far less vulnerable to pilling, as fibers are restricted from freely rubbing against each other. Additionally, wovens are easy to finish, as structure is built into the fabric, and retain structure in case of damage, as each fiber is held in place by many other fibers.

In addition to the mechanical properties of woven fabrics, there are environmental consequences that must be considered when choosing a woven fabric over knit fabrics. Woven fabrics, on the face, drive substantially higher environmental impact for all major metrics, than knits, when compared across all material densities. This is mostly driven by the high mechanical intensity of weaving fabric together; a summary can be seen in Table 5. Although, a one-to-one comparison of knits to wovens does not tell the full story. Given the lower vulnerability to pilling and damage, wovens last longer than knits. Given this longer life, when conducting a life-cycle assessment, the difference between knit and woven technology becomes less substantial than is originally apparent.

Furthermore, the mechanical properties of the fabric, including lifetime, wear rate, structural integrity, and fit, are highly dependent on the raw material used. Some material blends, especially the combination of natural and synthetic materials, may result in low wear rates, long lifetimes, improved fit, and strong structural integrity, regardless of the knitting or weaving process utilized. Therefore, designers must make holistic decisions that account for the interdependencies of raw material selection, yarn formation technique, and textile formation technique.

Table 5: Environmental Sustainability by Textile Formation Technique

Process	Climate Change (kg CO2 eq)	Eutrophication (kg PO4-- eq)	Water Scarcity (m3)	Resource Depletion - FF (MJ eq)	Source Reference (Refer to References)
Knitting (150 dtex)	0.3257	0.0001	0.0007	3.1876	[43]
Knitting (200 dtex)	0.1824	0	0.0004	1.7851	[43]
Knitting (300 dtex)	0.1216	0	0.0003	1.19	[43]
Knitting (45 dtex)	0.5212	0.0002	0.0011	5.1002	[43]
Knitting (70 dtex)	0.4777	0.0002	0.001	4.6752	[43]
Weaving (150 dtex)	8.573	0.0039	0.0183	83.8984	[43]
Weaving (200 dtex)	6.9053	0.0031	0.0147	67.5778	[43]
Weaving (300 dtex)	4.2821	0.0019	0.0091	41.9067	[43]
Weaving (45 dtex)	28.5765	0.013	0.0609	279.6615	[43]
Weaving (70 dtex)	18.3272	0.0083	0.0391	179.3574	[43]

All values provided above are global averages and substantial variability is possible across countries (particularly in the case of natural fibers)
dtex = grams per 10,000 meters (a measure of material density)

4.4 Fabric Finishing Evaluation:

Fabric finishing has the benefit of endowing materials and clothing with property enhancements that are not available in the untreated state. Some of these processes and associated benefits are described below with an overview of their resulting environmental impact in Table 6. [45]

- Compressive and Relaxation Shrinkage Control for Cotton: First, the fabric is wetted and dried to remove residual tensions from the manufacturing and distribution process. Next, the fabric is dampened and pressed against a heated cylinder resulting in a specified shrinkage level and increased number of fibers over a given area. This process results in several benefits, including reduced shrinkage for consumers during the use phase, increased durability, and a softer feel.
- Shrinkage Control for Wool: Wool is either treated with chlorine to destroy scales that form on the fibers or coated with resins. Both of these processes discourage shrinkage of wool in its fabric state.
- Durable Press: The process is highly dependent on the selected fabric and can be performed either during pre-processing or post-processing. In most cases, the fabric is treated with a chemical resin which is then cured through a heating process. This process results in a fabric or

garment that either easily returns to its original shape, with little effort, or maintains substantial resistance to shape change.

- Crease Resistance: Crease resistance is applied similarly to durable press, but rather than applying a resin to hold a shape, during crease resistance, a synthetic resin is applied that prevents the material from developing a permanent or semi-permanent crease.
- Antibacterial and Anti-Fungus Treatment: Germicides are applied to many materials to prevent the growth of bacteria, which could later lead to an infection for the consumer, and fungus, which is unsightly and could cause health hazards. These germicides are applied as a coating over the fabric. Treatment is largely effective in preventing the mildew and rot growth that is common in damp clothing.

Several of the processes above, have been compared against their environmental impact in Table 6 to provide visibility into the environmental sustainability of processing. This environmental sustainability assessment illustrates the substantial resource intensity of carbonization, scouring, heat-setting, and dyeing. Additionally, the water resource intensity of the dyeing process is evident.

Table 6: Environmental Sustainability by Fabric Finishing Process

Process	Climate Change (kg CO2 eq)	Eutrophication (kg PO4-- eq)	Water Scarcity (m3)	Resource Depletion - FF (MJ eq)	Source Reference (Refer to References)
1 drum operation (dye, waterproof, fatliquor)	0.4226	0.0002	0.0018	8.1124	[31]
2 drum operations (dye, waterproof, fatliquor)	0.8458	0.0003	0.0034	16.2298	[31]
3 drum operations (dye, waterproof, fatliquor)	1.2684	0.0005	0.0052	24.3422	[31]
Batch dyeing (Direct, sulfur, vat or reactive)	1.816	0.0011	0.0129	21.1267	[46]
Batch acid dyeing	1.7613	0.001	0.0123	20.646	[46]
Batch dyeing (Disperse or cationic dyes)	1.9998	0.0012	0.0153	23.688	[46]
Bleach of natural fibers	2.0508	0.0006	0.0028	24.5503	[43]
Bleach of synthetic fibers	2.0504	0.0006	0.0024	24.5457	[43]
Calendering	0.289	0	0	4.9928	[37]
Carbonization of raw material	12.7779	0.0053	0.0278	198.9067	[37]
Carbonizing- natural fibers	2.072	0.0007	0.0032	24.7848	[43]
Cellulase Enzyme treatment	2.0546	0.0009	0.0048	20.1079	[43]
Compacting	0.0965	0	0.0002	0.9445	[37]
Continuous dyeing - Acid dyes	1.5474	0.001	0.0111	17.3438	[47]
Continuous dyeing (Direct, sulfur, vat or reactive dyes)	1.6024	0.0011	0.0117	17.8268	[47]
Continuous dyeing (Disperse / cationic dyes)	1.543	0.001	0.011	17.218	[47]
Drying of Fabric	2.2173	0.0005	0.0098	36.4664	[31]
Heat setting (synthetic fibers)	2.0717	0.0007	0.0029	24.7817	[43]
Napping	0.0005	0	0	0.0051	[37]
Prepare for dye (e.g. scouring, bleaching)- natural fibers	2.072	0.0007	0.0032	24.7848	[43]
Sanforizing	0.289	0	0	4.9928	[37]

Schreinering	0.3474	0.0002	0.0007	3.4001	[37]
Scouring and carbonizing (natural fibers)	2.072	0.0007	0.0032	24.7848	[43]
Scouring and Heat setting (synthetic fibers)	2.0717	0.0007	0.0029	24.7817	[43]
Scouring (natural fibers)	1.765	0.0005	0.0032	22.8073	[43]
Scouring (synthetic fibers)	2.0716	0.0007	0.0028	24.7802	[43]
Solution dyeing	0.0637	0	0.0013	0.7807	[37]
Water repellancy (C6, C8, PFC-free)	1.5512	0.0003	0.0055	20.126	[41]
Waterproofing (C6, C8, PFC-free)	1.6416	0.0003	0.0059	22.7114	[41]
Weighting	0.3474	0.0002	0.0007	3.4001	[37]

All values provided above are global averages and substantial variability is possible across countries / regions

4.5 Garmenting Evaluation:

Garmenting activities are completed across a range of facilities, primarily in Asia. Although these facilities vary in their capabilities, the primary functions in the garmenting process are cutting and sewing fabric. In some factories, it was observed that managers have begun to implement automated processes. One example is the implementation of an automated jean pocket sewing machine, although workers were required to properly align fabric before the machine could start sewing. Another example is the implementation of an automated cutting machine that leverages nested cutting patterns to minimize scrap material and provide the required pieces for assembly.

Although there are examples of where automation and process improvement are being utilized to improve operations, the garmenting process is still largely the same as it was over one-hundred years ago. In this process area, work is primarily conducted through labor intensive practices that are dependent on worker experience and skill. As such, often customers request their product be produced in a factory they are comfortable with and have achieve good results with in the past.

In Garmenting, the primary metrics for success are cost and delivery. Given the long duration of steps leading up to garmenting and the short sales cycle, factories must be able to produce product quickly and with high quality. This is a baseline requirement, that if not met, will likely result in business moving from the factory. Given the highly competitive market and inability for factories to repurpose, it is essential that factories meet delivery, quality, and cost targets for their customers.

These targets vary slightly across factories, particularly for factories that are in the luxury business, as compared to the low-end business. Furthermore, over time as factories demonstrate strong performance across cost, quality, and delivery, they begin to move up the value chain from the low-end to luxury goods. This creates an incentive for factories to meet these targets at all costs. Unfortunately, these targets do not always run in parallel with environmental targets.

From an environmental sustainability standpoint, the primary driver of environmental impact is the consumption of electricity with associated Resource Depletion and Climate Change impact. Factories that turn off lights when the factory is not in use, install LED lighting, and institutionalize high efficiency equipment are able to reduce their environmental impact, while at the same time often lower their costs. Unfortunately, the environmental impact of the clothing industry is not universally recognized, and often factories are unaware of their impact and unwilling to make investments in environmental sustainability. This unwillingness to invest is mostly driven by the nature of their low margin business and a short-term outlook.

4.5.1 Regional Challenges:

When conducting the assessment, it was critical to evaluate factories, across all tiers of the supply chain, in regions around the world. As such, factories across southeast Asia that were representative of the global supply chain were asked to provide information on their environmental sustainability, resource consumption, emissions, and waste disposal. Furthermore, to engage the factories, visits were made to several facilities to collect information in person and understand the environmental mindset of workers. These visits were conducted only in China and India, as they make up a large subset of the enterprise supply chain. In these visits, it became quite clear that the mindset of workers in China and India, as a relates to environmental sustainability, are quite different. In China, likely as a result of government backed green initiatives and increased regulation, factories were quite aware of their environmental impact and were proactively taking steps to reduce current and future impact. The approach to environmental sustainability, or lack thereof, was quite different in our visits to factories in India. Most factories had a limited understanding of environmental sustainability and were not taking steps to actively engage in more sustainable practices. This finding mandated additional education with those factories and a much more refined business case for why environmental sustainability was important within their operations. Although the contrast in education was originally made clear when comparing the Chinese and Indian factories, the education gap does not stop there. As factories were engaged across the supply chain in collection of environmental data, these findings were extended to factories across a variety of countries. What we found, is that more education and explanation was required for factories that were in the earliest stages of the development curve.

In addition to education and government influence in environmental focus for factories, the difference seen in Indian and Chinese factories was also partially driven by the maturity of operations, sophistication of operations, and profitability. Those factories, primarily in China, who were producing luxury goods with high margin, were more willing to invest in the factory with a long-term outlook on investments. This long-term outlook allows factory managers to justify investments in sustainability. Furthermore, these factories have made operational improvements over time and the next step in these improvements is focused on variable cost reduction. Electricity is a prime candidate, which points factories in the direction of higher efficiency equipment and high efficiency lighting.

4.6 Existing Data Collection Tool and Data Collection Criteria:

The first step in developing the environmental footprints of both factories and products was to assess currently available data collected from factories. Later, a revised set of factory data would be combined with secondary data, collected from white papers, cases, external databases, and researchers, to form a holistic environmental footprint assessment. In previous research projects conducted at Li & Fung, a factory data collection tool had been developed to gather water, electricity, and waste data directly from the factories, as a means to evaluate factory-level environmental sustainability. This tool provided a good starting point for the development of a tool that provided the factory visibility, necessary, to conduct the desired assessments.

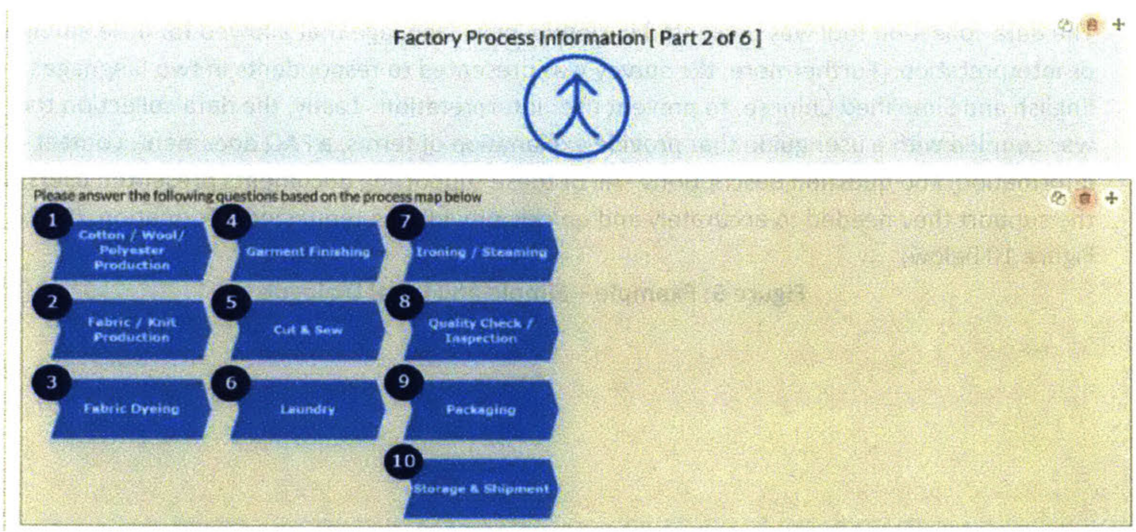
Furthermore, in revising the data collection tool, several suppliers were engaged. In this engagement, suppliers were asked to provide feedback on existing tools and recommendations to improve usability and clarify informational requests. This feedback was integrated into several revisions of the data collection tool, each of which were reviewed by a subset of suppliers and piloted to evaluate data validity and usefulness. Based on this feedback and the outcomes of several pilots, a final, fully revised, data collection tool was developed for release across a large subset of the supply base.

The revised data collection tool, to improve the user experience and aid in accurate data collection, needed to meet several design criteria. These design criteria are consistent with both engineering user centered design and business best practices. Below are examples of how these principles in user centered design were implemented in the data collection tool and how the use of these principles influenced the collection of accurate, representative data.

Key principles of user centered design:

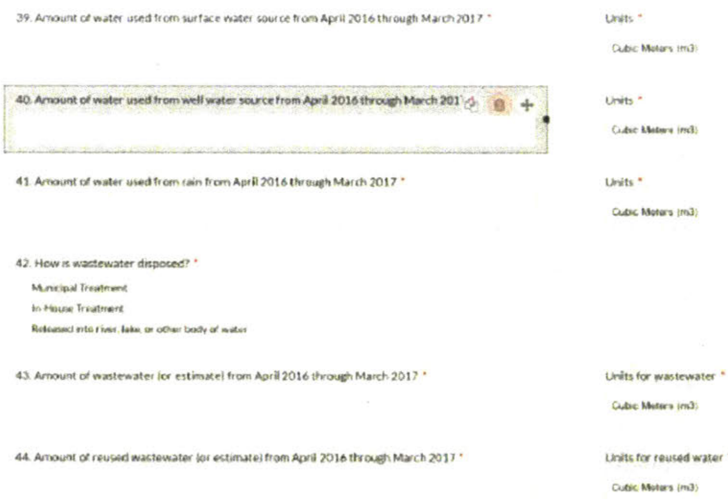
- *Design for users and their associated tasks*
  It was critical to outline the areas of the supply chain that would be discussed with the factories to baseline factory capabilities and align subsequent questioning with the areas the respondents were familiar. Furthermore, presenting the possible supply chain tasks allowed respondents to better visualize the areas that would be covered in the data collection tool. (See Figure 8 below)

Figure 7: Example – Design for Users and Associated Tasks



- *Be consistent with the tool and methodology*
  In prior data requests, respondents were asked to provide outputs from their internal calculations. It became clear, in the results from those responses, that respondents were either unclear of the calculation methodology or inconsistent in calculations. To ensure consistency across the tool and alignment with the proper methodology, respondents were only asked for available raw data in the local units. This information was then aggregated and manipulated in a back-end system to reduce human error and maintain consistency. (See Figure 9 below)

Figure 8: Example – Consistency in Tools and Methodology



- *Use simple, natural, and local dialogue*
  The data collection tool was presented in simple, plain language that allowed for little ambiguity or interpretation. Furthermore, the survey was presented to respondents in two languages, English and Simplified Chinese, to prevent user interpretation. Lastly, the data collection tool was coupled with a user guide that provide explanation of terms, a FAQ document, contact information, and question descriptions. All of these supporting documents presented users with the support they needed to accurately and quickly provide the requested information. (See Figure 10 below)

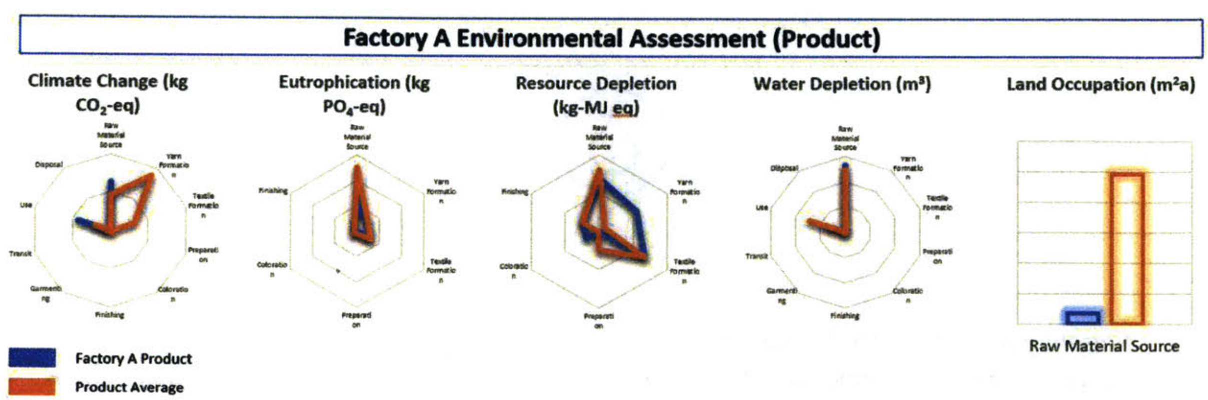
Figure 9: Example – Simple and Local Dialogue

- *Reduce mental effort required by the user*
  A successful data collection tool, given the circumstances and audience, required limited mental effort from respondents. Furthermore, it was critical that users were not asked to make any calculations or interpretations of the data. User interpretation or data manipulation would result in inconsistent data across factories and an inability to make appropriate assessments from factory to factory. As such, factories were asked to provide data in a raw format and calculations were made in a back-end model. (See Figure 11 below)

Figure 10: Example – Reduced Mental Effort

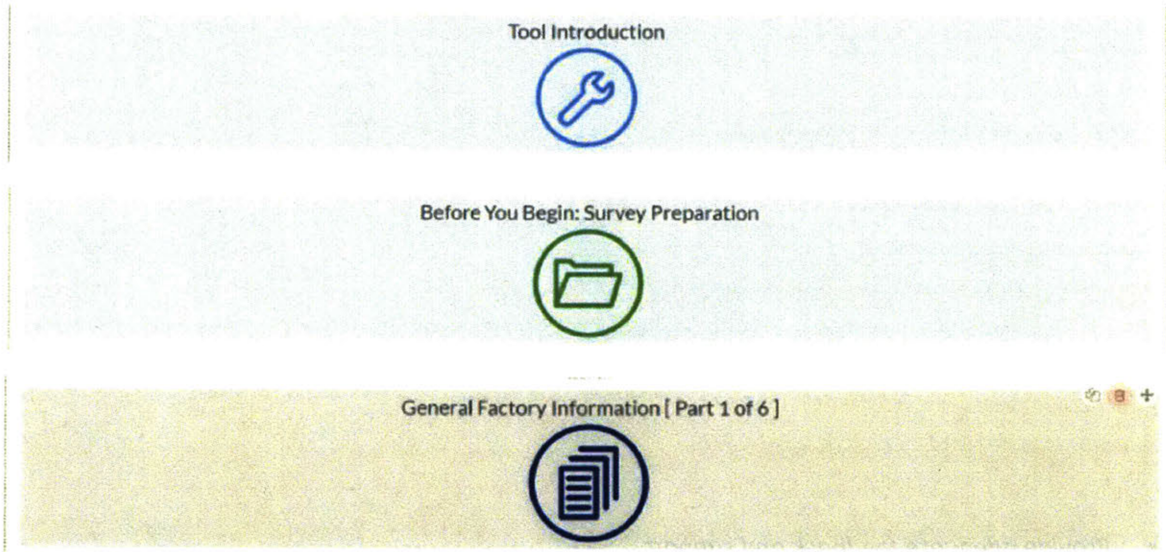
- *Provide adequate feedback and support*
  In addition to asking factories for information that could be used to complete assessments and evaluate environmental impact, tools were developed to provide feedback to factories and support future improvement. These tools allow factories to understand their performance relative to their peer group and provide a necessary feedback mechanism. It was found in previous exercises that suppliers were less motivated to provide information when they lacked visibility into the use of the data and received limited guidance on their performance. (See Figure 12 below)

Figure 11: Example – Feedback and Support



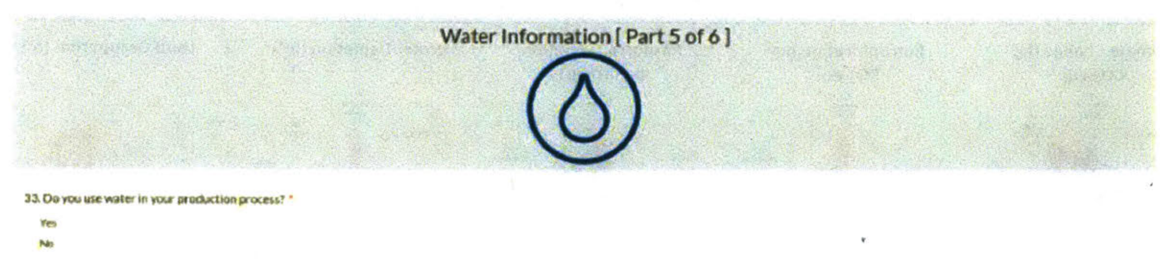
- *Provide simple and adequate navigation mechanisms*
  The data collection tool was split into nine sections, each with a limited scope and simple navigation between questions. Most of the navigation mechanisms were pre-built into the underlying platform, but these mechanisms were leveraged to allow users a stream-lined input process. Furthermore, each section was standardized to allow users to easily understand how to input responses. (See Figure 13 below)

Figure 12: Example – Simple Navigation



- *Let the user drive the interaction*
  A user-centered focus was taken to ensure only that information which was needed from the user was asked. As such, questions were intelligently added or redacted based on responses from users. Users who did not have involvement in certain areas, for example the washing or dyeing of clothing, were not asked questions on that topic. This allowed users to reduce time spent on non-value data input and focus their efforts where it would be most impactful. (See Figure 14 below)

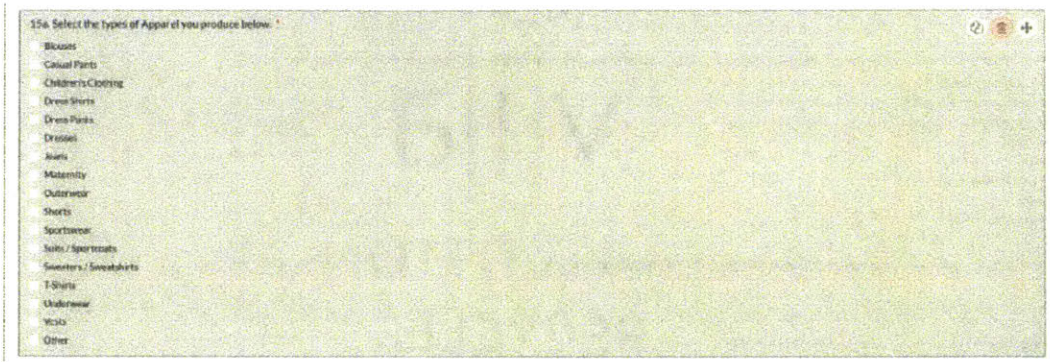
Figure 13: Example – User Interaction



- *Present information clearly and concisely*
  Simple, coherent dialogue was used in the data collection tool, so respondents would have a clear understanding of what information was needed. This dialogue was tested with suppliers to ensure questions were clear and all needed information was provided. Furthermore, early in

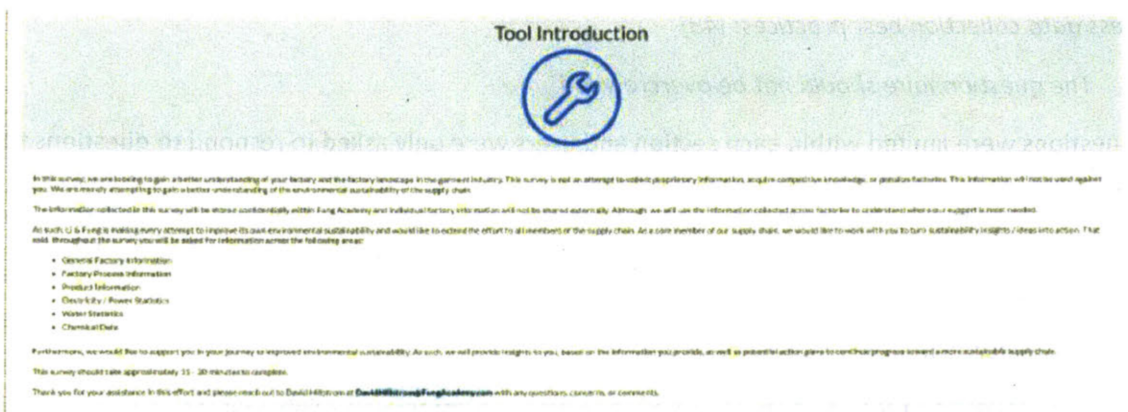
the tool, factories were asked to outline their capabilities. These capabilities were then used to determine which questions must be answered by a factory and which questions were not necessary to the assessment. (See Figure 15 below)

Figure 14: Example – Clear and Concise Information



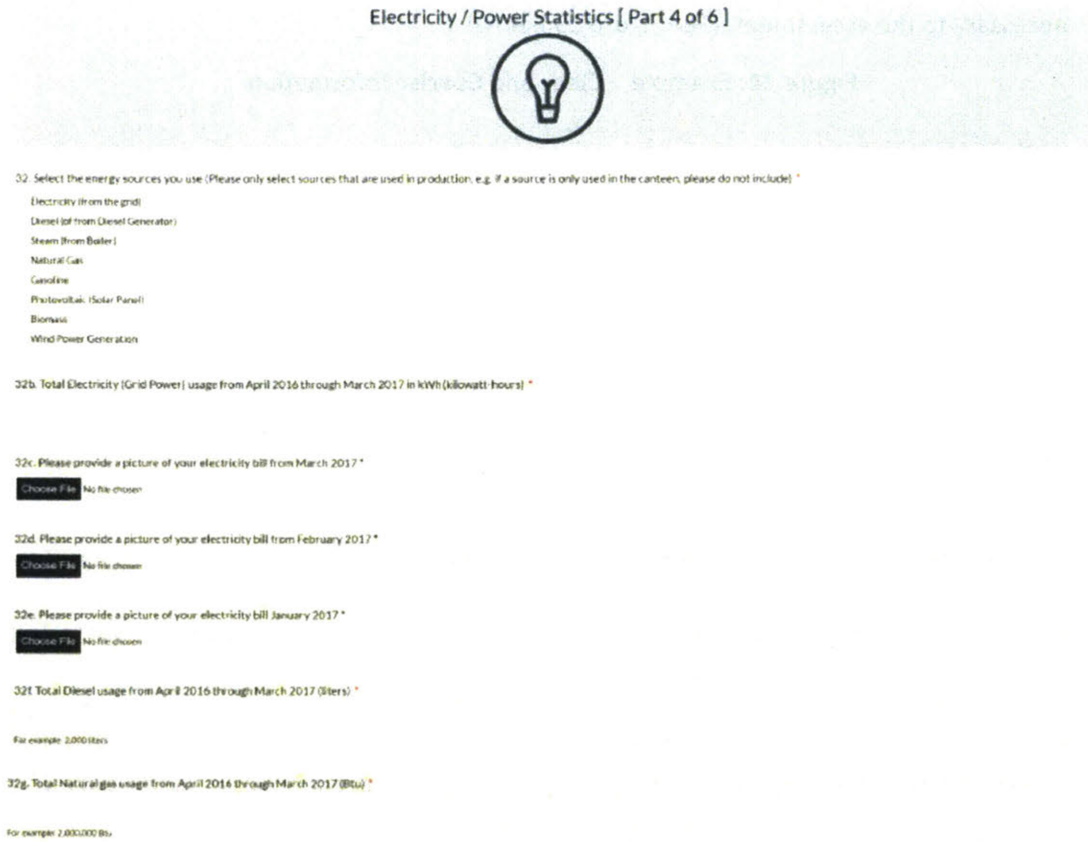
- *Help the user*
  User guidance was provided early and often to survey respondents. At the beginning of the data collection tool, respondents are provided with an overview of the survey and an outline of the information that will be requested. This provides respondents with the opportunity to collect all necessary data before proceeding with the survey. This is necessary as users were frustrated in the past with having to go back and collect information as they progressed through the survey. Additionally, by providing the context early on, respondents were able to better grasp the purpose of the survey and approach questions with an intelligent mindset. (See Figure 16 below)

Figure 15: Example – User Help



- *Reduce the potential for errors*
  It was observed in the results from previous data collection tools that tools of this nature are highly susceptible to user input error. This was seen particularly in the areas of resource consumption, including electricity, fossil fuel, water, etc. In this data collection tool and associated assessment tool, data that was clearly outside of normal bounds was flagged for the respondent. The respondent was then asked to validate the data and update as needed. Furthermore, screenshots of data were requested for validation purposes. (See Figure 17 below)

Figure 16: Example – Reduce Errors


Electricity / Power Statistics [Part 4 of 6]

32. Select the energy sources you use (Please only select sources that are used in production, e.g. if a source is only used in the canteen, please do not include) *

Electricity (from the grid)
Diesel (of from Diesel Generator)
Steam (from Boiler)
Natural Gas
Gasoline
Photovoltaic (Solar Panel)
Biomass
Wind Power Generation

32b. Total Electricity (Grid Power) usage from April 2016 through March 2017 in kWh (kilowatt-hours) *

32c. Please provide a picture of your electricity bill from March 2017 *

Choose File No file chosen

32d. Please provide a picture of your electricity bill from February 2017 *

Choose File No file chosen

32e. Please provide a picture of your electricity bill January 2017 *

Choose File No file chosen

32f. Total Diesel usage from April 2016 through March 2017 (liters) *

For example: 2,000 liters

32g. Total Natural gas usage from April 2016 through March 2017 (Btu) *

For example: 2,000,000 Btu

Business data collection best practices: [48]

- *The questionnaire should not be overcrowded*

Questions were limited within each section and users were only asked to respond to questions that were pertinent to their operations and capabilities. This was done to prevent users from being overwhelmed by the data collection tool. Furthermore, the data collection tool was paired down, based on internal and supplier feedback, to only ask those questions that suppliers would be able to answer with certainty.

- *Divide questionnaire into several parts*

The data collection tool was broken into nine sections to improve usability and reduce respondent fatigue. Each section was limited to a single topic and several topics were dedicated to guidance and instructions. The nine sections are as follows:

  - Tool Introduction
  - Survey Preparation
  - General Factory Information
  - Factory Process Information
  - Product Information

    - Electricity / Power Statistics
    - Water Information
    - Chemistry Data
    - Survey Tool Feedback
- *Label each part to help respondents in understanding the type of questions that follow*
  For each of the sections listed above, the sections were clearly labeled, and the associated questions were limited in subject. This allowed users to focus on a single section at a time with the clear understanding of which questions would be covered.
- *The questionnaire should be numbered sequentially and questions in each part should be sequentially numbered*
  Each of the six data collection sections were numbered to provide users insight into their progress. Furthermore, in each section, questions were numbered to show progress and provide a reference for inquiries.
- *Avoid confusing matrices*
  Questions were asked in simple dialogue boxes or selection dropdowns. This approach simplified user interaction and limited the scope of each question. Furthermore, each question was limited in scope to focus the user's attention and avoid confusion.

4.6.1 Revisions to the Data Collection Tool:

In addition to aligning the revised data collection tool with the principles outlined above, several other considerations were made to improve data collection and ensure quality data was obtained. During evaluation of the existing tool, it was determined that there was not sufficient data to evaluate environmental sustainability at a product level. It was critical to gain a better understanding of what products were produced in factories and which processes were used. Without this understanding, it was not possible to evaluate factories on a consistent basis or the products they produce. Furthermore, it wasn't possible to evaluate products at each level in the supply chain. As a result, it was requested from factories that they provide capability information, vendor data, and internal metrics.

Several data categories were identified as improvements and additions to existing tools. In the updated data collection tool, factories were requested to provide data on the first and last step in their internal operations, revenue and weight at a product category level, portfolio of fabric used and associated weight, certifications obtained for cotton and polyester raw material, and supply chain locations. This information was requested in addition to fields in the existing data collection tool. The existing data request asked for general factory information, worker statistics, electricity and energy usage, water and wastewater volumes, and chemical and hazardous material usage. Although, the data requested for chemical and hazardous materials was paired down to those materials suppliers could identify.

In the revised data collection tool, information was categorized into two areas, direct and indirect data. Direct data included information that would be incorporated into the environmental assessment. This information included energy usage, water usage, emissions, and waste. Additionally, this information was primarily defined by inputs and outputs of the system. The indirect data, defined the secondary data that would be integrated into the model for the selected products. This information primarily included sourcing locations, product mix, certifications, and capability areas. Use of indirect data includes leveraging factory locations to set CO2 emissions, associated with the grid electricity usage, and determine location specific emissions levels. Another example includes using lower-level supply locations to assess the water intensity needed to grow cotton in locations relevant to a specific product.

This data collection tool was then sent to more than 1600 factories across six countries. These countries included China, Bangladesh, India, Indonesia, Turkey, and Vietnam. In total, nearly 400 responses were received from cut and sew factories, and the information received from these factories was used as the basis for the first implementation of the Li & Fung Environmental Assessment Tool.

4.6.2 Primary Data Assessment:

Primary data points are mainly focused on the performance of the garmenting factories. These data points include, energy (both renewable and nonrenewable sources) consumption, water consumption, waste water disposal, material waste, chemical usage, and facility statistics. This data is the major source of data for garmenting facility evaluation. Primary data is essential for evaluation of garmenting facilities, as these facilities often have unique capabilities and there is very limited data available through external sources.

Primary data also provides essential insight into what secondary data is needed. Garmenting facilities are asked for information regarding where raw material is produced, where textile and yarn are manufactured, what types of materials are used in their operations, and where customers are located. This information is then used to develop the environmental profile of all aspects of a product through the supply chain.

4.6.3 Secondary Data Integration:

In addition to primary data collected from factories, secondary data was collected from across a large set of external sources. These sources were primarily not-for-profit organizations, for-profit environmental firms, governments, and universities. Furthermore, the data included electricity grid to CO2 conversion factors by country, global nonrenewable energy source conversion factors, country-specific agricultural data, transit distance and emissions factors, and country specific usage characteristics.

Although this secondary data was of incredible value, it was not useful without the aide of primary data from factories. The primary data provided the guide by which the secondary data could be applied to the environmental assessment. For example, the environmental impact of cultivating cotton is highly locale specific. A location with substantial annual rainfall is environmentally optimal to arid locations. Locations with limited rainfall drive high water scarcity, resource depletion, and climate change when cotton is produce. This is the result of a lack of replenishable water resources and the need for resource intensive water transport to the consumption location. Another example is the assessment of use phase environmental characteristics. It was found, when comparing the US, Europe, and Asia, that consumers demonstrate different behaviors. For example, consumers in the US are more likely to warm wash and machine dry their clothing than their Asian and European counterparts. These insights were built into the environmental assessment and driven by an understanding of consumer characteristics from primary data.

4.7 Transit Evaluation:

The primary considerations for transit for most supply chain managers are time and cost. Generally, as the time for transit decreases the cost of transit increases. Based on product specific needs and demand planning, air, water, and land transit options are employed. Although given the duration of the supply chain and the planning cycle, water and land transit are primarily used.

Another consideration, that is not often made, is the environmental impact of the transit phase. Impact is primarily driven in the Resource Depletion and Climate Change categories, as substantial fossil fuel usage is required in this phase. For the purposes of this assessment, the environmental assessment of transport was conducted between the source and end locations, based on country averages. Representative examples of Climate Change from clothing transit can be seen in Table 7, below.

Table 7: Representative Transit Environmental Impact Data

Process	Mode of Transit	Climate Change (kg CO2-e)
Shipping from China to USA	Land and Sea	0.41
Shipping from India to USA	Land and Sea	0.24
Shipping from Bangladesh to USA	Land and Sea	0.1794
Shipping from Indonesia to USA	Land and Sea	0.1587
Shipping from Vietnam to USA	Land and Sea	0.1414
Shipping from Cambodia to USA	Land and Sea	0.1573
Shipping from China to Europe	Land and Sea	0.1912
Shipping from India to Europe	Land and Sea	0.1514
Shipping from Bangladesh to Europe	Land and Sea	12.87
Shipping from Indonesia to Europe	Land and Sea	14.63
Shipping from Vietnam to Europe	Land and Sea	14.86
Shipping from Cambodia to Europe	Land and Sea	0.1504

*Representative examples, models were built to demonstrate Climate Change impact for transit between all potential locations

4.8 Use Phase Evaluation:

The use phase has been largely ignored for years by designers and manufacturers, and users are often unaware of the true cost of the use phase of their clothing. Depending on how clothing is treated by consumers it can result in a high cost of water and electricity consumption. This cost is not itemized for consumers and as a result is difficult to drive improvement. Some producers are beginning to investigate alternatives to the wash and dry phase through the implementation of new finishing processes and the use of alternative fibers.

Unfortunately, given the limited focus in this category, education around the environmental impact of the use phase is poorly understood. In places where clothing is washed using hot water and clothing is machine dried, the environmental impact can be quite substantial. Fortunately, in certain regions, particularly in parts of Europe and Asia where clothing is hang dried, the environmental impact is better understood, and users act accordingly. An outline of the environmental impact of the use phase, wash and dry, for various clothing categories is outlined in Table 8, below.

Table 8: Environmental Sustainability in the Use Phase

Process	Water Scarcity (US) (m3)	Climate Change (Dry - US) (kg CO2 eq)	Climate Change (Wash - US) (kg CO2 eq)	Water Scarcity (Asia/EU) (m3)	Climate Change (Dry - EU / Asia) (kg CO2 eq)	Climate Change (Wash - EU / Asia) (kg CO2 eq)
Blouses	0.0615625	1.390723872	6.953619359	0.0615625	0.695361936	6.953619359
Casual Pants	0.6532	1.775033764	8.875168821	0.6532	0.887516882	8.875168821
Dress Shirts	0.0615625	1.390723872	6.953619359	0.0615625	0.695361936	6.953619359
Dress Pants	0.284	0.771753811	3.858769053	0.284	0.385876905	3.858769053
Dresses	0.2109375	0.146118721	0.730593607	0.2109375	0.073059361	0.730593607
Jeans	0.6532	1.775033764	8.875168821	0.6532	0.887516882	8.875168821
Outerwear	0.01875	0.007305936	0.03652968	0.01875	0.003652968	0.03652968
Shorts	0.09	0.876712329	4.383561644	0.09	0.438356164	4.383561644
Sportswear	0.1425	0.55371305	2.768565249	0.1425	0.276856525	2.768565249
Suits / Sportcoats	0.4605	0.475956747	2.379783737	0.4605	0.237978374	2.379783737
Sweaters / Sweatshirts	0.1796875	0.476474092	2.382370459	0.1796875	0.238237046	2.382370459
T-Shirts	0.13125	2.609262883	13.04631442	0.13125	1.304631442	13.04631442
Underwear	0.1625	9.117808219	45.5890411	0.1625	4.55890411	45.5890411
Vests	0.13125	2.609262883	13.04631442	0.13125	1.304631442	13.04631442

*All values based on 2500W Dryer and 500W Washer with 8kg capacity per load (adjusted in model based on user input)

4.9 Disposal / Recycling Evaluation:

The disposal and recycling of old clothing has received increased attention in recent years as the costs of raw materials has risen and manufacturers are investigating more sustainable means to reduce product costs. This has resulted in new process development to recycle previously unused materials. Additionally, various companies are identifying ways to develop supply chains around old clothing. This focus on cost reduction and reuse will have associated positive impacts on environmental performance. As clothing is reused, the need to produce resource-intensive raw materials will decrease and the environmental impact of clothing, sitting in landfills, will decrease. Although environmental and cost improvements in the disposal phase are still quite limited, the potential is large and this area is receiving an increasing focus from the supply chain stakeholders who can institute change.

CHAPTER 5: DATA ANALYSIS

5.1 Li & Fung Environmental Assessment Tool:

Based on the data collected, as described in the previous section, an environmental assessment tool was developed to provide feedback to factories, internal stakeholders, suppliers, and customers. This assessment was developed through evaluation of the collected data. The specifics regarding the output calculations and data used can be seen in the following section. Calculations were conducted for Climate Change, Eutrophication, Resource Depletion, Water Depletion, and Land Occupation. Chemistry is currently limited to a qualitative assessment which flags hazardous materials that are in use at a garmenting factory.

5.2 Climate Change Methodology

Climate Change Subcategory: Raw Material, Yarn Formation, Textile Formation, Preparation, Coloration, and Finishing

Each of these categories were calculated using secondary data as the numerical inputs and primary data as the guide. To determine the value for the assessment, an average was taken, from multiple sources, based on the following data, provided in the data collection response.

- Material Type: Cotton, Acrylic, EL, Flax, Hemp, MEG, Nylon, Organic Cotton, Nylon / PA, PA, Polyester, Polyethersulfone, Polyethylene, Polypropylene, PTA, Silk, Viscose, Wool, and Unspecified
- Garment Type: Blouses, Casual Pants, Children's Clothing, Dress Shirts, Dress Pants, Dresses, Jeans, Maternity Clothes, Outerwear, Shorts, Suits / Sports Coat, Sweaters / Sweatshirts, T-shirts, Underwear, Vests, Other Categories
- Production Location

Climate Change Subcategory: Garmenting

Calculations for Garmenting Climate Change employs both primary and secondary data; primary data includes product weight(s), product category revenue(s), annual electricity usage, annual gasoline usage, annual natural gas usage, annual diesel usage, and number of units produced per product category. Secondary data used in the calculation is the country specific electricity consumption to CO2 emission factor, global gasoline consumption to CO2 emission factor, global natural gas consumption to CO2 emission factor, and global diesel consumption to CO2 emission factor. Using this data, the Garmenting Climate Change Calculation is as follows.

$$\left\{\frac{(Product\ Category\ Weight) * (Product\ Category\ Revenue)}{(Average\ Category\ Weight) * (Total\ Revenue)}\right\} * \left\{\frac{(Annual\ Electricity\ Usage) * (Country\ Specific\ CO2\ Factor)}{(Number\ of\ Category\ Units)} + \frac{(Annual\ Gasoline\ Usage) * (Global\ Gasoline\ to\ CO2\ Factor)}{(Number\ of\ Category\ Units)} + \frac{(Annual\ Natrual\ Gas\ Usage) * (Global\ Natural\ Gas\ to\ CO2\ Factor)}{(Number\ of\ Category\ Units)} + \frac{(Annual\ Diesel\ Usage) * (Global\ Diesel\ to\ CO2\ Factor)}{(Number\ of\ Category\ Units)}\right\}$$

Climate Change Subcategory: Transit

Transit calculations use customer and manufacturer data to calculate emissions between the locations based on a predetermined modal allocation, but can be updated based on supply chain specifics. The general formula for Transit Climate Change is below.

$$(Distance\ from\ Manufacturing\ Location\ to\ Customer\ Location) * \{(\%\ Land\ Transport * Land\ CO2\ Conversion\ Factor) + (\%\ Sea\ Transport * Sea\ CO2\ Conversion\ Factor)\}$$

Climate Change Subcategory: Use

The environmental impact calculations for the use phase are limited to Climate Change and Water Depletion. From a Climate Change perspective there are two processes that require evaluation, the dry phase and the wash phase. In these phases, country specific behavior is modeled through secondary data, while primary data contributes the product category weight.

$$Climate\ Change\ Wash: (Average\ Region\ Washer\ Wattage) * (Average\ Load\ Size)^{-1} * (Product\ Category\ Specific\ Weight) * (Number\ of\ Average\ Washes\ Per\ Year) * (Time\ Per\ Wash) * (Number\ of\ Years\ Used) * (Country\ Specific\ Electricity\ to\ CO2\ Conversion)$$

$$Climate\ Change\ Dry: (Average\ Region\ Dryer\ Wattage) * (Average\ Load\ Size)^{-1} * (Product\ Category\ Specific\ Weight) * (Number\ of\ Average\ Dries\ Per\ Year) * (Time\ Per\ Dry) * (Number\ of\ Years\ Used) * (Country\ Specific\ Electricity\ to\ CO2\ Conversion)$$

Climate Change Subcategory: Disposal

Given the high recyclability of clothing materials a -75% multiple factor is applied to the Raw Material process for clothing that is marked as recycled. No major Climate Change impact is assigned to disposed clothing.

5.3 Eutrophication Methodology

Eutrophication Subcategory: Raw Material, Yarn Formation, Textile Formation, Preparation, Coloration, and Finishing

Each of these categories were calculated using secondary data as the numerical inputs and primary data as the guide. To determine the value for the assessment, an average was taken, from multiple sources, based on the following data, provided in the data collection response.

- Material Type: Cotton, Acrylic, EL, Flax, Hemp, MEG, Nylon, Organic Cotton, Nylon / PA, PA, Polyester, Polyethersulfone, Polyethylene, Polypropylene, PTA, Silk, Viscose, Wool, and Unspecified
- Garment Type: Blouses, Casual Pants, Children's Clothing, Dress Shirts, Dress Pants, Dresses, Jeans, Maternity Clothes, Outerwear, Shorts, Suits / Sports Coat, Sweaters / Sweatshirts, T-shirts, Underwear, Vests, Other Categories
- Production Location

5.4 Resource Depletion Methodology

Resource Depletion Subcategory: Raw Material, Yarn Formation, Textile Formation, Preparation, Coloration, and Finishing

Each of these categories were calculated using secondary data as the numerical inputs and primary data as the guide. To determine the value for the assessment, an average was taken, from multiple sources, based on the following data, provided in the data collection response.

- Material Type: Cotton, Acrylic, EL, Flax, Hemp, MEG, Nylon, Organic Cotton, Nylon / PA, PA, Polyester, Polyethersulfone, Polyethylene, Polypropylene, PTA, Silk, Viscose, Wool, and Unspecified
- Garment Type: Blouses, Casual Pants, Children's Clothing, Dress Shirts, Dress Pants, Dresses, Jeans, Maternity Clothes, Outerwear, Shorts, Suits / Sports Coat, Sweaters / Sweatshirts, T-shirts, Underwear, Vests, Other Categories
- Production Location

5.5 Water Depletion Methodology

Water Depletion Subcategory: Raw Material, Yarn Formation, Textile Formation, Preparation, Coloration, and Finishing

Each of these categories were calculated using secondary data as the numerical inputs and primary data as the guide. To determine the value for the assessment, an average was taken, from multiple sources, based on the following data, provided in the data collection response.

- Material Type: Cotton, Acrylic, EL, Flax, Hemp, MEG, Nylon, Organic Cotton, Nylon / PA, PA, Polyester, Polyethersulfone, Polyethylene, Polypropylene, PTA, Silk, Viscose, Wool, and Unspecified
- Garment Type: Blouses, Casual Pants, Children's Clothing, Dress Shirts, Dress Pants, Dresses, Jeans, Maternity Clothes, Outerwear, Shorts, Suits / Sports Coat, Sweaters / Sweatshirts, T-shirts, Underwear, Vests, Other Categories

- Production Location

Water Depletion Subcategory: Garmenting

Calculations for Garmenting Water Depletion employs both primary and secondary data; primary data includes product weight(s), product category revenue(s), annual water usage, annual water re-usage, and number of units produced per product category. Secondary data is used to fill in informational gaps where present. Using this data, the Garmenting Climate Change Calculation is as follows.

$$\left\{\frac{(Product\ Category\ Weight) * (Product\ Category\ Revenue)}{(Average\ Category\ Weight) * (Total\ Revenue)}\right\} * \left\{\frac{(Annual\ Water\ Usage)}{(Number\ of\ Category\ Units)} - \frac{(Annual\ Water\ Reused)}{(Number\ of\ Category\ Units)}\right\}$$

Water Depletion Subcategory: Use

From a Water Depletion perspective there is one process that requires evaluation, the wash phase. In this phase, country specific behavior is modeled through secondary data, while primary data contributes the product category weight.

$$Water\ Depletion\ Wash: (Average\ Region\ Washer\ Wattage) * (Average\ Load\ Size)^{-1} * (Product\ Category\ Specific\ Weight) * (Number\ of\ Average\ Washes\ Per\ Year) * (Time\ Per\ Wash) * (Number\ of\ Years\ Used) * (Water\ Usage\ per\ Load)$$

Water Depletion Subcategory: Disposal

Given the high recyclability of clothing materials a -75% multiple factor is applied to the Raw Material process for clothing that is marked as recycled. No major Water Depletion impact is assigned to disposed clothing.

5.6 Land Occupation Methodology

Land Occupation which is solely limited to agricultural impact of the clothing supply chain is calculated for the raw material production of natural fibers, primarily cotton. For this calculation, country specific data was used, and a database was compiled that specifies country yields. These yields were used to calculate the land occupation in the following way.

$$(Country\ specific\ yield\ per\ kilogram)^{-1} * (weight\ of\ the\ product\ per\ kilogram) * \left(1 + \frac{percent\ material\ waste}{100}\right)$$

5.7 Methodology Assumptions

In the calculations, previously discussed, several assumptions were applied. A majority of the assumptions applied to the assessment and associated calculations are described below.

- Allocation of factory level data is based on product revenue and product weight (i.e., If a factory reports 1,000,000 kWh of annual electricity usage, a total revenue of $40M ($30M in t-shirts and $10M in jeans), products weights of 0.125 kg for t-shirts and 0.5 kg for jeans, the allocation of electricity to jeans would equal 57% ([0.5*10]/[0.5*10 + 0.125*30])

- Once the various factory level data had been allocated at a product level, this allocation was spread over the number of units to establish a per unit usage rate or emission rate (i.e., For the t-shirts previously discussed, if 1,000 units are produced, each unit would be responsible for consumption of 0.57*1,000,000/1,000 = 570 kWh of electricity
- In turn, all electricity consumption numbers were converted into their Climate Change equivalent based on the conversion factor associated with the country location for the factory (i.e., For a factory located in Cambodia, let's assume 1 kWh electricity = 0.8 kg CO2-e, and as a result the impact per pair of jeans would equal 570*0.8 = 456 kg CO2-e)
- If raw material types are not provided by the garmenting facility, the industry average is applied
- If product weights are not provided by the garmenting facility or are inconsistent with standard ranges, the industry average is applied
- Transit distances are based on the average distance between the garmenting facility and the consumer location, on a country by country basis, with 30% of modal transit allocated to trucking and 70% of modal transit allocated to marine transit
- The use phase and associated washing and drying behavior is based on regional averages with three primary classifications: USA, Europe, and Asia
- Raw Material, Yarn Formation, Textile Formation, Preparation, Coloration, and Finishing environmental assessments were conducted based on country specific data, where available, and globally when country specific data was not available
- Land Occupation was limited to the growth of cotton, the most land intensive, and assumed minimal for all other raw material categories
- The environmental impact of transport materials was neglected in the environmental assessment for the Transit category
- A global standard was applied to the emissions and depletion of abiotic resources, given the lack of visibility into the source of fossil fuels and limited differentiation

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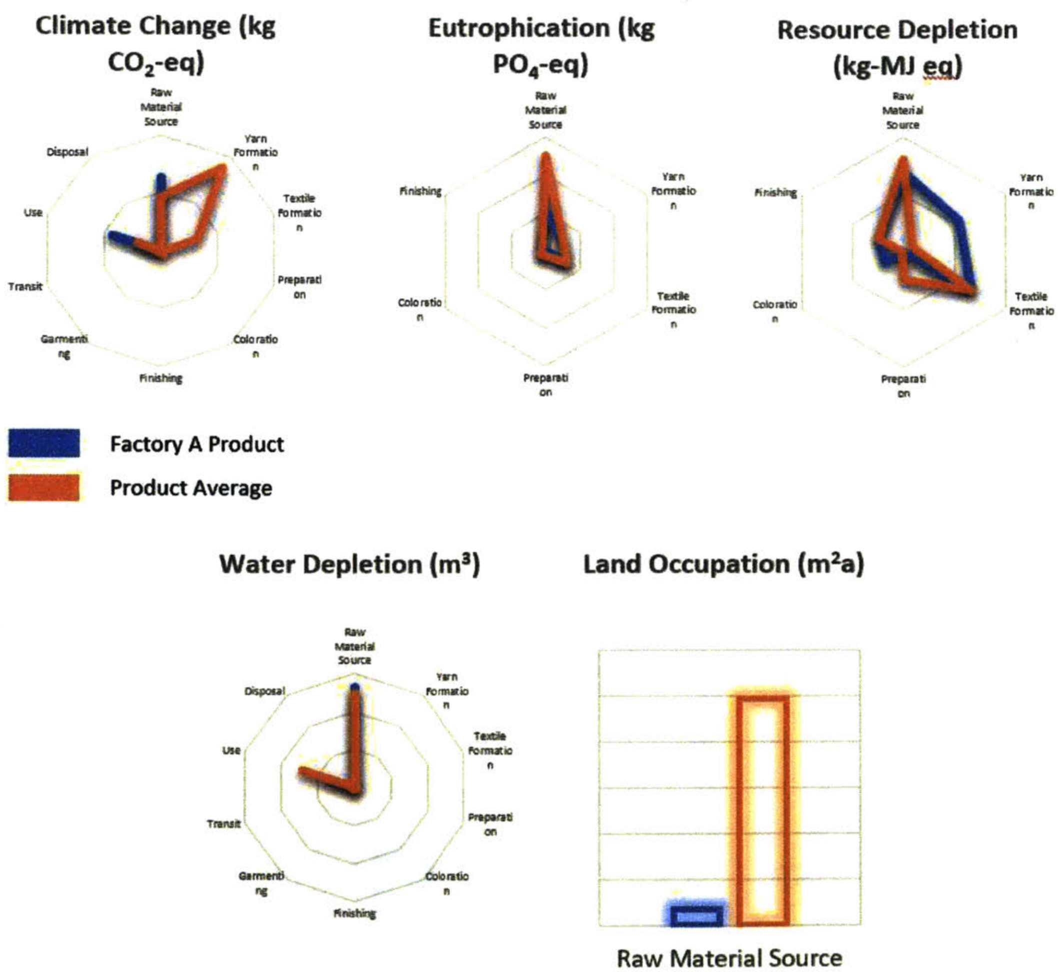
CHAPTER 6: RESULTS AND CONCLUSIONS

6.1 Total Supply Chain Impact Example:

In total, of the 1,657 factories, 331 factories were evaluated using the environmental assessment tool. These factories were limited to the cut and sew operation, as access to lower level suppliers was not available. Additionally, these factories represented the most reliable, consistent data and spanned the widest range of product categories. To demonstrate the assessment tool and its description of environmental impact, the product produced by two factories was compared. In this case, the product under assessment was a typical knit sweater. These factories are referred to as Factory A and Factory B. Across major product environmental categories, major differences were found. In all cases, both factories' products were compared to the average knit sweater.

Factory A Assessment:

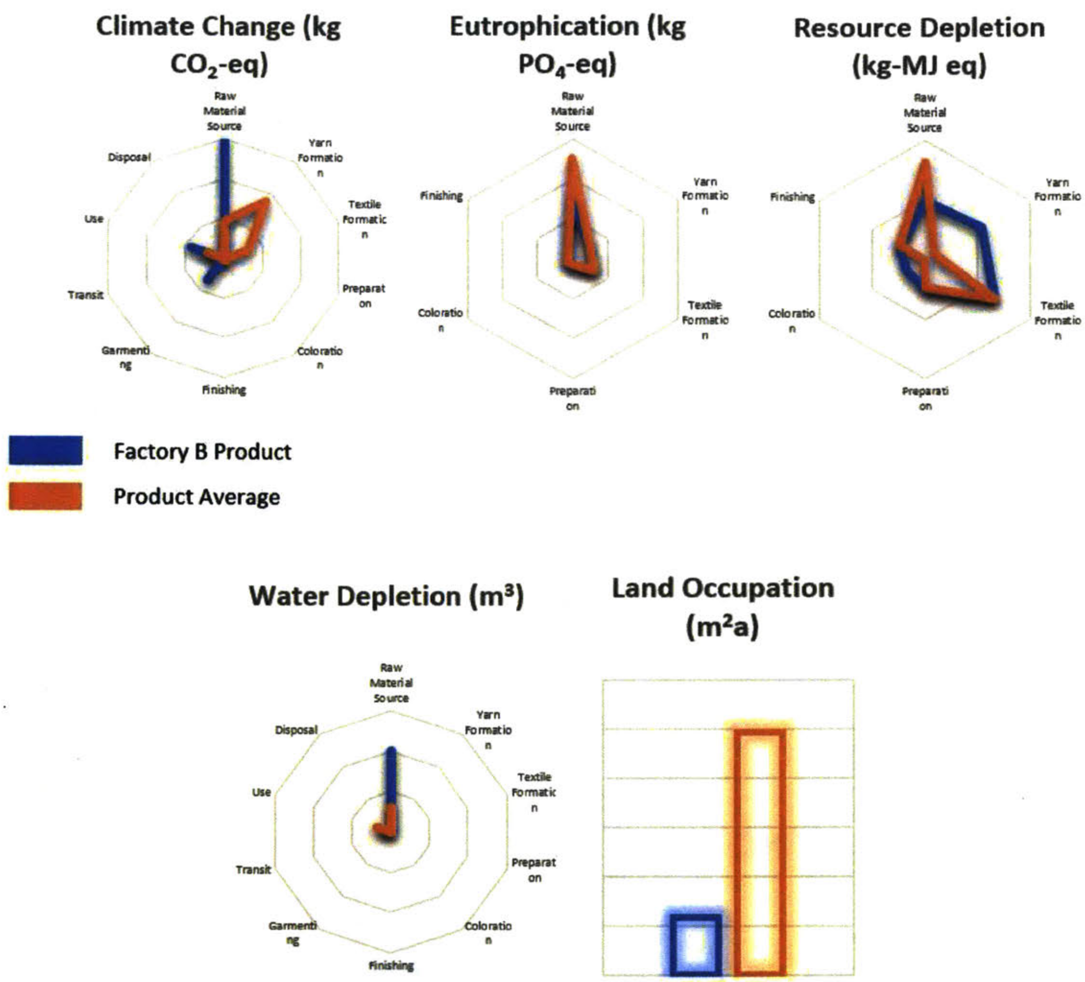
Figure 17: Factory A Assessment Output



- Factory A's sweater products compare favorably on dimensions of climate change impact, water depletion, and land occupation given heavy use of synthetic materials and efficient garmenting practices
- Uncertainty in the yarn formation process results in less positive performance as compared to the industry as a whole and the relatively high weight of products evaluated tends toward a high climate change impact during the use phase, although highly dependent on the use location
- Overall, no major hotspots exist for Factory A's product, but room for improvement is apparent at each stage in the lifecycle and across most primary metrics

Factory B Assessment:

Figure 18: Factory B Assessment Output



- On a climate change basis, Factory B performs well against the average factory, although material selection is the leading area of impact for Factory B where it performs worse than the industry average
- Across eutrophication and land occupation metrics, Factory B performs within the top 50 percentile
- As it relates to water depletion, Factory B performs worse than the industry average and this is largely the case given a high concentration of products leveraging cotton as a raw material

Factory A and Factory B Comparison:

- Environmental impact differences between those sweaters produced by Factory A and those produced by Factory B are primarily driven by upstream supply decisions
- Factory B's heavy use of cotton (70%) compared to Factory A's (32%) has led a to higher level of land occupation and water usage / depletion
- Little differentiation is found in both factories' performance across the areas of resource depletion and eutrophication as these steps are executed upstream in the supply chain and are relatively material-agnositc

6.2 Data Collection and Tool Results Feedback:

Updates to the data collection tool and performance feedback showed promise against previous attempts with 87% of respondents stating that they were either "satisfied" or "very satisfied" with the updated data collection tool, process, and supporting materials. Furthermore, several users provided feedback regarding the tool, as follows: (1) "I like this version, it's better than the previous ones" (2) "new and good experience" (3) "no [feedback], it is good" (4) "Its very interesting to know the environmental impact of the industry and implement best practices that support a sustainable future. We did not face any difficulties to do or collect the data during survey." (5) "This tool is user friendly"

User satisfaction and improved usability was also reflected in the results, where data was more consistently collected, and input errors were less prevalent. This allows for an improved data evaluation process, more actionable results for factories, and reduced factory follow up. The revised tool covered all necessary data collection fields and eliminated the need to conduct follow up requests, in order to fill in data gaps.

6.3 Ranking Environmental Impact:

The environmental impact of specific garments is highly dependent on the raw material used, processing activities, fabric finishes, dyeing technology, and location. Natural raw materials, like cotton are highly water intensive, while synthetic materials are highly abiotic resource intensive and their production emits large amounts of CO_2. Processing of raw material into workable material is highly energy intensive, particularly when inconsistent, natural fibers are used. Additionally, fabric finishing and dyeing is immensely water intensive. In most supply chains, these are the most water intensive processes, although cotton cultivation can be more water intensive when limited to arid regions.

Unfortunately, there is not a one size fits all view of clothing and associated environmental impacts. Rather, an entire supply chain view is needed to identify trade-offs across areas in the supply chain. Improvement in one area of the supply chain may result in worse performance in another area of the supply chain. That said, a movement to recycled materials, organic fibers, biodegradable fibers, and wash-free clothing would provide quick wins, with limited cross supply chain interference.

6.4 Solutions for an Environmentally Friendly Supply Chain:

Based on the assessments completed and analysis conducted, it has become clear that an optimized environmental sustainability approach must involve all stakeholders from design through consumer, across countries and with varying levels of involvement. Consumers must advocate and drive buying behavior for more sustainably sourced and manufactured clothing. Designers must be educated on the environmental impact of clothing and given the tools to make decisions that build sustainability into the design process. Furthermore, designers must be incentivized to make positive environmental sustainability decisions by building appropriate measures into the performance evaluation process.

Sourcing of raw materials, which are, in most situations, the largest contributor to environmental impact and product pricing, must be conducted more intelligently and with an increased focus on costs net negative environmental externalities. Only a few primary materials are used in production of clothing, including cotton, wool, and polyester, but the specific manufacturing conditions and environmental impact is heavily driven by location, standard operating procedures, and management. Each material has its own set of category specific impacts, although when sustainably sourced or when recycled material is employed the impact can be reduced dramatically.

Post-processing of raw material, which creates further burden on the environment, is categorized into three key areas: yarn formation, textile formation, and fabric finishing. Yarn and textile formation are highly energy intensive, although certain techniques and material densities can reduce impact. Furthermore, as much of the energy used in these processes is provided by the grid and grid power in locales of manufacturing is carbon intensive, steps should be taken to power the grid and manufacturing facilities with alternative / green sources. This would reduce the environmental impact of abiotic resource depletion.

Fabric finishing, typically used to impart characteristics on raw fabric that are not naturally present, is water intensive, although more recent technologies may mitigate this impact. Companies like DyeCoo have invented technologies that would allow for reliable dying that meets consumer needs without substantial water usage during the dying process. [49] Although, even these new technologies do not mitigate the human and environmental impact of using hazardous chemicals in the finishing process. Additional research and investment is needed to identify and investigate manufacturing solutions that eliminate the need for hazardous materials.

Furthermore, evaluations of the garmenting process and analysis of data from factories showed potential areas for improvement. Many of the differences between factories that cut and assemble garments showed that management, location, and internal processes are primary drivers in environmental performance. Many of the expected drivers of performance, including factory size, renewable energy adoption rate, and number of workers, had, in fact, limited bearing on factory specific performance. Rather, management decisions and standard practice were the primary driver.

Once production is completed and product enters the transit portion of the supply chain, little can be done to mitigate the environmental impact from a logistics standpoint. Rather, steps can be taken to locate facilities near the point of consumption and material use in distribution can be minimalize. Tonnage waste can be minimized through the use of reusable boxes, totes, and pallets and by replacing plastic bags with more renewable options. Unfortunately, there are no options for large scale, renewable shipping materials that are feasible, at this time.

The final and perhaps most important step in the supply chain of an article of clothing is the use and disposal phase. Through the recycling of clothing, a large portion of the environmental impact of raw material manufacturing can be mitigated. Further, this reduction in demand on raw material production can lead to more sustainable practices in harvesting and growing. Currently the high demand for cotton, wool, and other natural fibers leads producers to practices that place yield above environmental impact. Once an ever-increasing need to meet high yield targets subsides the yield vs environment paradigm will shift.

While the disposal phase presents its own unique set of challenges in how consumers are influenced to make environmentally sound decisions in the disposal of clothing, changing the everyday habits of consumers may be even more difficult. In certain parts of the world, consumers hand or cold wash clothing and air dry. Unfortunately, these practices are not prevalent in all economies. A shift from warm water washing and machine drying will have a substantial impact on both the Climate Change and Abiotic Resource Depletion categories. A cultural shift is not easy, but steps should be taken to educate consumers through garment tags and treatment recommendations.

6.5 Conclusions & Recommendation:

In evaluating the clothing industry, the industry's supply chains, and the associated implications, it is critical to frame the challenges, technologies, and solutions in a broad context. Thus, designers and buyers must consider the type of material, yarn and textile formation processes, and finishing applications in the context of consumer needs, material properties, cost constraints, and environmental sustainability needs. Often, these decision criteria run in contrast to each other, but in certain instances complimentary raw material, yarn, textile, and finishing selections result in products that are durable, meet consumer needs, and minimize lifetime environmental impact.

The introduction of blended fabrics has allowed clothing to be durable, resistant to environmental factors, soft, comfortable, and water-wicking. This is achieved by configuring natural and synthetic fibers through weaves that hold shape while promoting flexibility under strain. Additionally, fabric finishing promotes properties on fabrics that are not naturally present. All of these advancements have provided consumers with better options, but there is often an environmental tradeoff.

As was clear in the environmental assessments for raw material production through fabric finishing, clothing has a largely substantial negative impact on the environment. This impact influences climate change, abiotic resource depletion, water scarcity, and eutrophication. Recently, more environmentally friendly materials, like flax and jute, have provided an alternative to their less environmentally sustainable counterparts, including cotton and wool. Unfortunately, the supply of flax and jute is not widespread and these materials come with their own tradeoffs. Furthermore, a lack of development in alternative materials has resulted in little advancement in their finishing and applications. Lastly, given the mature nature of the clothing industry, little investment in sustainable technologies has been made, and rather cost reduction is the focus. Cost reduction efforts are driven by consumers demanding cheaper and cheaper products without understanding the implications of low price tags.

Initial insights into the garment supply chain have resulted in substantial, fruitful results, but steps can still be taken to drive improved insights and supply chain performance.

1. Monte Carlo analysis should be conducted on secondary data to provide a range of performance that reflects the environmental impact more accurately
2. Ongoing data collection from factories should be completed to evaluate performance over time; the factors that drive ongoing, improved performance should be identified
3. Primary data should be collected further down the supply chain to gain more precise results at all supply chain tiers
4. The feasibility of implementing supply chain-wide organic and recycled material should be evaluated and steps should be taken to conduct pilot programs
5. Results of the survey should be made immediately available to factories in unison with survey completion confirmation
6. Factory managers should be evaluated on their factory's environmental performance and results should be built into factory action plans

The results and work outlined in this thesis are a good first start in conducting environmental assessments of factories, but future steps can be taken to make the factory assessments increasingly actionable. As the supply chain becomes more transparent and the factory relationship more collaborative, real change can be made in the supply chain and environmental sustainability can become the focus. Factories are becoming increasingly aware of their need for environmental sustainability improvement and many are actively asking for guidance.

6.6 Prospects for Adoption

As mentioned in the previous section, adoption of environmental impact analyses in the garment industry must be approached holistically, across all levels of the supply chain and among all employees in the organization. For example, if designers don't take an environmentally-focused view when designing garments, there is little that can be done at other levels of the supply chain to optimize across product evaluation criteria, including environmental impact. This need to have buy-in across all members of a product deployment team and supply chain presents one of the largest barriers to adoption at scale. Rather, retailers must establish strict guidelines on the acceptable environmental impact of a garment and consumers must make it clear that this is important. If consumers are unwilling to make purchasing decisions based on the environmental impact of a garment or organization, there is little incentive for organizations to change their manufacturing and sourcing practices. In addition to retailers mandating levels of environmental performance from their suppliers, the government plays a role as well. Governments have the opportunity to set standards for the environmental impact of garments produced in and imported into their countries. Furthermore, for garments that do not meet the established standards, taxes and tariffs can be applied with proceeds deployed to offset negative environmental impacts.

Although an industry focused on their environmental impact with support from across the value chain and alignment with government officials is desired by all stakeholders, this end state is only possible with increased maturation of the industry. This maturation will occur in stages, and Li & Fung is in the early stages, yet further along the development curve than many others in the industry. Implementation of environmental impact tools and installation of environmental best practices across all levels of the organization will occur in stages.

1. **Industry Standard:** An industry standard must be established. This standard must account for environmental impact across MECE categories and establish quantifiable, comparable standards. Furthermore, best practices to offset impact and economic factors must be included. The Higg Index is a well established tool to provide stakeholders a starting point and with further investment may build the foundation for this industry standard.
2. **Staged Deployment:** Producers must evaluate the environmental impact in areas where they have visibility and based on the established standard. By starting with the areas where data is currently available, producers can build momentum and begin to better understand the interconnection between operation decisions. Furthermore, producers will begin to better understand the enablers that will enhance transparency in their supply chain and introduce tools that allow for the collection of necessary data.
3. **Mandate:** Once the tools and standards are established, organizations like Li & Fung and retailers have the opportunity to mandate the collection of all data necessary in the evaluation of garments according to the Industry Standard. This mandate propagates all levels of the supply chain and across all producing countries. If variation is allowed across countries or supply chain stakeholders, it is likely that the negative impact will move to the area of least resistance.
4. **Audit and Sustainment:** Lastly, retailers, governments, and/or organizations like Li & Fung must take steps to validate and audit supplier information and ensure that low environmental impacts are sustained. This will require procedural changes in how supply chain stakeholders operate and may require formal training for environmental auditors. These auditors must follow Industry Standards, and to avoid conflict of interest, should be decoupled from the core business.

Given the decoupling of Western consumers from the production of garments and the potential for garment producing countries to "Race to the Bottom", environmental standards are best implemented with involvement of Western governments and retailers. This view will likely carry with it substantial resistance as countries and their industrial producers attempt to retain freedom of consumption and pollution. Unfortunately, this is one area where a global view is required with visibility amongst consumers of the impact of their decisions. It is yet to be seen if consumers, at scale, will make purchasing decisions based on their implied environmental impact. If they are unwilling, the industry and governmental bodies must step in to ensure the industry and environments can be sustained for future generations.

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CHAPTER 7: REFERENCES

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CHAPTER 8: APPENDIX

Appendix 8.1: Higg Index Questionnaire [19]

General Information:

- Submission Type (raw material or process)
- Submission Name
- Brand
- Material Category
- Base Material
- Production Phase
- Facility
- Reporting Period (start and end dates of data collection period)
- Supporting documents
- Image General Description
- Energy use allocation

Materials, Energy, and Transport:

- Name and amount of product/process
- Energy inputs, amounts, and measurement approaches
- Material inputs, amounts, and measurement approaches
- Agricultural land inputs, amounts, and measurement approaches
- Packaging inputs, amounts, and measurement approaches

Self-produced Energy:

- Output types and amounts
- Fuel sources and amounts
- Emissions specific to on-site energy production
- Amount exported to grid or sold

Water Use and Treatment:

- Total water use for reporting period per kg of product
- Total amount of water discharged per kg of product
- Total amount of water treated on-site per kg of product
- Total amount of water returned to municipal source per kg of product

Emissions:

- Air emissions type and amount per kg of product
- Water emissions type and amount per kg of product
- Soil emissions type and amount per kg of product

Solid Waste and Recycling:

- Materials sent to landfill and their amounts
- Materials sent to incineration and their amounts

- Recycled materials and their amounts
- Hazardous materials and their amounts

Data Quality (ranking from very poor to very good):

- Technological Representativeness
- Temporal Representativeness
- Geographical Representativeness
- Parameter Uncertainty

Source:
(http://msicontributor.higg.org/uploads/msicontributor.higg.org/sac_textpage_section_files/14/file/MSI_Methodology_10-3-17_Final.pdf)

Appendix 8.2: Data Collection Tool

SECTION

Welcome to Li & Fung's Footprinting Tool

LI & FUNG

Click "Next" to start the survey!

SECTION

Tool Introduction

- General Factory Information
- Factory Process Information
- Product Information
- Electricity / Power Statistics
- Water Statistics
- Chemical Data

SECTION

Before You Begin: Survey Preparation

1. Annual sales and production quantity
2. Product input sources (for cotton, wool, polyester, etc.)
3. Power sources and annual consumption
4. Water sources and annual consumption
5. Water treatment methods and annual volume
6. Chemical usage

SECTION

General Factory Information [Part 1 of 6]

1. Factory name *

2. Enter your full name (First name followed by last name) *

Example: John Doe

3. Job title *

Example: Factory Manager

4. Email *

5. Factory City *

6. Factory State *

7. Factory Country *

8. Total Freight on Board (FOB) of the facility for April 2016 through March 2017 ($USD in millions) *

$

For example an input of 20 equals $20,000,000

9. Factory floor area in m2 (see example below) *

Include all floors of factory, but not the dormitory, canteen, or other non-factory buildings

10. Number of permanent factory workers: *

This number is for the factory workers only and should not include administrative staff

11. Number of contract factory workers: *

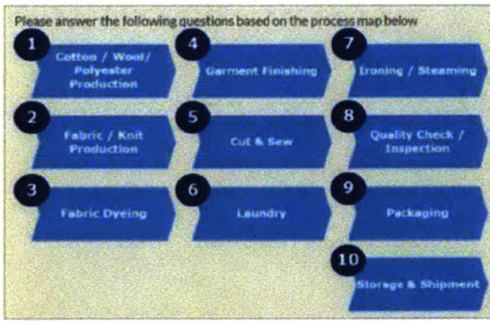
This number is for the factory workers only and should not include administrative staff

12. If there is anything else that is unique about your factory or helps characterize your factory, please share below: *

SECTION

Factory Process Information [Part 2 of 6]

Please answer the following questions based on the process map below



13. What is the FIRST step in your production process? *

Cotton / Wool / Polyester Production

14. What is the LAST step in your production process? *

Cotton / Wool / Polyester Production

13b. Do you launder (wash & dry) the garment? *

Yes

No

13c. Do you dye the fabric? *

Yes

No

Product Information [Part 3 of 6]

15. What was your freight on board (FOB) for Apparel from April 2016 through March 2017 ($USD in millions)? *

$

15a. Select the types of Apparel you produce below: *

- Blouses
- Casual Pants
- Children's Clothing
- Dress Shirts
- Dress Pants
- Dresses
- Jeans
- Maternity
- Outerwear
- Shorts
- Sportswear
- Suits / Sportcoats
- Sweaters / Sweatshirts
- T-Shirts
- Underwear
- Vests
- Other

15b. What was your freight on board (FOB) for Blouses from April 2016 through March 2017 ($USD in millions)? *

$

15c. What was your freight on board (FOB) for Casual Pants from April 2016 through March 2017 ($USD in millions)? *

$

15d. What was your freight on board (FOB) for Children's Clothing from April 2016 through March 2017 ($USD in millions)? *

$

15e. What was your freight on board (FOB) for Dress Shirts from April 2016 through March 2017 ($USD in millions)? *

$

15f. What was your freight on board (FOB) for Dress Pants from April 2016 through March 2017 ($USD in millions)? *

$

15g. What was your freight on board (FOB) for Dresses from April 2016 through March 2017 ($USD in millions)? *

$

15h. What was your freight on board (FOB) for Jeans from April 2016 through March 2017 ($USD in millions)? *

$

15i. What was your freight on board (FOB) for Maternity Clothes from April 2016 through March 2017 ($USD in millions)? *

$

15j. What was your freight on board (FOB) for Outerwear from April 2016 through March 2017 ($USD in millions)? *

$

15k. What was your freight on board (FOB) for Shorts from April 2016 through March 2017 ($USD in millions)? *

$

15l. What was your freight on board (FOB) for Sportswear from April 2016 through March 2017 ($USD in millions)? *

$

15m. What was your freight on board (FOB) for Suits / Sportcoats from April 2016 through March 2017 ($USD in millions)? *

$

15n. What was your freight on board (FOB) for Sweaters / Sweatshirts from April 2016 through March 2017 ($USD in millions)? *

$

15o. What was your freight on board (FOB) for T-Shirts from April 2016 through March 2017 ($USD in millions)? *

$

15p. What was your freight on board (FOB) for Underwear from April 2016 through March 2017 ($USD in millions)? *

$

15q. What was your freight on board (FOB) for Vests from April 2016 through March 2017 ($USD in millions)? *

$

15r. What was your freight on board (FOB) for Other Product Categories from April 2016 through March 2017 ($USD in millions)? *

$

16. What was your freight on board (FOB) for Bags from April 2016 through March 2017 ($USD in millions)? *

$

17. What was your freight on board (FOB) for Beauty Products from April 2016 through March 2017 ($USD in millions)? *

$

18. What was your freight on board (FOB) for Crafts from April 2016 through March 2017 ($USD in millions)? *

$

19. What was your freight on board (FOB) for Fabric from April 2016 through March 2017 ($USD in millions)? *

$

20. What was your freight on board (FOB) for Accessories from April 2016 through March 2017 ($USD in millions)? *

$

21. What was your freight on board (FOB) for Footwear from April 2016 through March 2017 ($USD in millions)? *

$

22. What was your freight on board (FOB) for Home Textiles from April 2016 through March 2017 ($USD in millions)? *

$

15s. Average Apparel Product Weight (grams per unit) *

15t. Average Blouse Product Weight (grams per unit) *

15u. Average Casual Pants Product Weight (grams per unit) *

15v. Average Children's Clothing Product Weight (grams per unit) *

15w. Average Dress Pant Product Weight (grams per unit) *

15x. Average Dress Shirt Product Weight (grams per unit) *

15y. Average Dress Product Weight (grams per unit) *

15z. Average Jeans Product Weight (grams per unit) *

15aa. Average Maternity Clothes Product Weight (grams per unit) *

15ab. Average Outerwear Product Weight (grams per unit) *

15ac. Average Shorts Product Weight (grams per unit) *

15ad. Average Sportswear Product Weight (grams per unit) *

15ae. Average Suit / Sportcoat Product Weight (grams per unit) *

15af. Average Sweater / Sweatshirt Product Weight (grams per unit) *

15ag. Average T Shirt Product Weight (grams per unit) *

15ah. Average Underwear Product Weight (grams per unit) *

15ai. Average Vest Product Weight (grams per unit) *

15aj. Average Other Product Weight (grams per unit) *

16b. Average Bag Product Weight (grams per unit) *

17b. Average Beauty Product Weight (grams per unit) *

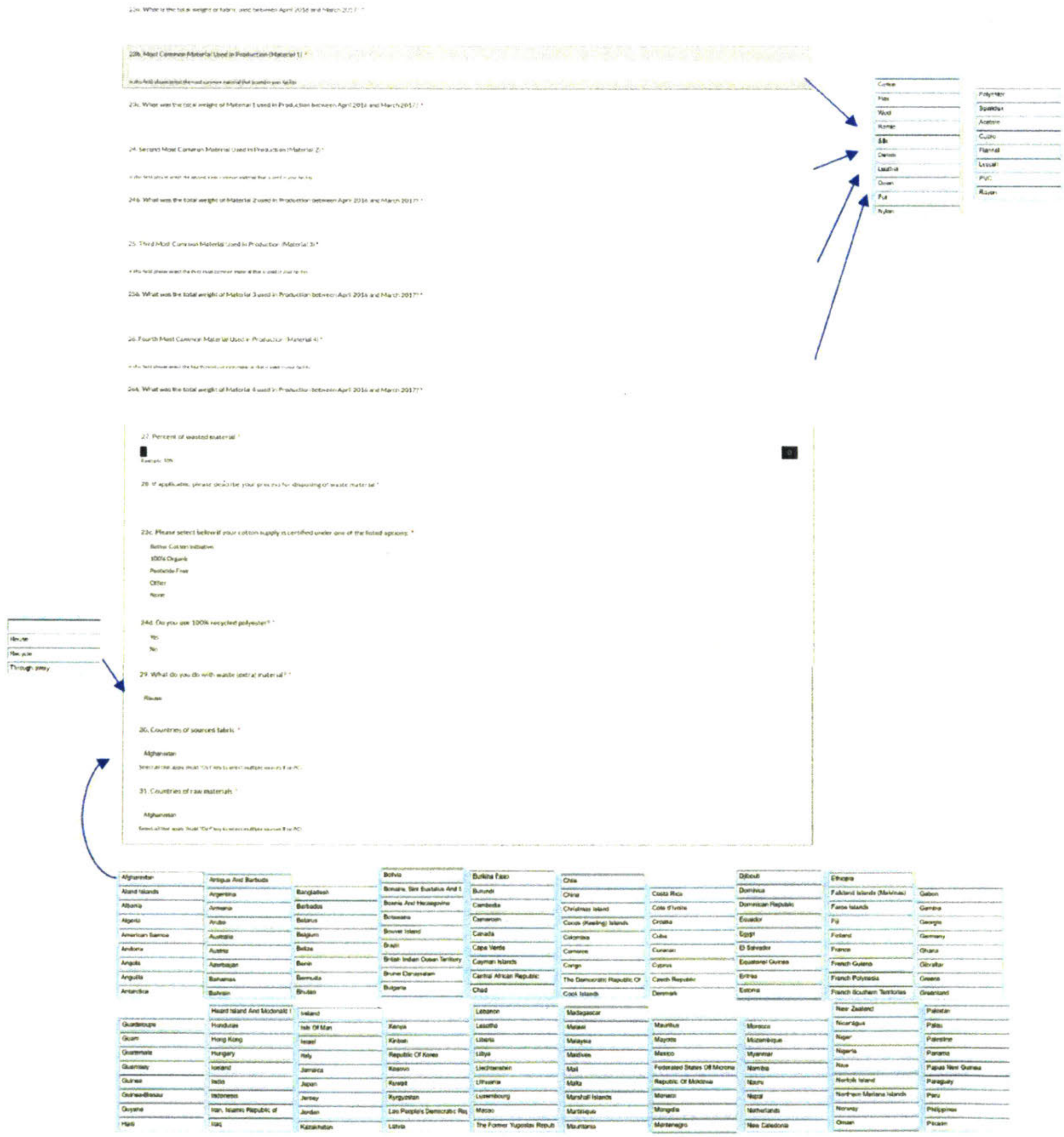
18b. Average Crafts Product Weight (grams per unit) *

19b. Average Fabric Product Weight (grams per unit) *

20b. Average Accessory Product Weight (grams per unit) *

21b. Average Footwear Product Weight (grams per unit) *

22b. Average Home Textile Product Weight (grams per unit) *


23a. What is the total weight of fabric used between April 2016 and March 2017? *
23b. Most Common Material Used in Production (Material 1) *
23c. What was the total weight of Material 1 used in Production between April 2016 and March 2017? *
24. Second Most Common Material Used in Production (Material 2) *
24b. What was the total weight of Material 2 used in Production between April 2016 and March 2017? *
25. Third Most Common Material Used in Production (Material 3) *
25b. What was the total weight of Material 3 used in Production between April 2016 and March 2017? *
26. Fourth Most Common Material Used in Production (Material 4) *
26b. What was the total weight of Material 4 used in Production between April 2016 and March 2017? *
Cotton
Flax
Wool
Silk
Denim
Leather
Down
Fur
Nylon
Polyester
Spandex
Acetate
Cupro
Flannel
PVC
Rayon
27. Percent of wasted material *
[redacted]
28. If applicable, please describe your process for disposing of waste material *
23c. Please select below if your cotton supply is certified under one of the listed options: *
Better Cotton Initiative
100% Organic
Pesticide Free
Other
None
24d. Do you use 100% recycled polyester? *
Yes
No
Reuse
Recycle
Through away
29. What do you do with waste (extra) material? *
Reuse
30. Countries of sourced fabric *
Afghanistan
31. Countries of raw materials *
Afghanistan
Afghanistan
Aland Islands
Albania
Algeria
American Samoa
Andorra
Angola
Anguilla
Antarctica
Antigua And Barbuda
Argentina
Armenia
Aruba
Australia
Austria
Azerbaijan
Bahamas
Bahrain
Bangladesh
Barbados
Belarus
Belgium
Belize
Benin
Bermuda
Bhutan
Bolivia
Bosnia And Herzegovina
Botswana
Bouvet Island
Brazil
British Indian Ocean Territory
Brunei Darussalam
Bulgaria
Burkina Faso
Burundi
Cambodia
Cameroon
Canada
Cape Verde
Cayman Islands
Central African Republic
Chad
Chile
China
Christmas Island
Cocos (Keeling) Islands
Colombia
Comoros
Congo
The Democratic Republic Of
Cook Islands
Costa Rica
Cote d'Ivoire
Croatia
Cuba
Curacao
Cyprus
Czech Republic
Denmark
Djibouti
Dominica
Dominican Republic
Ecuador
Egypt
El Salvador
Equatorial Guinea
Eritrea
Estonia
Ethiopia
Falkland Islands (Malvinas)
Faroe Islands
Fiji
Finland
France
French Guiana
French Polynesia
French Southern Territories
Gabon
Gambia
Georgia
Germany
Ghana
Gibraltar
Greece
Greenland
Guadeloupe
Guam
Guatemala
Guernsey
Guinea
Guinea-Bissau
Guyana
Haiti
Heard Island And Mcdonald I
Honduras
Hong Kong
Hungary
Iceland
India
Indonesia
Iran, Islamic Republic of
Iraq
Ireland
Isle Of Man
Israel
Italy
Jamaica
Japan
Jersey
Jordan
Kazakhstan
Kenya
Kiribati
Republic Of Korea
Kosovo
Kuwait
Kyrgyzstan
Lao People's Democratic Re
Latvia
Lebanon
Lesotho
Liberia
Libya
Liechtenstein
Lithuania
Luxembourg
Macao
The Former Yugoslav Repub
Madagascar
Malawi
Malaysia
Maldives
Mali
Malta
Marshall Islands
Martinique
Mauritania
Mauritius
Mayotte
Mexico
Federated States Of Microne
Republic Of Moldova
Monaco
Mongolia
Montenegro
Morocco
Mozambique
Myanmar
Namibia
Nauru
Nepal
Netherlands
New Caledonia
New Zealand
Nicaragua
Niger
Nigeria
Niue
Norfolk Island
Northern Mariana Islands
Norway
Oman
Pakistan
Palau
Palestine
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Pitcairn

Poland		Sao Tome And Principe	Slovenia			Turkmenistan		
Portugal	Saint Helena, Ascension And	Saudi Arabia	Solomon Islands	Svalbard And Jan Mayen	Thailand	Turks And Caicos Islands	Uruguay	
Puerto Rico	Saint Kitts And Nevis	Senegal	Somalia	Swaziland	Timor-Leste	Tuvalu	Uzbekistan	
Qatar	Saint Lucia	Serbia	South Africa	Sweden	Togo	Uganda	Vanuatu	
Reunion	Saint Martin (French Part)	Seychelles	South Georgia And The Sout	Switzerland	Tokelau	Ukraine	Vatican City State	Wallis And Futuna
Romania	Saint Pierre And Miquelon	Sierra Leone	South Sudan	Syrian Arab Republic	Tonga	United Arab Emirates	Venezuela	Western Sahara
Russian Federation	Saint Vincent And The Grenа	Singapore	Spain	Taiwan	Trinidad And Tobago	United Kingdom	Vietnam	Yemen
Rwanda	Samoa	Sint Maarten (Dutch Part)	Sri Lanka	Tajikistan	Tunisia	United States	British Virgin Islands	Zambia
Saint Barthelemy	San Marino	Slovakia	Suriname	Tanzania	Turkey	United States Minor Outlying	Virgin Islands, U.S	Zimbabwe

Electricity / Power Statistics [Part 4 of 6]

32. Select the energy sources you use (Please only select sources that are used in production, e.g. if a source is only used in the canteen, please do not include) *

Electricity (from the grid)
Diesel (or from Diesel Generator)
Steam (from Boiler)
Natural Gas
Gasoline
Photovoltaic (Solar Panel)
Biomass
Wind Power Generation

32b. Total Electricity (Grid Power) usage from April 2016 through March 2017 in kWh (kilowatt-hours) *

32c. Please provide a picture of your electricity bill from March 2017 *

Choose File No file chosen

32d. Please provide a picture of your electricity bill from February 2017 *

Choose File No file chosen

32e. Please provide a picture of your electricity bill January 2017 *

Choose File No file chosen

32f. Total Diesel usage from April 2016 through March 2017 (liters) *

For example: 2,000 liters

32g. Total Natural gas usage from April 2016 through March 2017 (Btu) *

For example: 2,000,000 Btu

32h. Please provide a picture of your natural gas bill from March 2017 *

Choose File No file chosen

32i. Please provide a picture of your natural gas bill from February 2017 *

Choose File No file chosen

32j. Please provide a picture of your natural gas bill from January 2017 *

Choose File No file chosen

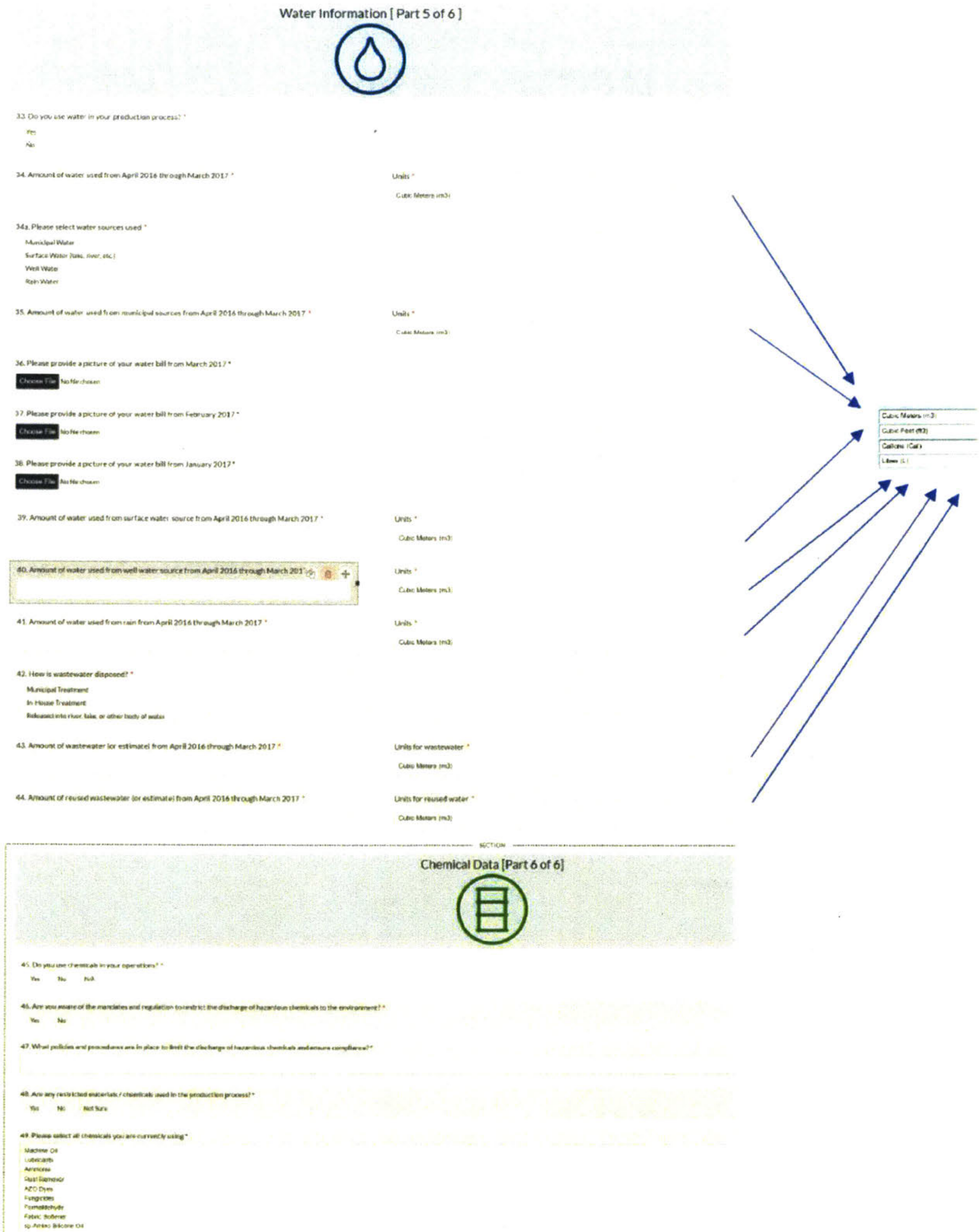
32k. Total Gasoline usage from April 2016 through March 2017 (liters) *

For example: 2,000

32l. Total power generated through Photovoltaic (Solar Panels) from April 2016 through March 2017 in kWh (kilowatt-hours) *

32m. Total power generated through Biomass from April 2016 through March 2017 in kWh (kilowatt-hours) *

32n. Total power generated through Wind Power from April 2016 through March 2017 in kWh (kilowatt-hours) *



Water Information [Part 5 of 6]

33. Do you use water in your production process? *

Yes
No

34. Amount of water used from April 2016 through March 2017 *

Units *
Cubic Meters (m3)

34a. Please select water sources used *

Municipal Water
Surface Water (lake, river, etc.)
Well Water
Rain Water

35. Amount of water used from municipal sources from April 2016 through March 2017 *

Units *
Cubic Meters (m3)

36. Please provide a picture of your water bill from March 2017 *

Choose File No file chosen

37. Please provide a picture of your water bill from February 2017 *

Choose File No file chosen

38. Please provide a picture of your water bill from January 2017 *

Choose File No file chosen

39. Amount of water used from surface water source from April 2016 through March 2017 *

Units *
Cubic Meters (m3)

40. Amount of water used from well water source from April 2016 through March 201

Units *
Cubic Meters (m3)

41. Amount of water used from rain from April 2016 through March 2017 *

Units *
Cubic Meters (m3)

42. How is wastewater disposed? *

Municipal Treatment
In House Treatment
Released into river, lake, or other body of water

43. Amount of wastewater (or estimate) from April 2016 through March 2017 *

Units for wastewater *
Cubic Meters (m3)

44. Amount of reused wastewater (or estimate) from April 2016 through March 2017 *

Units for reused water *
Cubic Meters (m3)

SECTION

Chemical Data [Part 6 of 6]

45. Do you use chemicals in your operations? *

Yes No N/A

46. Are you aware of the mandates and regulation to restrict the discharge of hazardous chemicals to the environment? *

Yes No

47. What policies and procedures are in place to limit the discharge of hazardous chemicals and ensure compliance? *

48. Are any restricted materials / chemicals used in the production process? *

Yes No Not Sure

49. Please select all chemicals you are currently using *

Machine Oil
Lubricants
Ammonia
Rust Remover
AZO Dyes
Fungicides
Formaldehyde
Fabric Softener
sp-Amino Silicone Oil

Cubic Meters (m3)
Cubic Feet (ft3)
Gallons (Gal)
Liters (L)

Please sign below and continue to next page to provide your feedback

Kindly sign then click submit *

Signature

SECTION

Survey Tool Feedback

46. We are always looking for your thoughts on how we can improve. In the following section, I have provided a few brief questions to capture your feedback. If you have the time, please complete as your feedback is integral to future improvements to this tool.

	Very Satisfied	Satisfied	Neutral	Unsatisfied	Very Unsatisfied
How would you rate the overall experience?					

47. What would you recommend to improve the tools and where did you face difficulties? *

Thank you!

Your feedback is appreciated! We will use the data to improve sustainability practices!

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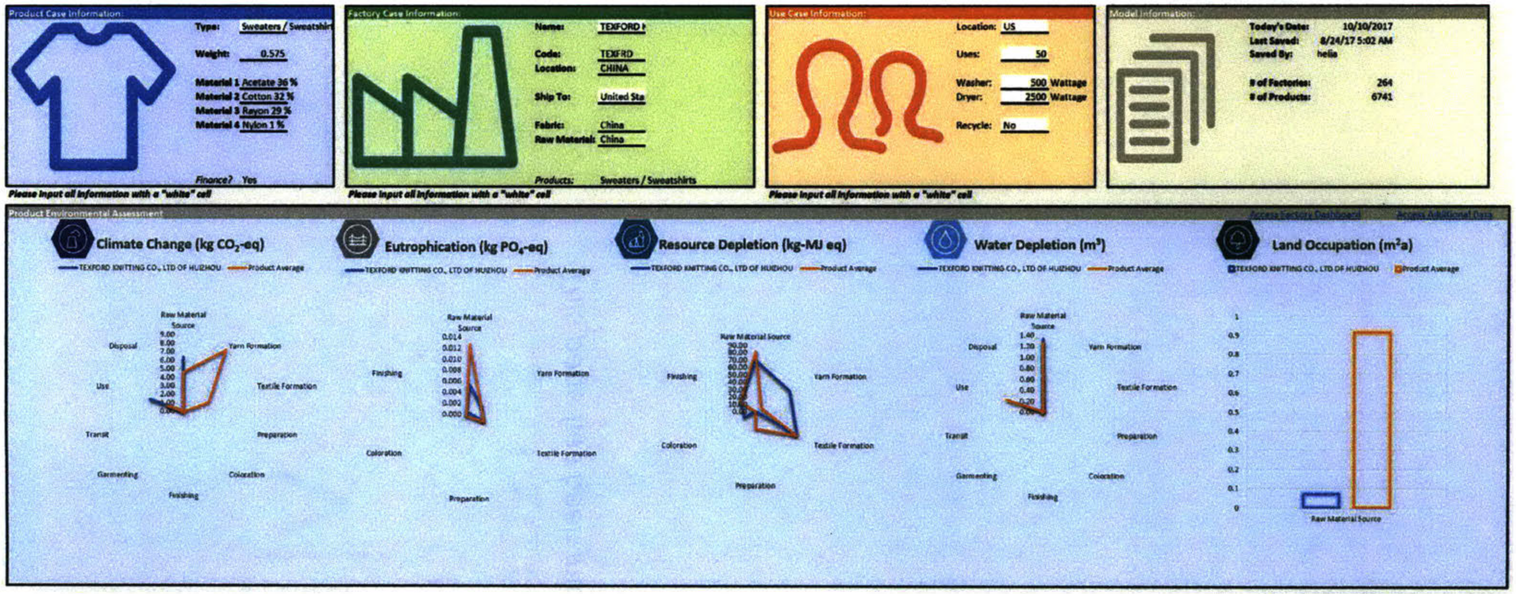
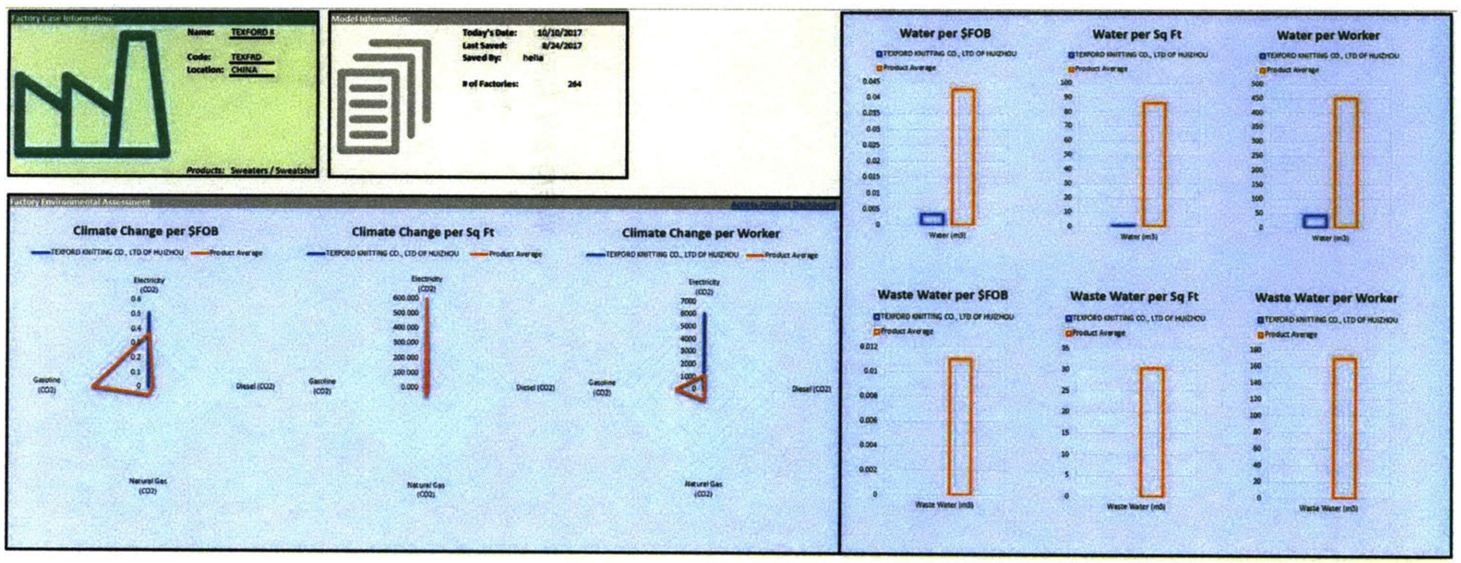
Appendix 8.3: Product & Factory Environmental Assessment Tool





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