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Wilson College of Textiles

JTATM
Journal of Textile and Apparel, Technology and Management

Volume 11, Issue 1, 2019

Quantifying Apparel Consumer Use Behavior in Six Countries: Addressing a Data Need in Life Cycle Assessment Modeling

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ABSTRACT

The consumer use phase of a product life cycle often creates a significant portion of the environmental burdens and in many cases the consumer use environmental impacts can be reduced with small behavioral changes. Due to hot water washing and mechanical drying, the apparel consumer use phase has been recognized as an environmental hotspot significantly contributing to multiple impact categories. Despite the importance of this phase, there is a lack of data describing apparel consumer use behavior that is fundamental to perform comprehensive LCAs. To address this need, consumer data was collected from over 6,000 global respondents spanning China, Germany, Italy, Japan, the United Kingdom and the United States characterizing the use of T-shirts, knit collared shirts and woven pants. A particularly significant variable required for LCA is the total washes per lifetime, for which global averages were determined to be 17.3 washes, 22.2 washes and 23.5 washes for T-shirts, knit collared shirts and woven pants, respectively, with substantial inter-country variation. In addition, clothing lifetime was examined and respondents reported an average first-life use period of 37 months, 40 months and 42 months for T-shirts, knit collared shirts and pants, respectively. Washing water temperature and machine technologies are reported and vary by country. Clothes drying methods were also examined and respondents reported high machine drying rates in the United States (73%) and less than 13% in all other nations. For garment end-of-life fate, Asian countries reported higher values of clothing disposal while European countries and the United States reported more donations to charity. This publication provides robust consumer use data by country and on global levels that can be used in future LCAs and other apparel research. Additionally, these data can be used to benchmark current laundering technologies and identify consumer use behavior changes that could reduce the environmental impacts of apparel.

Keywords: Textile consumer use, sustainability, LCA, washing, drying, laundering, greenhouse gas

1. Introduction

1.1 Trends in Apparel Consumption and Production

The apparel industry experienced significant changes in the last 15 years that continue to affect manufacturers, consumers and the environment. These changes are evident both in retail stores and data from the apparel industry. McKinsey (2016) demonstrates that from 2000 to 2014, global

production of clothing doubled and along with this increase, consumer unit sales of garments increased by 60 percent. These drastic increases in production volume and decreases in garment ownership time can be explained in part by consumer demand for *Fast Fashion* items, i.e. apparel manufactured at higher production rates and often at lower costs (Cachon & Swinney, 2011; Cook & Yurchisin, 2016). Fast-fashion is often made with lower quality materials, simple construction, and less quality controls, resulting in products with decreased durability. Consumers gravitate toward fast-fashion items as they satisfy their need for on-trend and fashion forward statement pieces and don't always consider the environmental impact (Zarley & Yan 2013; McNeill & Moore, 2015). This trend is inherently unsustainable as it emphasizes disposable, low durability, low quality garments that in many cases consume non-renewable resources and create immense amounts of waste (Siegle 2011; Cline 2012; and Albeniz & Victor, 2014)

With changing consumer preferences demanding fashion at low prices, manufacturers have shifted to cheaper materials such as polyester, Figure 1. From 1980 to 2014, total fiber demand increased by approximately 55.7 million tons, with polyester accounting for 73.4% of the increase (Textile World, 2015). This increased use of polyester has implications for the environment. Kirchain et al. (2015) reports the greenhouse gas emission and equivalent global warming potential of a T-shirt made from polyester to be 5.5 kg $CO_{2\,eq.}$, which is approximately 2.6 times higher per T-shirt compared to one made of cotton (Kirchain et al., 2015). Using the Sustainable Apparel Coalition's LCA tool, the Higg Index, to compare materials on a per kg basis, the global warming potential (GWP) of cotton and polyester are reported to be less different with cotton having approximately 20% higher GWP impacts (Sustainable Apparel Coalition, 2016). The Higg Index GWP calculation, however, does not account for the carbon absorbed during cotton plant growth that will be in part stored in landfills or in other uses beyond the 100-year time horizon (Lippke et al., 2010). Including this carbon absorption and retention beyond the 100-year time horizon reduces the cradle-to-grave GWP of cotton garments, but does not reduce the GWP of synthetic garments as they are oil derivatives that do not sequester carbon from atmosphere during production. When including fossil fuels used in polymer production for both materials globally, Kirchain et al. (2015) estimates that cotton produces 98 billion kg CO_2 eq. and polyester clothing produces 282 billion kg CO_2 eq.

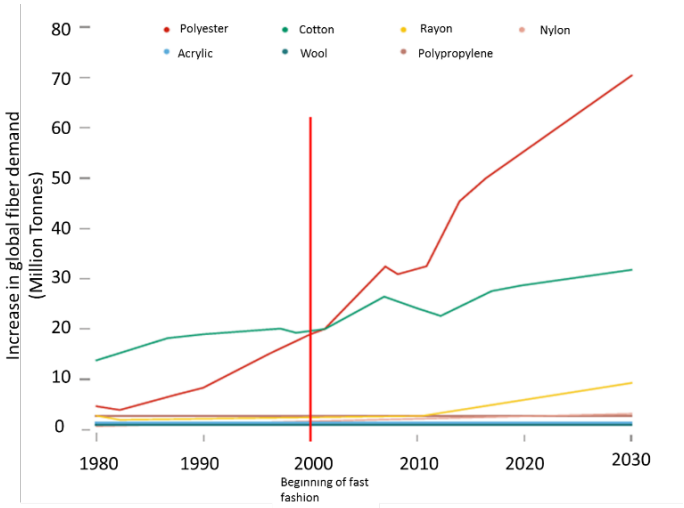

Figure 1. Increase in global fiber demand in million tonnes. Note: Only 43% of these textile fibers are associated with apparel production (adapted from: Textile World, 2015; Cobbing & Vicaire, 2016)

The environmental impacts of apparel are not only associated with material production. The consumer use and post consumer use phases of a garment life cycle have been shown to have significant environmental impacts as well (Golden et. al., 2010; Subramanian & Golden, 2015). These impacts have been documented by peer-reviewed literature, industry reports and ISO 14044 certified LCA studies (Cotton, 2012; Cotton, 2017; Levi Strauss & Co., 2013). The key factors driving the environmental impacts of the consumer use phase are number of uses, laundering frequency, washing methods, drying methods and end-of-life fate. In addition to these factors, an emerging field of study surrounding microfiber pollution in water bodies has indicated that microfibers from laundering synthetic apparel are a major source of this form of pollution (Napper & Thompson, 2016).

1.2 Consumer Use Microfiber Emissions

An important factor associated with increased synthetic apparel use is the creation of microfiber plastics during consumer laundering. Microfiber pollution has recently come to popular attention with articles in *Science* and other major journals discussing the sources and their unknown, but potential, associated environmental and human health impacts (Napper & Thompson, 2016; Andrady, 2011; Browne et al., 2011; Cole et al., 2011; Law & Thompson, 2014). According to Browne (2011), plastic debris less than 1 mm in the longest dimension are considered microplastics and are accumulating in marine habitats and aquatic life. Apparel laundering was shown to be a significant source of these microplastics as microfibers, where Browne et al. (2011) determined that a single garment can produce more than 1,900 microfibers per wash. Fibers from polyester and acrylic materials were found in the ocean and municipal waste effluent streams, which led scientists to suspect synthetic apparel as a major contributor to the microfiber pollution issue (Browne et al., 2011; Napper & Thompson, 2016).

Further analysis of apparel laundering scenarios with multiple fabric types and washing conditions has shown that 700,000 fibers could be released in washing machine effluent for each 6 kg load of acrylic fibers (Napper & Thompson, 2016). This same study also indicated that polyester fabric could release 496,000 microfibers per 6 kg wash. Interestingly, when polyester was blended with cotton fibers (70% polyester and 30% cotton) the number of microfibers released was reduced by 72% (Napper and Thompson, 2016). Additionally, washing conditions exhibited a significant effect on the microfibers released, although Napper & Thompson (2016) indicated that more research needs to be performed to fully understand the impacts of washing conditions on fiber releases.

The microfibers released during clothes laundering are making their way to the ocean, presenting a major threat to aquatic ecosystems (Browne et al., 2011). Data characterizing consumer use laundering conditions and frequency is needed to quantify the impacts of apparel microfibers emissions.

1.3 Life Cycle Assessment Methodology

Life cycle assessment (LCA) is the accepted methodology for quantifying the environmental impacts of a product service or good across the various stages of its life cycle (ISO 14044, 2016; Daystar & Venditti, 2017). This methodology uses four phases: defining goal and scope, life cycle inventory analysis, life cycle impact assessment, and interpretation. The goal and scope phase clearly defines what the functional unit of the analysis is, such as a T-shirt, as well as the life cycle stages of interest. The goal and scope also defines the intended use and audiences of the final study. The next phase, life cycle inventory analysis, tabulates the inputs from nature and outputs to nature. Water use, energy, water effluent, and CO_2 emissions are all types of inventory flows that are measured and reported in the life cycle inventory phase. The life cycle impact assessment phase relates the environmental flows to the potential to impact the

environment. The interpretation step of the LCA method is not necessarily the last step, rather it is performed throughout the process allowing the researcher to learn from the study and modify the other aspects to meet the changing needs of the study and the data that is available for the study.

The LCA method has been used extensively to quantify the environmental impacts of numerous apparel items and other materials (Cotton, 2012; Cotton, 2017). These studies can use different scopes to examine the environmental impacts, however, cradle to grave studies including raw material manufacturing, garment manufacturing, consumer use, and product end of life are most comprehensive, Figure 2. Due to the inclusive nature of the cradle to grave LCA method, data describing all studied life cycle stages is required. This manuscript provides data required to perform the consumer use and end of life phases of apparel LCA that is not currently avaialbe in literature. Additional literature describing the LCA methodology can be found in literature (Daystar & Venditti, 2017).

Figure 2. Cradle to grave life cycle assessment framework for apparel (Cotton, 2017)

1.4 Study Goals

Apparel life cycle environmental impacts are greatly influenced by consumer laundering behavior, yet there is limited data available characterizing consumer use behavior (Roos et al., 2015). This research aims to fill the knowledge gap surrounding the consumer use behavior for T-shirts, woven causal pants and knit collared shirts for six countries including China, Germany, Italy, Japan the United Kingdom and the United States. To fill this knowledge gap, a consumer use survey was developed by Cotton Incorporated's Director of Market Research and implemented by a third-party market research company. A copy of the survey is provided in Appendix A, for reference. The objective of this research is to help inform future LCAs focused on apparel and to help product designers consider the full life cycle of products, which could lead to designs with lower environmental impacts.

2. Research Methodology

2.1 Survey Administration

Consumer use behavior data were collected by an international third-party market research company surveying respondents in the uppermost fraction of apparel-consuming countries regarding their use and laundering practices for T-shirts, knit collared shirts and woven pants. The survey was conducted from May through June 2015 in six countries including the China, Germany, Italy, Japan the United Kingdom and the United States. In the United States, Japan, Italy, the United Kingdom and Germany the survey was a self-administered, quantitative, online survey using the research company's multi-million member panel as well as their certified partner panels. Panel

member invitations were sent via email and were demographically balanced to the population of each country. Panel members were required to answer screening questions to ensure that they qualified for participation. Qualification for participation ensured respondents:

- Were age 18+;
- Were a resident of the US, UK, Germany, Italy, Japan, or China;
- Owned at least one T-shirt, one polo shirt, and one pair of casual slacks;
- Machine or hand washed their own T-shirts, polo shirts, or casual slacks.

Prior to full survey implementation, a pilot survey was administered to a small random batch of respondents (aiming for 10% of the total completes for the study). The pilot survey was reviewed and approved by Cotton Incorporated's Director of Market Research in the Consumer Marketing Division, prior to implementation. The pilot survey was used to ensure that the electronic questionnaire functioned as designed and that data quality was consistent throughout the survey implementation period. Data quality was verified using a software application designed specifically for data validation and tabulation which checked the questionnaire for: question basing (e.g., answered by respondents who should have, and blank for those who should not), question typing (e.g., single select, checkbox, verbatim, numeric), number of answers (e.g., a "pick 3" question contained 3 answers, or "exclusive" answers were not selected with others), logical consistency (e.g., percentages must add up to 100%), face validity of the responses (do the responses make sense), and adherence to priority picking schemes. This data check was reran with every data extraction and reporting cycle to ensure consistent quality throughout the questionnaire fielding period and in final reporting. No major modifications were required to the pilot survey prior to full survey implementation.

An internet-only methodology was used for those countries having 60% or greater internet penetration. In order to secure a representative sample in China, a mixed mode methodology was used, which included 40% self-administered online surveys and 60% face-to-face interviews. The questionnaires were similar across countries, with minor differences to account for cultural distinctions.

Approximately 1,000 consumers were surveyed per country with a total sample of just over 6,000 respondents, Table 1. Respondents were ages 18 and older and were representative of each country's demographics. In order to qualify for the survey, respondents had to own at least one T-shirt, one knit, collared shirt and one pair of woven pants. Each respondent had to wear and launder (hand or machine wash) their own garments. These survey requirements may introduce some bias into the sample, however, they were necessary to obtain a complete dataset for each garment type.

Table 1. Consumer Use Phase Survey Responses by Country

Country	Respondents
China	1,003
Germany	1,005
Italy	1,004
Japan	1,000
United Kingdom	1,014
United States	1,015

2.2 Garment Types

The survey collected data on consumer use behavior for three types of clothing: T-shirt, knit collared shirt and woven pants. These three types of clothing, shown in Figure 3, were displayed in pictures to the survey respondents to insure their ownership of each garment. Using garment pictures as a guide was necessary to increase clarity of the study. Jeans are explicitly excluded from the sample, due to unique use behaviors associated with denim garments. For example, some consumers avoid washing jeans to preserve coloring and to create a "distressed" jean aesthetic (Levi Strauss & Co., 2016).

Figure 3. Clothing types surveyed showing woven pants, knit collared shirts, and T-shirts from left to right as presented in the survey.

2.3 Respondent Demographics

The respondent demographics for each country and as a whole were representative of the population, Figure 4. There were approximately 4% more female respondents than male respondents on average. The age demographics were separated into eleven age classes. The over-65 age class was an open-ended age group and reported the highest level of respondents, except in China and Italy.

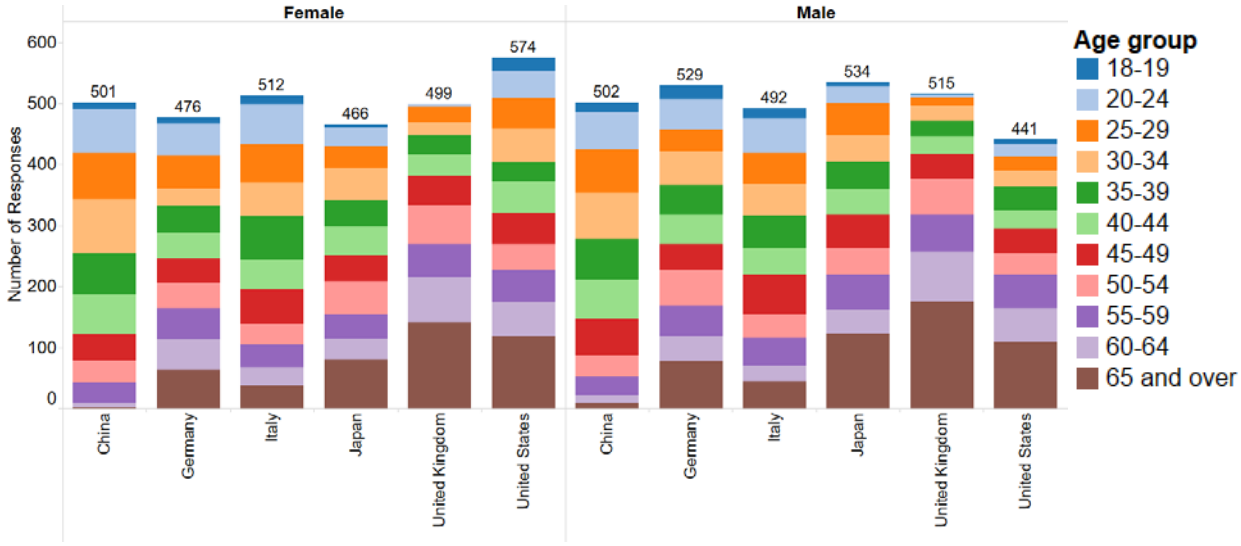

Figure 4: Respondent demographics by country, age class, and gender

3. Results and Discussion

3.1 Consumer Use Behavior

3.1.1 Garment Ownership

Garment ownership is an important metric when determining the overall usage patterns. This study inquired about the number of garments owned and not the number of items purchased per year. Of the surveyed countries, U.S. respondents reported the highest ownership of T-shirts and woven pants while the Italian respondents owned more knit collared shirts, Table 2. China and Japan both reported the lowest number of garments for all categories. Smaller living space, and thus closet space, of households in China and Japan could explain the lower ownership numbers for these garments (OECD, 2016). Additionally, income levels and cultural practices may also influence garment ownership levels. As a global average (the average of the surveyed countries), respondents owned 8.2 pairs of woven pants, 9.1 knit collared shirts, and 15.3 T-shirts. Comparison with the literature is difficult due to past study's focus on consumer rates of purchase opposed to rates of ownership. For example, a previous UK study reports purchase rates of approximately eight T-shirts per year, compared to the higher ownership statistic (15) indicated in this survey data (Allwood et al., 2006).

Table 2: Garment ownership by country and garment type

Items owned	China	Japan	United Kingdom	Germany	Italy	United States	Global Average
T-shirts	7.0	12.8	15.0	18.9	17.5	20.5	15.3
Woven pants	6.4	6.8	8.0	8.2	9.8	10.2	8.2
Knit Collared shirts	5.8	8.1	8.7	9.2	12.7	10.2	9.1

3.1.2 Product Lifetime

The number of uses the consumer achieves within the garment lifetime plays an important role in the overall garment life cycle environmental impacts. As the number of uses associated with the garment increases, the manufacturing burdens associated with the production of the garment will be distributed over a greater number of uses, lowering the overall impacts per use of the garment (Allwood et al., 2006). This statement assumes a Life Cycle Assessment (LCA) functional unit of one use of the garment, similarly seen in Roos et al. (2015).

However, some studies choose other functional units such as the total impacts of the garment type (Cotton, 2012; Cotton, 2017). If a functional unit of total impacts per garment is used, the environmental impacts of the garment would increase with increasing uses, however, this functional unit can be misleading when considering the true service or function the garment provides. Using garments for longer periods of time, both in first ownership and subsequent ownerships, can reduce the environmental impacts of apparel consumption (Allwood et al., 2006). Therefore, using the garment for a shorter period of time and replacing it more frequently, as associated with the fast fashion trend reported by McKinsey, would result in greater environmental impacts. Studies show that an average person purchases 60% more clothing and keeps the clothing for half as long compared to 15 years ago (Cobbing & Vicaire, 2016; McKinsey, 2016). McKinsey also reports that some consumers treat low-priced garments as "nearly disposable," only using them seven or eight times (McKinsey, 2016).

Subjects were surveyed using the garment lifetime as the frame of reference. The garment lifetime refers to the number of years respondents used a garment in a "standard" way. Thereby excluding secondary garment use such as a shop rag, or the use after being resold or given to a second consumer. There was considerable variation among countries' average lifetime of use; China reported the lowest years of use while the U.S. reported the highest, Table 3. The use lifetime trends for the different apparel types were generally consistent when comparing countries. T-shirts usually reported the lowest lifetime in years of use, followed by knit collared shirts and woven pants.

Table 3. Garment lifetime measured in years of use by country and garment type

Years of first use	China	Germany	Italy	Japan	United Kingdom	United States	Global Average
T-shirt	1.3	2.7	2.9	3.3	3.8	4.5	3.1
Knit Collared Shirt	1.6	2.9	3.1	3.8	3.9	4.4	3.3
Woven pants	1.6	3.2	3.3	4.4	4.0	4.6	3.5

Respondents were also asked to indicate the material primarily comprising the garment that lasted the longest, Table 4. Respondents were provided with three material types: cotton, polyester and rayon. On average, 54% of respondents indicated that clothing made of cotton lasted the longest. Italy and Germany reported the highest levels for this measure at 63% and 62%, respectively. Japan reported the lowest percentage with the perception of cotton lasting the longest at 39%. In all countries except Japan, cotton was ranked as lasting the longest followed by polyester and then rayon. Since garment lifetime can play a significant role in the cradle-to-grave environmental impacts, using materials that extend product lifetimes is important in minimizing the environmental impacts of apparel. Based on the consumer data, cotton apparel indicates a longer lifetime compared to polyester and rayon, thereby reducing the garment cradle-to-grave environmental impacts for garments constructed of cotton fiber. It is important to note that consumers' indication of which material lasts the longest may not be a function of material physical performance, rather, it may be dependent upon the appearance, odor retention, sentimental value or other parameters beyond structural integrity.

Table 4. Consumer response to materials lasting the longest in garment use

Last the longest	China	Japan	Italy	Germany	United Kingdom	United States	Global Average
Clothing made primarily of cotton	50%	39%	63%	62%	59%	50%	54%
Clothing made primarily of polyester	28%	43%	19%	23%	22%	31%	28%
Clothing made primarily of rayon fibers	21%	19%	18%	15%	20%	19%	19%

3.1.3 Uses Before Laundering

Another important factor in determining laundering consumer use behavior is the number of times a person uses the garment before washing. Consumers with a higher number of uses per washing will create lower environmental impacts during the use phase of the garment. There has even been a trend among denim jean owners to forgo laundering jeans for an extended period of time and instead opt to freeze the jeans to reduce odors for subsequent uses (Levi Strauss & Co., 2016). Levi suggests not washing their jeans but rather freezing them once a month to extend the jean lifetime and reduce environmental impacts (Levi Strauss & Co., 2016). This idea of reducing the number of garment launderings in part stemmed from an LCA that Levi performed in 2013 which determined that a significant portion of overall environmental impacts resulted from the use phase (Levi Strauss & Co., 2013). In response, they began a campaign to change the way in which consumers used their product.

For the garment types examined in this work, there is no such known consumer practice of forgoing washing for freezing clothing, however, the data show that many garments are used numerous times before laundering, Table 5. For T-shirts, the average days worn before laundering was the lowest and most consistent among the three garment types, ranging from 1.6 to 2.4 average days of wear before laundering for the United States and China, respectively. The global average days worn before washing for a T-shirt was 1.94 days. T-shirts are often worn as undershirts (or as a first layer) and used during more rigorous activities that would result in perspiration, which could lead to more frequent launderings. Similarly, Roos et al. (2015) reported T-shirts wear frequency in Sweden as twice before laundering.

Knit collared shirts indicated higher average days worn and greater variation among countries compared to T-shirts. For knit collared shirts, the average days worn ranged from 1.8 to 3.02 for the United States and China, respectively. The global average days worn for knit collared shirts was determined to be 2.23 days.

The average days before washing pants had the largest inter-country variation as well as the highest values. The average number of days consumers used pants before laundering ranged from 3.05 to 7.1 for the United States and Japan, respectively. The global average days worn before the laundering of pants was 4.86 days.

Table 5. Number of days wear before laundering by country

Days worn before laundering	China	Germany	Italy	Japan	United Kingdom	United States	Country Average
T-shirt	2.4	1.9	2.0	1.8	1.9	1.6	1.9
Knit Collared Shirt	3.0	2.2	2.3	2.2	1.9	1.8	2.2
Woven Pants	4.3	5.5	4.2	7.1	5.1	3.0	4.9

Another factor which may influence the number of days worn prior to laundering is the material type. In this study, consumer use behavior was not captured by material type. However, research suggests that fabric type can influence the level of odor during and after garment use. McQueen et al. (2014) determined that polyester T-shirts had higher odor intensity after 20 uses during exercise over a ten-week period. In the same study, polyester T-shirts showed a buildup of odors after washing, while cotton T-shirts did not. For both garment types, laundering did decrease the odor intensity, however, odor build up was apparent after launderings for polyester. This odor build up could influence consumer laundering behavior, as more than one wash may be required to fully remove odors. For the same reason, consumers may discard polyester garments earlier. Increased laundering due to odor accumulation would increase the life cycle energy use and environmental impacts of T-shirts and other garments. Further research should be performed to determine laundering behavior by fabric type to fully explore the influence of material type and odor accumulation's impacts on consumer use behavior.

3.1.4 Launderings per Garment Lifetime

The total number of washes per garment lifetime is an important metric in the cradle-to-grave environmental impacts of clothing. The number of launderings occurring over the course of a garment's lifetime is a function of how many days a person uses the garment before washing it, the length of time a person uses the garment and the frequency of use of the garment. In this survey, the number of launderings per lifetime of a single garment was not directly queried, rather it was calculated from other variables as described by the below equation. This calculation was employed to attain an average number of launderings and to reduce the bias of a consumer using and washing their favorite items more frequently. The average lifetime of the garment in months was multiplied by the number of washes the consumers reported per month, and then divided by the total number of garments owned by type (calculation below).

$$\textit{Washes} \text{ per Lifetime} = \frac{\textit{Lifetime (months)} \times \textit{Washes per Month}}{\textit{Number of Garments}}$$

Data and results from this calculation are listed in Table 6 and in Figure 5.

The data indicated that T-shirts had the lowest number of washes per lifetime followed by knit collared shirts and woven pants, with global averages of 17.3, 22.2 and 23.5 washes per lifetime, respectively. When comparing total washes per garment lifetime by country, Germany consistently reported lowest washes per garment lifetime while Japan reported the highest, Figure 5. Of the three garment types, T-shirts consistently reported the lowest number of washes per lifetime while woven pants generally reported the highest number of washes per lifetime, except in the United Kingdom and China.

In a 2006 LCA study on T-shirt life cycle impacts in the United Kingdom, researchers used an assumed value of 25 laundering cycles for the consumer uses compared to the 17.3 T-shirt launderings as determined by this study. This difference may reflect the general trends of fast fashion manufacturing and of shorter use cycles with

lower priced garments (Allwood et al., 2006). Another study that focused on Swedish consumer use, reported the number of washes for a T-shirt to be only 11 times, however, this data was based on trade flow and population data, rather than consumer surveys (Roos et al., 2015). There are alternate studies that report laundering data based on 'expected technical performance' of a garment that consistently report higher values for all garment types compared to studies that used parameters based on statistics of real consumer behavior (Roos et al., 2017).

Table 6. Calculation of number of launderings per lifetime by garment type. Data based on survey average.

Category	Description	T-Shirts	Knit Collared Shirts	Woven Pants
Lifetime	Average months a garment is owned and worn on a regular basis (first-life)	37.2	39.6	42.0
Washes per month	Average number of washings per month	7.1	5.1	4.6
Number of garments	Average number of garments owned	15.3	9.1	8.2
Washes per lifetime	Total Washings in a Lifetime (first -life)	(37.2x 7.1) / 15.3 = 17.3	(39.6 x 5.1) / 9.1 = 22.2	(42.0 x 4.6) / 8.2 =23.5

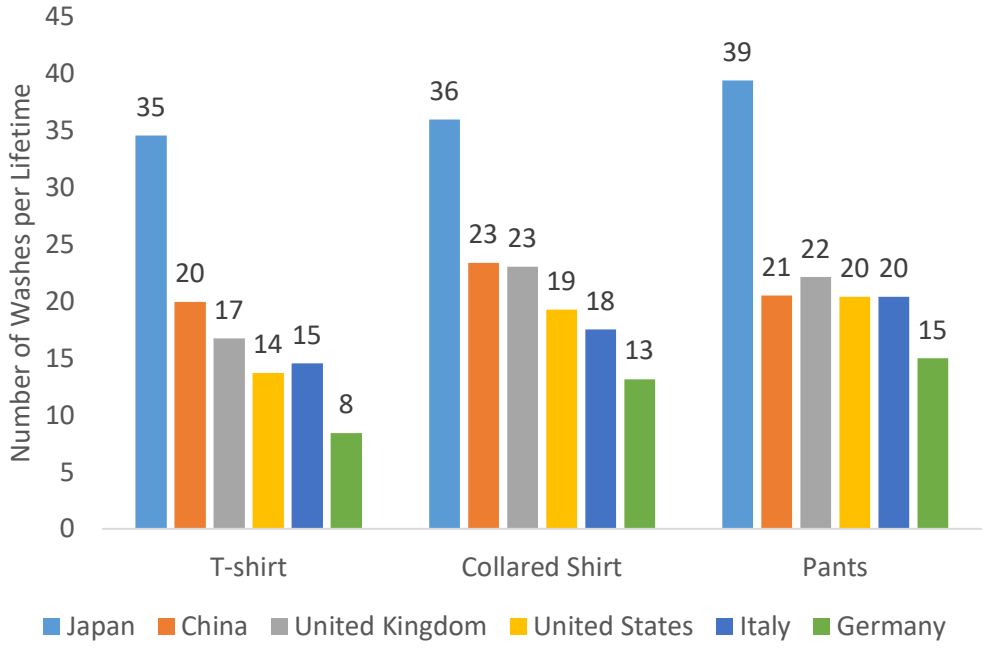

Figure 5. Number of washes per lifetime by country and garment type

3.2 Laundering

Apparel use phase life cycle impacts are recognized as significant and primarily associated with laundering, however, these impacts are difficult to determine (Levi Strauss & Co. 2013). The environmental impacts vary based on a multitude of variables including washing methods, washing technologies, washing settings, drying methods and other potential influences. This section presents key consumer use data required to determine laundering environmental impacts. The data presented here, in conjunction with additional related findings such as Yasin et al. (2016) that examine energy usage during laundering, can be used to determine the overall impacts of apparel laundering.

3.2.1 Washing

3.2.1.1 Washing method

The activity of washing clothing has been demonstrated as a significant contributor to the cradle-to-grave impacts of a garment (Levi Strauss & Co. 2013; Cotton, 2017). As such, it is important for product designers and LCA practitioners to use precise garment specific laundering data whenever possible. The survey results indicated that the predominant global method for washing is through machine use at home, Table 7. Developed nations including Germany, Italy, Japan, the United Kingdom and the United States indicated machine wash rates of 88% or higher. China reported a lower machine wash at home rate of 69% with hand washing accounting for the second most popular method among the Chinese (25%). The lower at home washing rates among the Chinese may be due to traditional cultural practices, lower disposable income, or less household space that can be dedicated to washing machines (Nation Master, 2017). As China further develops and the GDP per capita increases, the machine-washing rate may increase in the future.

Additional methods including dry cleaning, and the use of laundering methods outside of the home were also captured in the survey. The results suggest that dry cleaning use was consistently low, ranging from one to three percent in all examined countries. Use of a laundromat or shared laundry facility was most common in the United States with 8% of respondents reporting use of this method. In contrast, the other countries use of laundromats and shared laundry facility indicated lower frequencies ranging from 1%-2%.

Table 7. Average-washing methods used by country (average washing methods for T-shirt, collared knit shirt and woven pants)

Washing Methods	China	Germany	Italy	Japan	United Kingdom	United States
Machine wash at home	69%	97%	88%	95%	97%	89%
Hand wash	25%	1%	9%	3%	1%	1%
Machine wash in a laundromat or shared facility	2%	2%	1%	0%	2%	8%
Send to the dry cleaner	3%	1%	2%	3%	1%	3%

3.2.1.2 Washing machine type

Washing methods are an important factor in the overall life cycle impacts of apparel items which can be reduced by using more efficient washing machine technology as well as cold wash water (Levi Strauss & Co., 2013). Levi Strauss reported that the impacts of washing could be reduced by 32% when switching from conventional to efficient washing technology for hot water washing. European respondents reported using high efficiency, front-loading machines at rates of 89% or higher, Table 8. The Asian countries of Japan and China also reported relatively high uses of high efficiency, top-loading washing machines with 75% and 48%, respectively. Only the United States reported dominant use of top-loading

machines with an agitator, accounting for 58% of U.S. washing machine type among the sample.

To gain further insights into the washing machine technology reported, Table 8 lists the average electricity price in U.S. dollars (2015) for each country. These electricity prices correspond to the average for the year in which the survey was performed. European electricity prices were on average $0.28 per kWh and European respondents reported over 95% high efficiency washer use (top-load and front-load). Japan with an average price of $0.28 per kWh also reported a high efficiency washer use of 91%. China, with the lowest average electricity price reported of $0.11 per kWh, had high efficiency use of 84%. The United States, with an average electricity price of $0.18 per kWh, reported only 43% high efficiency washing machine use.

The European nations and Japan indicated the highest electricity prices as well as the highest adoption rates of efficient washing machines. Although both China and the United States indicated relatively lower adoption rates of high efficiency washing machines, China, with lower electricity prices (and the lowest overall) compared to the United States, indicated markedly higher adoption rates for high efficiency machines (83%) compared to the US (41%). With steady increases in electricity prices in the US and the promotion of Energy Star products, consumers may be likely to switch from low to high efficiency washing machines, which will ultimately reduce the average environmental impacts of the garment laundering process.

Table 8. Washing machine technologies used and electricity prices by country (Statista, 2016)

Washer type	China	Germany	Italy	Japan	United Kingdom	United States	Country Average
Front Load High Efficiency	35%	90%	89%	16%	98%	24%	59%
Top Load High Efficiency No Agitator	48%	8%	6%	75%	1%	17%	26%
Top Load With Agitator	16%	1%	4%	7%	1%	58%	15%
Electricity price (2015 US $)	0.11	0.33	0.31	0.28	0.21	0.18	0.24

3.2.1.3 Water temperature

Another important factor in the laundering process is the water temperatures selected by the user. In terms of environmental impacts, Levi Strauss & Co. determined that jean washing environmental impacts could be reduced by as much as 28.5% in the United States and 46.0% in China if cold water is used instead of warm water. With laundering representing a large portion of apparel cradle-to-grave impacts for several categories, switching from warm to cold water washing could significantly reduce the overall cradle-to-grave impacts of apparel (Cotton, 2017).

When examining laundering washing temperatures, two temperatures were reported, one for the wash and one for the rinse, Table 9. On average across the countries surveyed, “cold cold” and “warm cold” were reported at 33% each, while “warm warm” was reported at 28%. The other temperature options were used at lower levels. The data suggest a relatively even distribution of water temperatures used across the three temperature variants, however, temperature use by country varied greatly. China and Japan reported the highest use of “cold cold” washing temperatures at 65%, followed by the US (44%) Italians indicated the highest use of “Warm cold" washing temperatures with 58% reporting this choice, while the remaining countries reported warm cold

usage ranging from 19% to 36%. The "warm warm" washing temperature had the highest frequency in the United Kingdom and Germany where 46% and 54% of the respondents used this setting, respectively. In contrast, the other countries reported lower "warm warm" use values ranging from 13% to 24%.

Consumers' wash water temperature preferences can be complex, involving consumer perceptions, energy prices, available detergents and climate conditions (Neff, 2010). With increased energy prices in Europe and globally, greater concern for the environment and more accessibility to detergents designed for colder washing temperatures, increasing numbers of consumers are switching to lower temperature washing (Neff, 2010). Although this study did not examine consumer washing temperature preferences, the countries with the most opportunity to increase adoption of "cold cold" washing methods include Germany, Italy and the United Kingdom. Neff (2010) points out that users in these Western European countries, rely on warm water to kill bacteria and increase cleaning ability, however, given new detergent options which claim to achieve this effect may catalyze adoption of colder wash temperatures.

Additionally, the environmental impacts of wash water temperature are highly dependent on the quantity of water used and where the water is heated. Pakula and Stamminger (2009) report that while Europeans tend to use lower quantities of water per wash cycle on average, they concurrently use higher temperatures. In the same study, the researchers determined that European consumers used 60 liters of water per wash on average compared to 144 liters in the US. Despite the differences in water quantity required for washing, the same study reported energy uses per cycle of 0.95 kWh and 0.43 kWh for Western Europe and the United States, respectively, indicating water temperature as the dominant factor for energy use in laundering. One additional factor that influences energy use during laundering is the source and heating method of the laundering water. In many high efficiency washing machines the wash water is heated within the machine, in conjunction with a central water heating system. This integrated heating system can reduce the energy needed for wash water as losses to plumbing and hot water storage are reduced. In Japan, warm bath water is often used to wash clothing which can reduce both the impacts of water use and also water heating, as the water impacts would either be fully or partially allocated to bathing (Pakula & Stamminger, 2009).

Table 9. Washing machine temperature use by country

Water Temperature	China	Germany	Italy	Japan	United Kingdom	United States	Country Average
Cold Cold	65%	2%	15%	65%	5%	44%	33%
Warm Cold	19%	32%	58%	20%	31%	36%	33%
Warm Warm	13%	54%	24%	14%	46%	14%	28%
Hot Cold	1%	5%	2%	0%	7%	3%	3%
Hot Warm	0%	6%	1%	0%	10%	2%	3%
Hot Hot	0%	1%	0%	0%	1%	1%	1%

3.2.2 Drying

The clothes drying method also represents an important parameter when modeling the environmental impacts of the garment use phase. Line drying uses no fossil fuel energy, while machine drying is energy intensive requiring electricity or natural gas for heat. Roos et al. (2017) state that the energy required for tumble drying can be nearly four times greater than the energy use

required to wash clothing in 40-degree C water. By this logic the researcher suggests that clothes drying represents the most influential variable in consumer laundering energy use. Furthermore, Allwood et al. (2006) determined that tumble drying uses 60% of the use phase energy, and when ironing, tumble drying, and hot water washing were forgone, apparel cradle-to-grave environmental impacts could be reduced as much as 50%. Since laundering, especially drying behaviors, show variation by nation and cultures, data describing behavior for different regions of the world is critical in determining the environmental impacts of laundering and more broadly, apparel.

On average, among this study's data, 70% of the respondents did not use a machine to dry clothing, 18% indicated using a machine only, and 12% indicated using a combination of line drying and machine drying, Table 10. The United States reported the highest level of machine drying at 73% and reported 14% for a combination of air drying and machine drying. The US machine drying percentage was more than six times any other country and represents an obvious opportunity for this country to lower the environmental impacts of their apparel usage. The results suggest that other countries primarily air dried clothing mixed with some use of machine drying. Drying behavior variations among garment types were not suggested by the data, therefore only the garment average is reported in Table 10.

Table 10. Global textile drying methods by drying type and country

Country	Air dry (line, lay flat, drip dry)	In a machine dryer	Combination of machine dryer and air dry
China	80%	3%	17%
Germany	77%	12%	11%
Italy	90%	4%	5%
Japan	91%	3%	7%
United Kingdom	69%	12%	19%
United States	13%	73%	14%
Average	**70%**	**18%**	**12%**

In addition to drying method, the survey asked questions to determine ironing behavior. Ironing is typically performed by an electric device that can consume significant amounts of energy and create environmental impacts resulting from electricity production. Of the countries surveyed, Italy consistently reported the highest level of ironing for all garment types, Table 11. The ironing percentage ranking was consistent among countries for all garment types. Japan reported the lowest level of ironing incidence at 10-15% depending on garment type. When considering these results, note that garment types not included in the study design, such as formal wear, would likely drive ironing rates higher.

Table 11. Percent of respondents reporting ironing use by country and garment type.

Country	T-shirt	Woven Pants	Knit Collared Shirt
Italy	83%	72%	89%
United Kingdom	63%	68%	65%
Germany	51%	50%	57%
China	23%	40%	31%
United States	11%	36%	24%
Japan	10%	23%	15%

3.3 End-of-Life

The end-of-life (EOL) fate is an important aspect of modeling the cradle-to-grave environmental impacts of clothing. Many garments are used for a period of time by the consumer and are discarded in good working condition. With yearly sales of 1.8 trillion dollars, the apparel industry creates a massive quantity of material and subsequent waste (Cobbing and Vicaire, 2016). Where garments end up after their first use is primarily up to the consumer and, to an extent, the options available to the consumer. When garments are given to a second-hand clothing store, the garment may be used for subsequent lives which not only reduces the overall waste associated with clothing, but also reduces the garment production impacts over the product lifetime. According to Cobbing and Vicaire (2016), North Americans purchased on average 16 kgs of clothing in 2014 which if thrown away and not used for subsequent lives, creates large amounts of waste. Due to waste implications of clothing EOL as well as the potential to extend the lives of garments, data describing consumer use behavior and final fate of garments are critical to any apparel LCA and for creating strategies to reduce waste and lower environmental impacts of clothing.

Survey results indicate that EOL fate varied by country and by clothing type. Japan reported the highest levels of disposal to waste managment for all garment types with an average of 63% of surveyed garments thrown away, Table 12. European countries and the United States reported donating more clothing to charity while the Asian countries of China and Japan threw more clothing away. The United States reported the lowest level of garment disposal to waste managment, an average of 12%, and the highest level of donation after use for all garment types except for the T-shirt, Table 12. The reuse of T-shirts for rags and other purposes was the highest of the three garment types with a cross country average of 24%. Woven pant and collared knit shirt reuse country averages were 9% and 13%, respectively. China consistently reported higher levels of donating garments to charity or giving garments to a friend with reported averages of 13% and 20%, respectively. The lowest reported EOL options (in ascending order) were recycling, selling clothing, keeping clothing in a closet, and giving to a friend.

Table 12: End-of-life fate by country and country average[1]

	Country	Donate to charity	Give them away (to a friend or as hand-me-downs)	Keep them (in closet or	Re-use or use them in a different	Recycle/Clothes recycling bin	Sell them	Throw them away
Knit Collared Shirt	China	14%	22%	14%	16%	0%	3%	32%
	Germany	55%	9%	9%	10%	0%	6%	12%
	Italy	50%	11%	8%	19%	0%	3%	9%
	Japan	4%	3%	8%	14%	0%	8%	62%
	United Kingdom	56%	2%	4%	13%	2%	3%	21%
	United States	66%	7%	4%	7%	0%	6%	10%
	Country Average	**41%**	**9%**	**8%**	**13%**	**0%**	**5%**	**24%**
Woven Pants	China	13%	19%	16%	12%	0%	2%	37%
	Germany	54%	10%	11%	7%	0%	5%	13%
	Italy	52%	12%	9%	14%	0%	2%	11%
	Japan	5%	3%	9%	8%	0%	9%	66%
	United Kingdom	58%	2%	5%	7%	1%	3%	23%
	United States	67%	6%	4%	5%	0%	7%	11%
	Country Average	**42%**	**9%**	**9%**	**9%**	**0%**	**5%**	**27%**
T-shirt	China	12%	18%	13%	21%	0%	3%	34%
	Germany	47%	8%	7%	20%	0%	4%	13%
	Italy	41%	9%	7%	31%	0%	1%	10%
	Japan	3%	2%	7%	22%	0%	6%	60%
	United Kingdom	47%	2%	4%	22%	2%	2%	21%
	United States	44%	6%	4%	26%	0%	4%	16%
	Country Average	**32%**	**8%**	**7%**	**24%**	**0%**	**3%**	**26%**
	Average All	**38%**	**8%**	**8%**	**15%**	**0%**	**4%**	**26%**

[1]EOL fate by country results are rounded and may not sum to 100%.

4. Conclusions

This work determined consumer use phase behavior of T-shirts, knit collared shirts and woven pants based on survey data from more than 6,000 consumers from China, Japan, Germany, Italy, the United Kingdom and the United States. An understanding of apparel consumer use behavior is fundamentally important to a variety of stakeholders including LCA practitioners and apparel marketers, sustainability and energy analysts and textile manufacturers. This work is the first of its kind representing a comprehensive analysis of apparel use in peer-reviewed literature. Empirical results from this analysis of cross-cultural consumer use behavior for apparel provide a foundation for understanding potential environmental impacts introduced by global apparel consumption.

In general, the data suggests that consumer use behavior is unique in different countries and by garment types. Important parameters surrounding how long consumers keep clothing, number of items owned, washing technology used, drying behavior

and end-of-life fate should be incorporated into environmental studies when possible, instead of using proxy data or assumptions to infer these behaviors. There are also numerous factors that can potentially influence consumer use behavior that are unique to different cultures and countries. Examples of such factors include: availability and price of energy, water and laundering equipment. With the inclusion of the primary data collected in this survey, LCA studies will more accurately calculate the environmental impacts of clothing use and end-of-life. More accurate apparel consumer use and LCA data will provide designers and textile engineers with a better understanding of where the environmental impacts of their products originate and can help inform designs to minimize these impacts. Additioanly, the availability of consumer use data would enable the addition of the consumer use life cycle phase to existing sustainability indexes, such as the Higg.

These data also support that the consumer plays an important role in the environmental impacts of their clothing. Buying clothing second hand, fixing older clothing, washing less, air drying and passing old clothing on for a second use are some of the key behaviors consumers can do in order to reduce their impacts on the environment. Additionally, purchasing clothing made of fibers that last longer and garments that have better build quality can reduce the environmental impacts. In this survey, more than half of the respondents indicated that fabric made of cotton lasted longer than polyester and rayon. This perception could be related to higher quality clothing using greater levels of cotton or the willingness for consumers to wear cotton clothing for a longer period of time.

Though the data provide important initial insight into cross-cultural consumer apparel use behavior, the inherent limitations of the country sub-samples should be considered when generalizing the results beyond the study's empirical scope. Demographic data are provided to inform country specific application of the findings. Additionally, the garments selected for this inquiry, though common across cultures and consistently laundered in the home do not fully represent the full range of products that consumers potentially launder. Further research can build upon the descriptive findings of this study, by focusing on these considerations in the empirical approach.

5. Acknowledgments

This research could not have been completed without funding and contributions from Cotton Incorporated and the assistance of Melissa Bastos, Michele Wallace, and Edward Barnes.

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7. Appendix A: Global Laundering Questionnaire (2015)

Q1 In which country or region do you currently reside?

Q2 Are you…?

1 Male
2 Female

Q3 In what year were you born?

Q4 How many of the following clothing items do you own? If you are not sure of the exact number, please provide us with your best estimate.

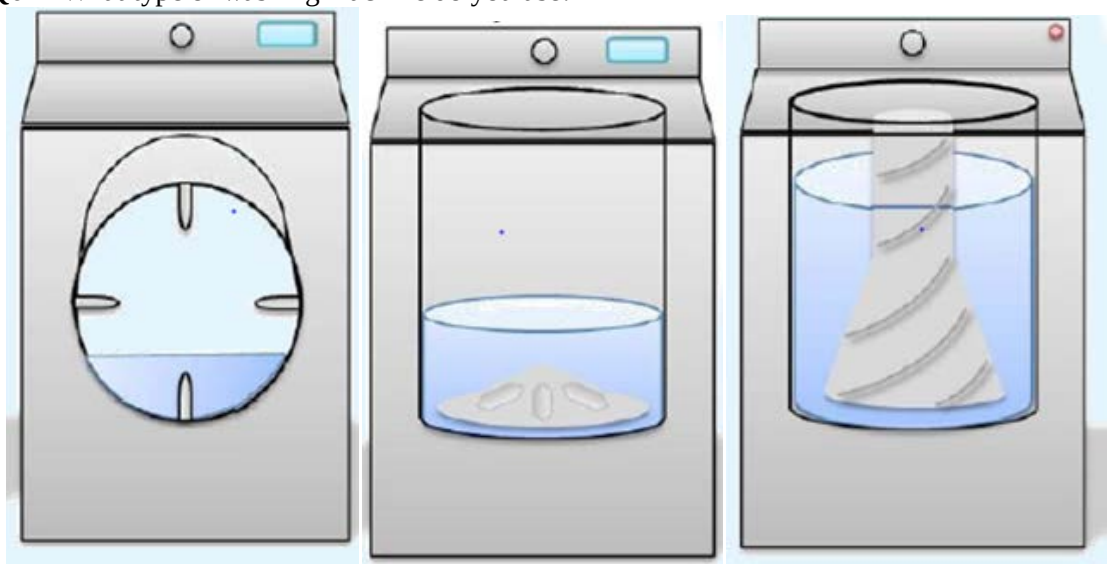
1 Casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] such as khakis, chinos, cords, capris (excluding denim jeans, athletic or sweat pants, leggings/jeggings, and shorts)
2 Polo or golf shirts - pull over shirts with a collar that can be either short sleeve, long sleeve, or sleeveless
3 T-shirts - pull over shirts without a collar that can be either short sleeve, long sleeve, or sleeveless

1 Casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] (excluding jeans)	*2* Polo or golf shirts	3 T-shirts
		

Q5 In general, how do you usually wash the following clothing items?

1. Send to the dry cleaner	2. Machine wash at home	3. Machine wash in a laundromat or shared facility	4. Hand wash	5. I do not wash my own laundry

Q6 What type of washing machine do you use?



1 Top loading (Vertical Axis) [ALL COUNTRIES EXCEPT FOR THE UK [with an agitator]
2 High Efficiency Top Loading (Vertical Axis) [ALL COUNTRIES EXCEPT FOR UK [without an agitator]
3 High Efficiency Front loading (Horizontal Axis)
4 Not sure
5 Other (please specify)_____
6 I do not use a washing machine.

Q7
Now consider how you *wash* and *rinse* your clothing. In general, which water temperatures do you select when washing and rinsing the following items?
Q8

	Cold Cold	Warm Cold	Warm Warm	Hot Cold	Hot Warm	Hot Hot
1 Casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] (excluding jeans)						
2 Polo-style shirts						
3 T-shirts						

Q9
Approximately how many times per month do you wash each of the following? If you wash a particular item less often than once a month, please enter a '0'.

1 Casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] (excluding jeans)
2 Polo-style shirts
3 T-shirts

Q10 In general, how many days do you wear each of the following before you wash or dry clean them?
Q11 # of Days of wearing before washing or dry cleaning
1 Casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] (excluding jeans)
2 Polo-style shirts
3 T-shirts

Q12 Do you wash your casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] with other types of clothing or only with other casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks]?

1) I typically wash my casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] with other types of clothes.
2) I only wash my casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] with other casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks].

Q13 Do you wash your polo-style shirts with other types of clothing or only with other polo-style shirts?

1) I typically wash my polo-style shirts with other types of clothes.
2) I only wash my polo-style shirts with other polo-style shirts.

Q14 Do you wash your T-shirts with other types of clothing or only with other T-shirts?

1) I typically wash my T-shirts with other types of clothes.
2) I only wash my T-shirts with other T-shirts.

Q15 In general, when washing the following do you usually wash them with a small, medium, large, or extra large load of laundry?

1) Small
2) Medium
3) Large
4) Extra large

1 Casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] (excluding jeans)
2 Polo-style shirts
3 T-shirts

Q16 In general, how do you dry the following items?

	In a machine dryer	**Air dry (line, lay flat, drip dry)**	**Combination of dryer and air dry**
Casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks]			
Polo-style shirts			
T-shirt			

Q17 *Do you typically iron the following items?*

1 Yes
2 No

1 Casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] (excluding jeans)
2 Polo-style shirts
3 T-shirts

Q18 Approximately how many days per month do you wear each of the following? If you wear a particular item less often than once a month, please enter a '0'.

1 Casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] (excluding jeans)
2 Polo-style shirts
3 T-shirts

Q19 On average, for how many years do you wear each of the following types of clothing before you consider them to be worn out, no longer wear on a regular basis or give away? If less than 1 year please enter "0".

1 Casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] (excluding jeans)
2 Polo-style shirts
3 T-shirts

Q20 In general, what do you do with the following when you no longer plan to wear them? Please select the best answer.

1 Casual [IF UK OR JAPAN: [trousers]: ALL OTHERS: [slacks] (excluding jeans)
2 Polo-style shirts
3 T-shirts

[RANDOMIZE]

1) Throw them away
2) Donate to charity
3) Give them away (to a friend or as hand-me-downs)
4) Re-use or use them in a different way (such as rags for cleaning, sew them into other items, use for craft projects, etc.)
5) Sell them (including yard sale, consignment shops, flea markets, etc.)
6) Keep them (in closet or in storage)
7) *Other, please specify* _____ *[Capture verbatim]*

Q21 Based on your clothing buying and wearing experiences, please select which type of clothing is best described or represented by each of the attributes displayed. *Please select the single best response for each attribute.*

[randomize stubs; randomize columns]	**Type of Clothing**		
	Clothing made primarily of cotton	Clothing made primarily of polyester	Clothing made primarily of rayon fibers (such as viscose, Tencel, rayon, Lyocell, Modal, etc.)
1. Lasts the longest			
2 Falls apart the most			
3 Easiest to reuse in a different way when I am done wearing it			
4 Most often thrown in the trash when I am done wearing it			
5 Most sustainable or environmentally-friendly			
6 Most likely to degrade in a landfill			
7 Takes the longest to dry after washing			
8 Hardest to wash			