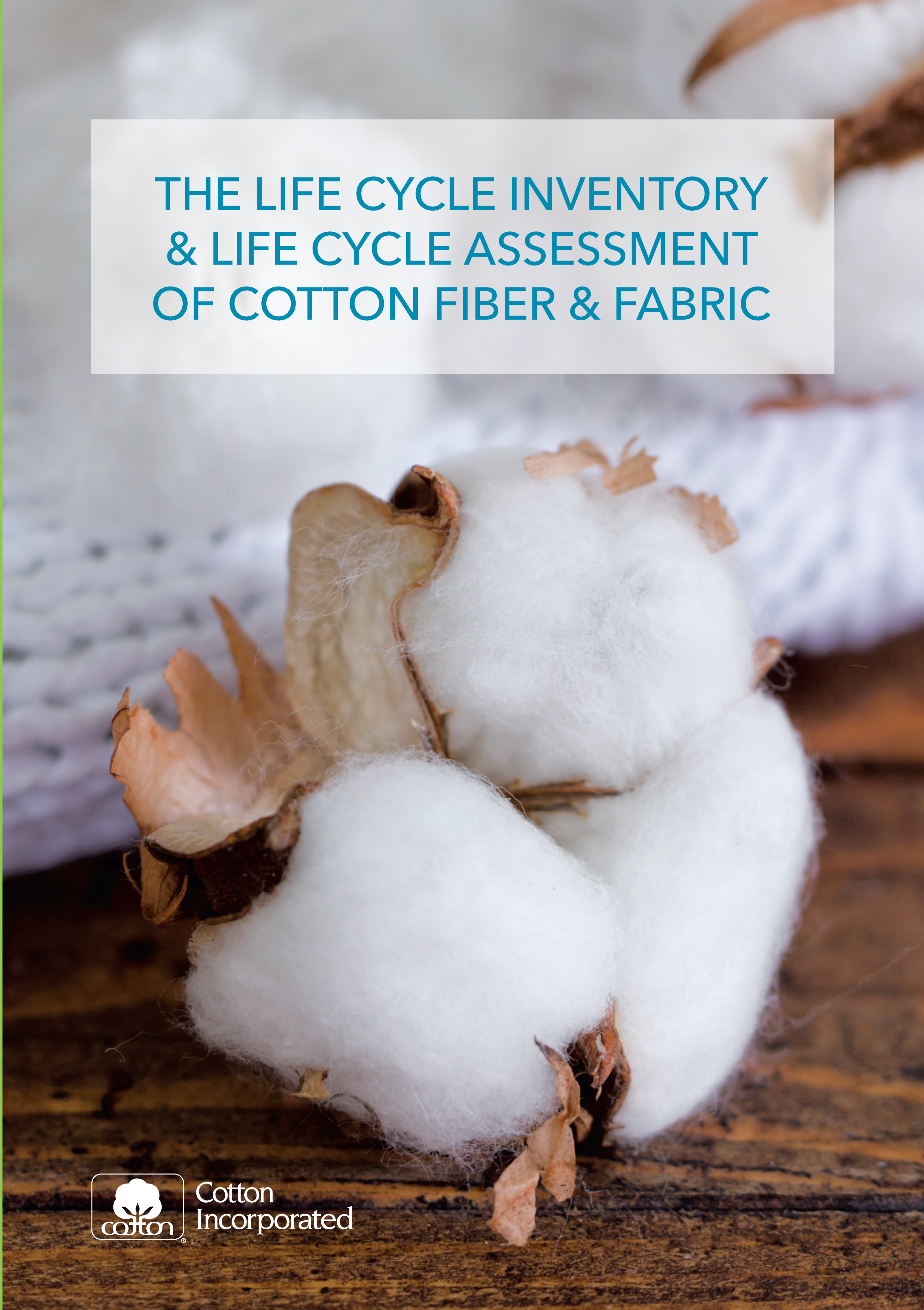
THE LIFE CYCLE INVENTORY & LIFE CYCLE ASSESSMENT OF COTTON FIBER & FABRIC



Cotton Incorporated

MONITORING CONTINUOUS IMPROVEMENT

The data required to understand the environmental impacts of a textile product is vast—starting with cotton cultivation and spanning through the consumer use to the product end of life phases (Figure 1). Life Cycle Assessment (LCA), which measures potential environmental impacts from raw material extraction to disposal, is an accepted tool and framework designed for such analyses. LCA provides valuable insights to decision makers by identifying key impact areas, often referred to as "hotspots," and enables environmental benchmarking.

In 2010, The Cotton Foundation performed the most comprehensive LCA of cotton clothing ever attempted. To keep the information current, and to take advantage of improved LCA methodologies that emerged over the five-year span, an update to the original LCA was undertaken. Therefore, a primary objective of this project was to provide robust and recent life cycle inventory (LCI) data for global cotton fiber production, textile manufacturing, and consumer use to ensure accurate representation of impacts from cotton in other LCAs, and to include new LCA metrics in that process.

FIGURE 1: Illustration of the LCA processes for an apparel product.

HOW WE PERFORMED THE STUDY

To quantify cotton garment environmental impacts, the LCA was divided into three primary phases:

1 COTTON FIBER PRODUCTION

The data for fiber production represent a global average of the three largest cotton-producing regions (the United States, India, and China) and top three-cotton exporting countries (the United States, India, and Australia) for the years 2010 to 2014. These regions, combined, accounted for 67% of the world's cotton production during the study period. The data collected included raw fiber production from field through the ginning process and include soil type, climate, seed and chemical inputs, water and fuel use, as well as key dates associated with production—such as planting, fertilizer application, and harvesting.

2 COTTON TEXTILE AND GARMENT MANUFACTURING

The data for textile processing are global averages of mills in South Asia, Central Asia, East Asia, Eurasia and Latin America. These areas accounted for 85% of investment in knit manufacturing and 59% of investment in woven production in 2014. The process steps included yarn production, fabric formation (knitting or weaving), and wet processing—preparation, dyeing, and finishing. Data elements for each process included raw material inputs and outputs; energy inputs by source; chemical input, output and emissions; and solid waste amounts and means of disposal (such as whether the waste was recycled, sold, or sent to landfill). Information about garment production (cut & sew) was taken from the previous cotton LCA study in 2010. Mill data for textile production and for cut-and-sew were supplemented with process energy calculations from machinery manufacturers and data available from Cotton Incorporated experts.

3 CONSUMER USE AND DISPOSAL

Background data on use phase energy and materials were taken from existing government publications, literature values, and thinkstep's GaBi database. Those figures were combined with consumer behavior data from a global survey of consumers conducted by a third-party market research company. The survey pool consisted of at least 1,000 respondents from each of the surveyed countries—the United States, China, Japan, Italy, Germany, and the United Kingdom. The study posed questions about consumers' use, laundering, and disposal practices for knit T-shirts, collared knit shirts and woven pants.

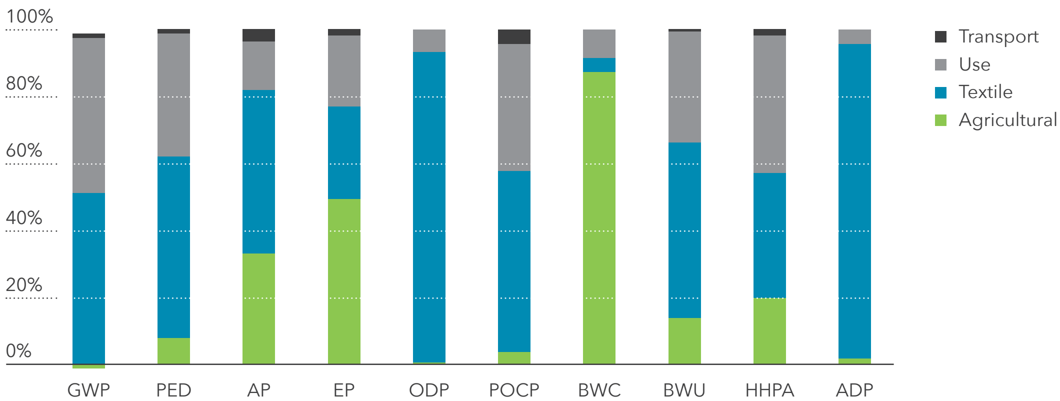
For all phases this study considered fourteen different impact categories; however, for brevity, this summary will only present 10 of the indicators described in the following table.

Impact Category	Abbreviation	Description
Global Warming Potential	GWP	A measure of greenhouse gas emissions, such as CO_2 and methane.
Primary Energy Demand	PED	The total raw energy used—for example the energy content of the coal used to generate electricity.
Acidification Potential	AP	A measure of emissions that cause acidifying effects to the environment. An example impact is acid rain.
Eutrophication Potential	EP	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P).
Ozone Depletion Potential	ODP	A measure of air emissions that contribute to the depletion of the stratospheric ozone layer.
Photochemical Ozone Creation Potential	POCP	A measure of emissions of precursors that contribute to ground level smog formation.
Blue Water Consumption	BWC	Water that is removed from a lake, stream or aquifer and not returned to the watershed it was taken from. For example, this does not include water for power generation that is returned back to the river it was taken from.
Blue Water Use	BWU	Any water that is withdrawn from a lake, stream or aquifer. This includes water used for power generation.
Human Health Particulate Air	HHPA	Particulate matter air emissions such as dust.
Abiotic Resource Depletion	ADP	A representation of the consumption of non-renewable resources leading to a decrease in their future availability.

RESULTS

When the entire cotton life cycle is considered, the Textile Manufacturing and Consumer Use phases dominated most of the impact categories, as illustrated in Figure 2 for the knit, collared casual shirt. While there were slight differences for the T-shirt and woven pant, all products show trends similar to the knit collared casual shirt for the relative magnitude of each phase. The impacts of transportation between phases (i.e., moving the bale of fiber from the gin to the textile mill and transporting final products to retail) were combined. From Figure 2 it is apparent that transportation was not a significant contribution to any impact category, partly because much of the transportation was by sea in bulk containers. Additional details are discussed by phase in the next sections.

FIGURE 2: Relative contribution to each impact category for knit collared casual shirt.



AGRICULTURAL PHASE

Although Agricultural Production's contribution to total impact was lower than the Consumer Use and Textile Manufacturing phases in most categories, agriculture did have the major portion of the impacts on water consumption and eutrophication potential. Figure 3 shows processes within the agricultural phase and their contribution. Blue Water Consumption (BWC) was driven by irrigation water use, and, while 50% of the water for cotton in the world is derived from rainfall, a majority of the irrigation water used is transpired by the plant and leaves the watershed from where it was taken. Similar results were found in the 2010 cotton LCA and, since that time, research efforts to increase water use efficiency on-farm have been implemented. For example, research was conducted to refine thresholds to trigger an irrigation event based on sensors in the field monitoring real-time conditions.[1] Field emissions due to nitrogen fertilizer runoff and leaching were identified as major contributors to overall impact on eutrophication potential. Nitrous oxide emissions were also a significant contributor to acidification potential. The energy associated with nitrogen fertilizer

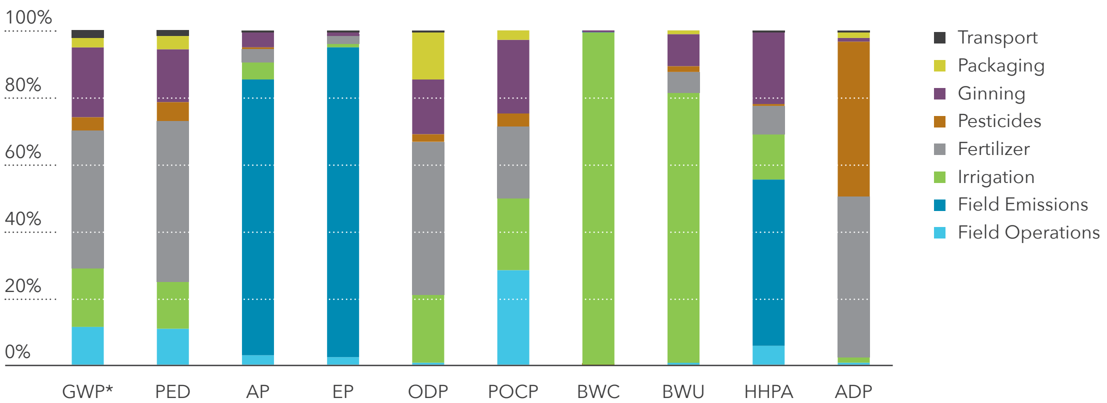
1 A grower oriented publication was released in 2015 and is available at: https://cottoncultivated.cottoninc.com/wp-content/uploads/2015/12/Soil-Moisture.final-web1.pdf

manufacturing was also significant. Nitrogen management is also an area that has had increased research focus since the previous LCA, including a study involving universities from all U.S. cotton growing regions to update nitrogen recommendations made to farmers.[2] One of the key findings was the importance of accounting for nitrogen carried over in the soil from the previous crop. It should be noted that water and nitrogen are key inputs that have been the focus of agronomic studies around the world for decades, and the LCA results, both past and present have reinforced the importance that this research continues.

From Figure 3 it is noted that biogenic carbon is not represented in the figure, otherwise GWP for the agricultural phase would be a negative value. This reflects the fact that there is more carbon removed from the atmosphere and stored in the fiber than is emitted in growing and ginning the crop. This carbon was assumed to be re-emitted in the use phase during disposal, as there is no data available on how much of the carbon in a textile product remains sequestered for more than 100 years.

Several impact categories were not included, such as Social and Biodiversity, because they are beyond the scope of this environmental LCA. However these are areas of concern to the cotton industry. Cotton production, ginning and textile production are labor intensive activities which generate millions of jobs around the world. Biodiversity is also enhanced through soil health practices and crop rotations, both recommended and increasingly common practices in cotton production.

FIGURE 3: Contributions of different processes to the total impact of the agricultural phase of the LCA.



The GWP offset from biogenic carbon is not represented in this figure.

2 Main et al. 2013 Effects of nitrogen and planting seed size on cotton growth, development and yield. Agronomy Journal 105(6):1853-1859.

TEXTILE MANUFACTURING

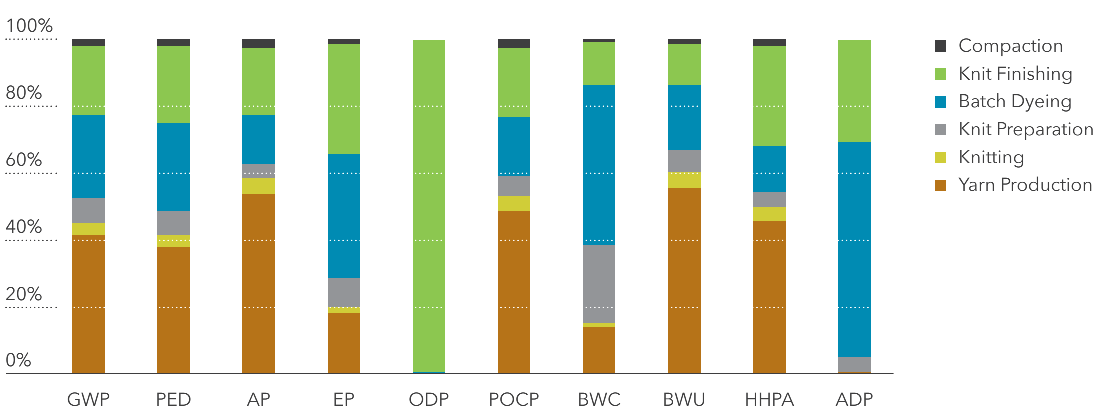
The Textile Manufacturing phase was the largest contributor to all but two impact categories (BWC and EP), as seen in Figure 2. For everything but ADP and ODP, the large share was a result of high energy usage in yarn production and weaving (Figure 4). Yarn manufacturing, for this study, included opening, carding, drawing, combing, roving and ring spinning. Based on number of spindles, ring spinning, which is the traditional means for creating yarn, is the dominant yarn production method used globally for staple fibers. Because the spinning frame has a slower productivity and preparation requires more intermediate steps, ring spinning is known to have higher energy requirements, per unit of output, than rotor spinning.[3] In spite of the energy use, this traditional method is still widely used for cotton and synthetic staple fibers, because only ring spinning results in the finer, smoother, softer yarns that are necessary for some products.

The second largest energy use was attributed to either fabric formation (for pants) or to wet processing (for shirts). In fabric formation, weaving a fabric typically required more energy than (weft) knitting of fabric, per unit of output. Like the yarn case, end-product requirements (functional or aesthetic) are also the reason not all textile products are knitted. The type of raw material or method of yarn formation does not change the overall importance of fabric formation.[4] Compaction is a mechanical process that occurs after finishing to control shrinkage. As this is a dry process and requires relatively little energy, it had a minimal contribution to all the impact categories.

Although energy use in wet processing of knits can significantly contribute to the overall life cycle assessment, the number of complicating factors (e.g., machinery type, number and type of chemistries, number of processes, water requirements, etc.) limits the ability to make any observations similar to those made about yarn and fabric production. However, as with yarn and fabric, end use requirements can result in chemical or process choices that are more energy intensive than others.

The potential depletion of ozone and natural mineral resources was mainly a result of chemicals used in dyeing and finishing. The production and disposal of dyes, finishes and auxiliary chemicals requires large amounts of materials (synthesized or natural), unlike yarn and fabric production, which use relatively small amounts of material inputs other than cotton. Some of these chemicals are consumed in wet processing, while others must be treated for disposal. However, it is important to keep in mind that in absolute terms, the magnitude of ozone depletion potential is very small as most ozone-depleting chemistries have been largely eliminated.

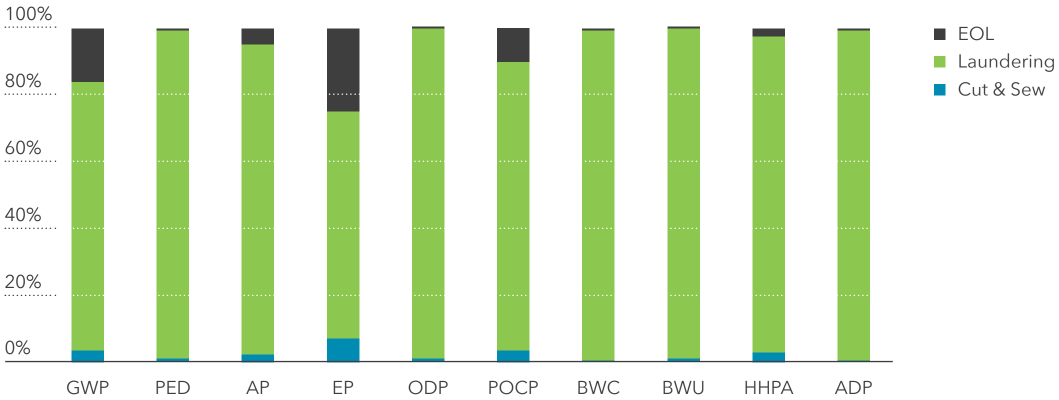
FIGURE 4: Contributions to the textile phase (knits) of the LCA.



3 Koç, E. and E. Kaplan. 2007. An investigation on energy consumption in yarn production with special reference to ring spinning, Fibers & Textiles in Eastern Europe, 15:4, 18-24.

4 van der Velden, N.M., Patel, M.K. and Vogtländer, J.G. 2014. International Journal of Life Cycle Assessment 19: 331. doi:10.1007/s11367-013-0626-9

FIGURE 5: Contributions of different processes to the impacts of the consumer use phase of the LCA.



CONSUMER USE AND DISPOSAL PHASE

The Consumer Use phase also had significant contributions to energy use, greenhouse gas emissions and blue water use. Compared to the 2010 study, the relative impact of the use phase decreased for all metrics as the study was expanded to be representative of a global consumer, as opposed to exclusively a U.S. consumer in 2010, as well as increased metrics to more accurately assess laundering habits. Use phase impacts are dominated by consumer use due to laundering (Figure 5). The contribution from dryer use was smaller than might be expected, as 76% of global consumers indicated they used line drying (data not shown). Use phase impact reduction can be made through the change of laundering behavior by switching from machine drying to line drying, using cold wash water with appropriate detergents, and using higher efficiency washing machines.

There is one caution to interpretation of the use phase impacts. Based on the survey data it was determined the average global consumer launders an apparel product approximately 20 times (in average cases, the garment is worn multiple times before being laundered). Lowering the number of washes has an obvious benefit in lowering the impacts in the use phase; however, this may not be a net environmental gain if the lower number of washes is due to poor product quality that results in decreased product life. For any product comparisons, the product's lifetime would need to be considered. Considering the larger contribution of textile manufacturing on several of the impact metrics, it is expected that increasing product durability could decrease the environmental impact of apparel product manufacturing as the total impact is amortized over the life of the garment. In addition to lifetime differences, a robust LCA-based product comparison requires precise attention to system boundaries and independent expert input from both products.

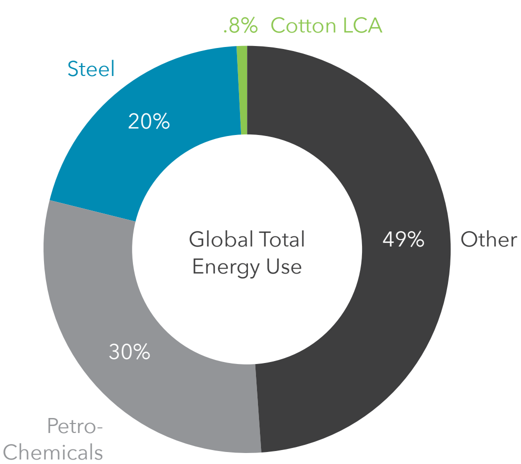
Another emerging area of environmental impacts for laundering, which is not currently addressed by LCA metrics, is the issue of micro-fibers in the aquatic environment. There is growing awareness of the dangers of microplastics in the ocean and one source for those is washing of garments.[5] Currently there is no evidence that this is an issue for cotton, but polyester and acrylic fiber have been identified in sewage effluent that was discharged to natural waters.

5 Brown, M., P. Crump, S. Niven, E. Teuten, A. Tonkin, T. Galloway, and R. Thompson. 2011. Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks. Environ. Sci. Technol. 45(21):9175–9179.

RESULTS IN CONTEXT

The previous sections focused on examining the results of the LCA and identifying opportunities for improvement—a key objective of this study. But is also important to put the impact of cotton apparel in context with other products and industries. For comparison purposes, it was assumed that all of the 26 million tonnes of cotton produced globally was manufactured into a collared knit shirt, that the shirt was laundered 20 times, and then disposed of according to the results of this study. That is, the total energy use and greenhouse gas emissions in the life cycle of the knit shirt were applied to all the cotton in the world. Figure 6 illustrates that less than 1% of the world's energy use is associated with the life cycle of cotton garments and similar results were also found for greenhouse gas emissions. Global data sets are not available for water use estimates; however, a global estimate of agricultural water use indicates that cotton cultivation only represents 3% of the water used for agricultural crops.[6]

FIGURE 6: Estimate of cotton's share of global energy use (data on global energy use from the U.S. Energy Information Association for 2013, www.eia.gov)



CONCLUSIONS

For the life cycle phases that are outlined (Agricultural Production, Textile Manufacturing, and Consumer Use), textile manufacturing was the largest contributor to twelve of the fourteen impact categories. The major sources of potential impact for manufacturing were wastewater emissions from wet processing facilities, energy use in yarn manufacturing and weaving, and upstream production of energy and process chemicals. The Agricultural phase had significant impacts on eutrophication potential and blue water consumption. Nitrogen fertilizer production and use and irrigation water contributed the largest share to impacts in the Agricultural Production phase. While the Consumer Use phase was not a primary driver for any one metric, the impact of laundering and disposal was similar in magnitude to the Textile Manufacturing phase on several metrics, such as energy use and greenhouse gas emissions. A key source of variance in the use phase is the number of launderings, which indirectly relates to garment life. That is, a garment which is well-constructed has a long life and is more likely to have more laundering cycles that would increase the impact of the use phase and change the relative ranking of the phases. Creating textiles with a shorter useful life as a means to decrease impact in the consumer phase would not have the desired positive impact on the environment.

6 Hoekstra, A. Y. & Chapagain, A. K. (2007). Water footprints of nations: water use by people as a function of their consumption pattern. Water Resource Management, (21)1, 35–48.

RECOMMENDATIONS

To reduce water consumption and eutrophication potential, irrigation and fertilizer use during cotton cultivation should be further optimized. In the textile manufacturing phase, areas for improvement (for any commonly used fiber) include increasing energy efficiency, use of cleaner energy sources, and "greener" process chemicals and processes to create finished fabric. Impact reduction could be achieved through changes in consumer behavior. Though the industry cannot control consumer behavior, consumers can be influenced by labeling and by manufacturing choices that lower the use of water and energy during laundering. Laundering practices such as switching from machine drying to line drying, using cold wash water with appropriate detergents, and using more efficient washing machines are readily available to consumers.

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