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Life Cycle Assessment of Four Different Sweaters

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ABSTRACT Life cycle assessment (LCA) is a methodological tool to describe the impacts of a product over its lifetime, from 'cradle to grave.' Despite increased employment of LCA, textile LCA studies are often private, outdated, not transparent, or lack accurate data. Further, we know of no LCA study specific to sweaters. This screening LCA combines published literature and data from OpenLCA databases (Ecoinvent 3.3 and GaBi Professional) to conduct a comparative LCA for four sweaters. To determine the composition of these sweaters, we massed and assessed the material composition of 117 sweaters in October 2015. Based on results, our study compares one sweater of 100% cotton (21% of total sweaters), one of 100% wool (0.08% of total sweaters), one of 100% acrylic (11% of total sweaters) and one 60% cotton and 40% polyester (4% of all sweaters, though 21% of sweaters were cotton-polyester blends). As previous studies on textiles have focused on either material production or the use phase of textiles, we assess a more complete product life cycle for the consumer in the United States. We quantified the environmental burden of fiber production, sweater creation, and use in terms of the ten TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) impact categories that include global warming potential (GWP) and eutrophication. Although the use phase had the largest global warming potential for each sweater, the use phase did not have the highest impact in all categories. In all ten TRACI categories, the wool sweater had the least impact, in large part because of the assumed consumer behavior (not drying the sweater) that can be applied to any sweater material.

INTRODUCTION

Life cycle assessment (LCA) is a methodological tool to describe the environmental, economic, or social effects of a product over its lifetime, from raw material extraction to disposal. It is a relatively new methodology, dating to 1966. The process involves three steps. First, the goal and scope of the study are defined. Second is an inventory analysis that evaluates the inputs and outputs of each stage of a product's lifespan. Third, an impact analysis assesses how the inputs and outputs found in the inventory analysis affect the environment. Impact is converted into common, equivalent units. For example, the release of methane, twenty-five times more potent per molecule emitted than carbon dioxide as a

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greenhouse gas, is reported as a carbon dioxide release equivalent, and presented as 'global warming potential'. While previous studies on textiles have focused on either material production (Beton et al., 2014; Cardoso, 2013; Laursen et al., 2007; van der Velden et al., 2014) or the use phase of textiles (Steinberger et al., 2009), I assess a more complete sweater life cycle for a typical consumer in the United States. This project is also unique in that it assesses and compares sweaters made of a variety of fiber materials, including a blend. Information provided in this study has the potential to influence consumers, designers, and other stakeholders in decisions and behaviors to lessen environmental impacts of their products at purchase and throughout the lifetime of the sweaters.

Existing LCA studies of textiles often exclude or hardly include the consumer as a stakeholder (Beton et al., 2014; Laursen et al., 2007; van der Velden et al., 2014) and only assess one or two fabric types, completely excluding blends (Cardoso, 2013; Steinberger et al., 2009; van der Velden et al., 2014). Several LCA studies also focus on just one step in production, such as acrylic fiber production (Yacout et al., 2016) or cotton yarn production (Bevilacqua et al., 2014); these limited studies have the benefit of in-depth and precise information for one stage of production, but are less holistic and inclusive than larger-scale LCA studies. However, all LCA studies take a unique approach to constructing the functional unit and the system boundaries. For example, van der Velden et al. (2014) chose a functional unit of 1 kg of fabric. While their study extensively covers the possible variations in the manufacturing process of a garment, little consideration is put into the use phase due to the unknown variations in consumer behavior.

This study seeks to fill the gaps in apparel life cycle assessments by utilizing the best available LCA apparel and textiles data and applying it to sweaters that represent some of the most common blends and the variety of different sweaters that are available for purchase. The scope of this study is the immediate supply chain of four different sweaters: fiber production, garment creation, transportation, and use (see Figure 1). Inputs like farm machinery construction or truck construction are excluded in the final results; however, the inputs from the packaging of sweaters in corrugated cardboard boxes during the transportation stage are included, due to their availability and their necessary use in transit. This study is consumer-focused, in that its goal is to provide consumers with information they may use to alter their habits. Because of this focus, several stages of the sweater's life, like spinning to yarn and weaving, are included together in a category called 'garment creation.' While the objective of this study is exploratory, it has two guiding hypotheses: the use phase of a sweater will have the largest impact on account of its continuous re-use by the consumer and the energy from washing and drying the sweater for re-use (Steinberger et al., 2009), and that fiber creation stages would have the next largest impact, especially in the case of wool due to animal agriculture impacts.

METHODS

Overview

Data inputs for each stage in a sweater's life cycle have been run through a TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) analysis in openLCA. Developed by the United States Environmental Protection Agency, TRACI is a tool that assesses inputs of a system, such as

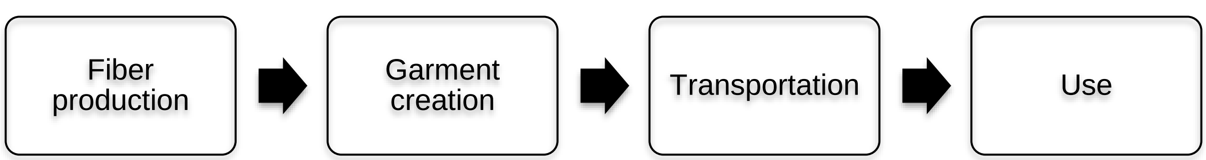

Figure 1. General life cycle diagram of sweaters considered in this study.

Joules of natural gas, and converts those inputs to common environmental impact categories (i.e. global warming potential from carbon dioxide equivalents) to describe the impacts of that stage of production. 'Impacts' in this study refers to the nine different categories of TRACI analysis (see Appendix). When available, input information for a stage in production is taken directly from the Ecoinvent or GaBi Professional databases, which contain information on the environmental impacts of an assortment of products (see "notes" on following page). When unavailable, literature was consulted, typically for energy consumption values that were then run through the GaBi Professional database to obtain the impacts associated with electricity use in the country of production via TRACI analysis. Much of the highly-cited literature does not report global warming potential, eutrophication, or other impact categories, instead reporting energy usage in MJ or kWh (Laursen et al., 2007; Steinberger et al., 2009; van der Velden, 2014). A benefit of using the energy consumption of sweater or textile production allows the production process itself to be located in different regions, thus capturing the reality of a globally diverse energy mixture (and consequential diverse and/or varying environmental impacts).

Transportation

Locations for each stage in production were determined by locating the highest-producing region of raw materials in the world, then the highest-producing region of textiles in the same country, then the highest-trafficked port in that country. Distances between these locations were determined using Google Maps, which provides a realistic route that a cargo vehicle may take. The size of the truck used was the average of a 14.6304 m cargo truck and a 16.1544 m cargo truck, and its impact was determined using data from NREL, the National Renewable Energy Laboratory. Data on outputs from driving (NREL) were converted to impacts using TRACI conversion factors (Bare, 2011). The distance from the port of production to the US port (Long Beach, CA in all cases) (AAPA World Port Rankings, 2015) was determined using searoutes.com. 12.192 m intermodal containers were used for sea transportation (Rodrigue et al., 2016), and data for the impact of transoceanic transportation is from the Ecoinvent professional database. Mathews et al. (2002) determined a distance of 1825 km from Long Beach to Ann Arbor, MI (port to retailer), and this distance was selected for this study as well.

To determine the impact of one sweater during the transportation from the factory, it was necessary to know the number of sweaters in a truck or an intercontinental box. Truck dimensions were found on a truck rental website, and the intercontinental box dimensions were found on searoutes.com. Retailers were contacted in April, 2017 and asked about the dimensions of a typical box and the number of sweaters within it. Answers varied, but the most common answer was a 40.64 cm^3 box filled with 30 to 50 sweaters (this study assumes 40 sweaters in a 40.64 cm^3 box are shipped from the factory). Corrugated cardboard boxes were only considered during the shipping of the manufactured sweaters. Impacts of the shipment of raw materials, like cotton or wool, was determined by the weight capacity of the truck. Data on the corrugated cardboard box production itself ('packaging') is directly from Ecoinvent and is included in this study (see Appendix). The impact of a consumer's travel to obtain the sweater is omitted.

Use Phase

Use phase information is from Steinberger et al. (2009), which assumes a 3.9 kg laundry load and assumes 50 washes for a T-Shirt and 6 washes for a jacket. A sweater's function seemed to be in the middle of a T-shirt and jacket, so 28 laundry cycles are assumed. From Steinberger et al.'s (2009) data, electricity use information, in MJ, for 1 kg of fabric in a 3.9 kg load was calculated. Using the mass of individual sweaters (varied for the 4 sweaters included in this analysis), the impact per sweater was converted based on its fraction of the 3.9 kg load.

Sweater Selection

117 sweaters from Target and Macy's were measured for their mass and material-make up in October and November of 2015. The most common sweaters were selected for analysis: 100% cotton (21% of all sweaters), 100% acrylic (11% of all sweaters), and a cotton-polyester blend (21% of all sweaters). The 60% cotton-40% polyester was the most frequent cotton-polyester blend (4% of all sweaters were a 60%-40% blend). The 100% wool sweater was selected based on the curiosity of the authors (0.08% of all sweaters, n=1) and the desire to examine a broad range of sweater materials. Sweater mass was determined by the average of each sweater material.

Notes on the 100% cotton sweater

a. **Sweater specification**
The cotton sweater represents the average mass of all measured 100% cotton sweaters, 441 g.

b. **Cotton production**
Data for the production of cotton is directly from Ecoinvent.

c. **Sweater creation**
Data for the creation stage is from Seinberger et al. (2009) and is summed in this study.

d. **Transportation**
Steinberger et al. (2009) sources its cotton apparel from India. Because their data was utilized in the creation stage, their location is also utilized for the transportation stage. Cotton production is assumed to be in Mashrata, and textile manufacturing is assumed to be in Tirapur. Mumbai is the port from which the completed sweater is shipped, and it arrives in Long Beach, CA and is retailed in Ann Arbor, MI.

Notes on the 100% wool sweater

a. **Sweater specification**
The sweater mass in this study is that of the single measured 100% wool sweater, 350 g.

b. **Wool production**
Data for the production of wool (sheep farming) is directly from Ecoinvent.

c. **Sweater creation**
Data for the creation of wool sweaters is from Cardoso (2013). The energy inputs discovered in their study were used in this study. In cases of a reported range of energy use, the ranges were averaged.

d. **Transportation**
The Inner Mongolia region of China is the world's top wool producing region (EU SME, 2011) and the garment is assumed to be created in Zhejiang, one of China's top garment producing provinces (EU SME, 2011).

e. **Use**
Wool sweaters are often not meant to be tumble-dried in heat. Therefore, this sweater is assumed to be air-dried, thus excluding it from the tumble-dry portion of the use phase.

Notes on the 60% cotton, 40% polyester sweater

a. **Sweater specification**
The sweater is the average of all measured 60% cotton/40% polyester sweaters, 545 g.

b. **Fiber production**
Data for the production of cotton is from the Ecoinvent database. Polyester fiber creation is from Steinberger et al. (2009).

c. **Sweater creation**
Data for polyester fiber creation and sweater creation from Steinberger et al. (2009). Impacts for this sweater were allocated by percentage; therefore, 218 grams of a polyester sweater were analyzed and added to the 327 grams analyzed of a cotton sweater.

d. **Transportation**
The cotton for this sweater is sourced from Xiajang, the region that produces the most cotton in China (EU SME, 2011). There was no reliable source for the raw material source for polyester, or the method of

transportation. This stage in transportation has been omitted.

Notes on the 100% acrylic sweater

a. Sweater specification
The average 100% acrylic sweater measured 445 g.

b. Acrylic fiber creation and sweater creation
The data for the fiber and sweater creation are from Beton et al. (2014) and could not be disaggregated. Further, Beton et al. (2014) used the ReCiPe analysis method to assess environmental impacts. In an attempt to convert ReCiPe results for climate change to TRACI results, 5 random products, analyzed with both the TRACI and ReCiPe (E-Egalitarian) methods, were compared in OpenLCA in search of a common conversion factor. None existed, and conversion factors from ReCiPe to TRACI ranged from 1.07 to 2.2. The average of these conversion factors were used to convert the Beton et al. (2014) climate change value to what a TRACI analysis of the same inputs may yield.

c. Transportation
No reliable data was found for the raw material source for acrylic, or the method of transportation. This stage in transportation has been omitted.

RESULTS

Results for the nine TRACI impact categories of each of the four sweaters are presented in the Appendix, Tables 1-4. "NA" signifies that data was not available either in the literature or in OpenLCA. For the acrylic sweater's fiber creation and sweater manufacture, the impact category 'Global Warming Potential' was the only category for which reliable data was found (Beton et al., 2014). Figures 2 and 3 show comparisons of all sweaters and their respective life cycle stages in the selected category Global Warming Potential. These figures show the Global Warming potential in kg CO_2 equivalents (Figure 2) and each life cycle stage's contribution as a percentage of the whole sweater's Global Warming Potential (Figure 3).

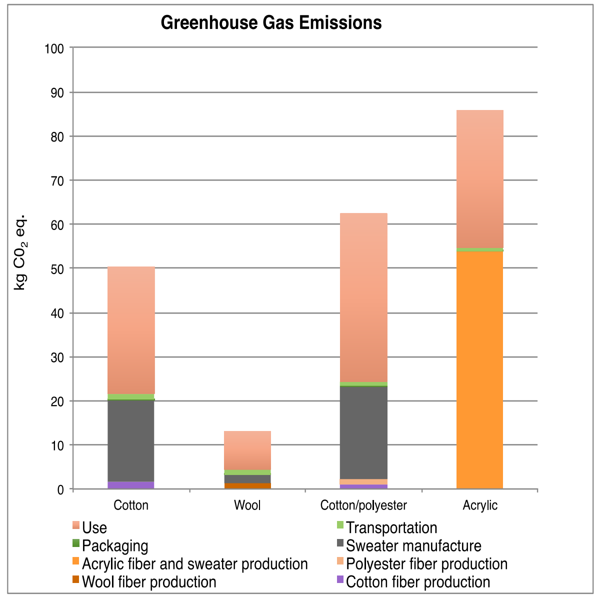

Figure 2. Greenhouse gas emissions in kg CO_2 equivalence. The use phase creates the most emissions of the cotton, wool, and cotton/polyester sweaters (see Appendix, Tables 1-3). In the case of the acrylic sweater, most emissions occur in the fiber and sweater production stages (see Appendix, Table 4).

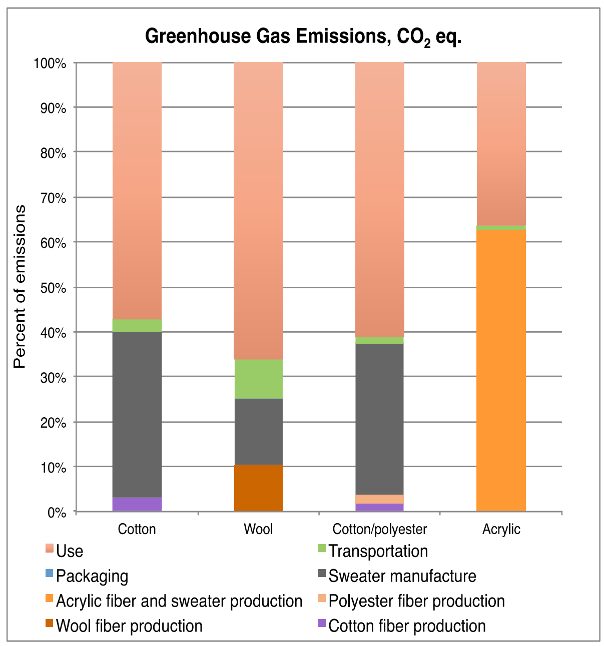

Figure 3. Greenhouse gas emissions as a percentage of the whole sweater's emissions. The use phase accounts for the largest percent of emissions in kg CO_2 equivalency for the cotton, wool, and cotton/polyester sweaters. While the use phase for the acrylic sweater account for a large percentage of emissions (36.27%), the fiber and sweater production accounts for 62.82%.

Figures 4 and 5 show comparisons of Ecotoxicity contributions of each process in each sweater, in Comparable Toxicity Units: ecotoxicity (CTUe) (Figure 4) and CTUe as a percentage of the whole sweater (Figure 5). Acrylic sweaters have been omitted from Figures 4 and 5 due to insufficient information for comparison.

Acidification

Acidification is the increasing concentration of hydrogen ions within a media (air and water). The sweater creation phase had the largest acidification in the 100% cotton and 100% wool sweaters, while the cotton/polyester blend's and acrylic's largest source of acidification was in the use phase (see Appendix).

Ecotoxicity

Ecotoxicity uses chemical inputs known to cause harm to environments and is a more general health measurement than the Carcinogenics and Non-carcinogenics impact categories. Cotton was the largest contributor to Ecotoxicity. Wool creation was less impactful but still the largest contributor of the wool sweater. The use phase was the acrylic sweater's biggest Ecotoxicity contributor (see Appendix; Figures 4 & 5).

Eutrophication

Eutrophication is an excess of algae due to the enrichment of an aquatic ecosystem with unnecessary nutrients and threatens the health of the ecosystem. The highest eutrophication value is due to transportation in the cotton and wool sweaters, and use in the cotton/polyester and acrylic sweaters (see Appendix).

Global Warming

Global warming potentials are calculated by measuring outputs of life cycle stages to equivalent carbon dioxide in terms of potency (Bare, 2011). TRACI calculates global warming potentials of a 100-year horizon. The use phase dominates the global warming potential of a sweater except for when it is not tumble-dried (the wool sweater) (see Figures 2 &3). In the case of the acrylic sweater, the combined fiber creation and sweater manufacturing stages

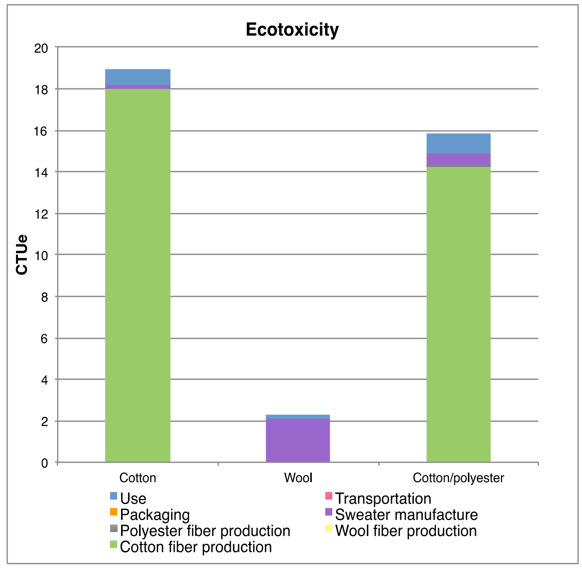

Figure 4. Ecotoxicity in CTUe. Cotton fiber production, required for the cotton sweater and cotton/polyester blend, has the largest Ecotoxicity impact. A 100% cotton sweater creates 17.98 CTUe; when in the blend, it has a value of 14.27 CTUe (see Appendix, Tables 1 & 3). The stage of the wool sweater that has the largest impact on Ecotoxicity is the sweater manufacture stage, with a value of 2.08 CTUe (see Appendix, Table 2).

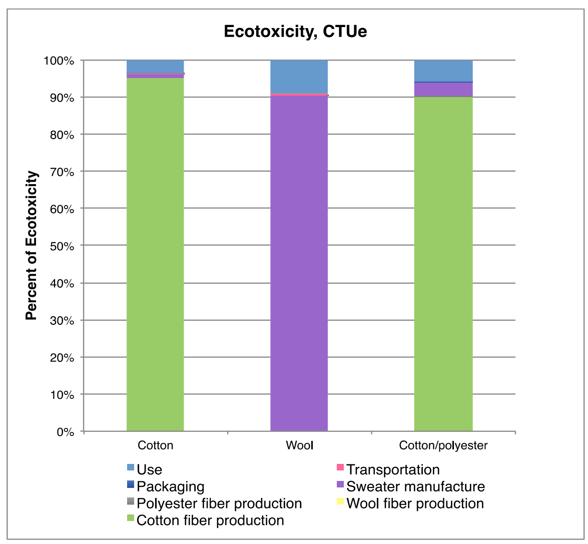

Figure 5. Ecotoxicity as a percentage of the whole sweater's Ecotoxicity. Cotton fiber production makes up for at least 90% of Ecotoxicity impact in the 100% cotton and 60%cotton/40% polyester sweater. In the 100% wool sweater, sweater manufacture accounts for 84.50% of Ecotoxicity.

makes it difficult to determine which of the two stages contributed more to global warming, though it is clear that the use stage contributes less than half of the sweater's impact on global warming (see Appendix; Figures 2 & 3).

Ozone Depletion

Measuring ozone depletion uses a similar potency-equivalence as calculations for global warming potential. Ozone depletion was small for all impact categories, with fiber creation being the biggest contributor for cotton and cotton/polyester sweaters, and the sweater creation stage being the largest contributor for the wool sweater (see Appendix).

Photochemical oxidation

Photochemical oxidation is the creation of smog, caused by nitrogen oxides and volatile organic compounds reacting in sunlight. The transportation stage created the most smog in all sweaters except the cotton/polyester blend, where the use phase was the larger contributor (see Appendix).

Carcinogenics & Non-carcinogenics

These measures of human health effects are based on chemical inputs that are known to cause harm to human health, either by cancer or otherwise. The transportation stage had the largest effect on human health in both categories in all sweaters (see Appendix).

Human Health – Respiratory Effect, Average

Respiratory effects refer to the health effects of inhaling particulate matter. In the case of the wool and acrylic sweaters, the use phase contributed most to respiratory effects from particulate matter, 100% cotton sweaters released most particulate matter in the transportation phase, and the sweater blend released most particulate matters in the sweater creation stage (see Appendix).

DISCUSSION

In agreement with other studies (van der Velden et al., 2014; Steinberger et al., 2009), the use phase is a large contributor to the environmental impact of a sweater, particularly in the global warming potential and photochemical oxidation categories. This was expected due to the continuous use of the sweater; while it is only created once, it is washed (in this case) 28 times. The use phase did not contribute most in all impact categories for various reasons. One of the highlights is the high Ecotoxicity of cotton (see Figures 3 & 4). High Ecotoxicity values of cotton are most likely due to extensive fertilizer use in the fiber creation phase (Steinberger, 2009; Cardoso, 2013). Synthetic sweaters did have high contributions to global warming potential due to their large energy requirements in fiber and sweater creation processes. However, their global warming potentials were not as high as has been suggested by Beton et al. (2014), who attributes high global warming potentials to synthetic fibers due to the combustion energy required for their finishing and electricity demand for their formation, printing, and dyeing.

Wool is the only sweater that was the least impactful in all nine impact categories. However, with the considerable gap in knowledge of the acrylic sweater's fiber and sweater creation impacts, further research would be necessary to verify wool being the most environmentally-friendly fabric. Further, the small impact of wool is largely in part due to being excluded from the tumble-dry step of the use phase. At this time, consumers may not be fully informed enough to be able to purchase the absolute least impactful sweater type, but they can modify their use behavior to significantly reduce their sweater's global warming potential (and any other impact category). Using a drying machine uses almost twice (wash: 4.9 MJ/kg, drier: 9.1 MJ/kg) as much energy as the washing machine, thus line-drying can make a considerable change in a sweater's impact and energy consumption.

The hypothesis that the fiber creation would have the highest impact after the use phase was true only of the cotton and cotton/polyester sweaters' ozone depletion. In general, fiber creation stages were low-impact in all categories. This may be due to other products associated with a fiber's creation. The cotton plant is used for fibers and cottonseed, used to make oil and stock feed. Impacts for cotton growth are allocated to both products, and as there is a larger mass of cottonseed than cotton fiber in the plant, more of the impacts associated with growing cotton are allocated to cottonseed. Similarly, Ecoinvent data for wool also represents sheep raised for meat. Thus, the full impacts of 'fiber creation' are only a portion of the impacts of sheep rearing. Allocations for polyester and acrylic fiber creations in the utilized data are unknown, but are unlikely, as neither reference (Steinberger et al., 2009; Beton et al., 2014, respectively) mention co-product allocations.

While geography was carefully considered in this project, it is unlikely that locality matters much in transportation. However, regions may have their own energy mixes that would make a sweater life stage process more or less impactful. Certain regions have cleaner energy mixes than others; thus, a sweater made in California, U.S.A. would likely have a smaller impact than one made in China, especially in terms of global warming potential, because the energy supplied to the factory is cleaner, not simply because it is being made closer to the consumer (Shehabi et al., 2014).

Textile LCA studies have a lot to consider due to high variance in every process in its lifetime. Even the most comprehensive LCA studies only measure specific scenarios. Further textile LCA research should aim to best represent physical (rather than hypothetical) textiles and practices used to create them, especially in regards to geographically specific methods and resources. But even before more accurate models of the textile supply chain are studied, manufacturers should improve baseline data in regards to their resource usage and outputs, and share this data, particularly in regards to synthetic fibers.

ACKNOWLEDGEMENTS

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APPENDIX

100% Cotton Sweater			Acidification	Ecotoxicity	Eutrophication	Global warming	Ozone depletion	Photochemical oxidation	Carcinogenics	Non-carcinogenics	human health respiratory effects, average
		Units	kg SO_2 eq	CTUe	kg N eq	kg CO_2 eq	kg CFC-11 eq	kg O_3 eq	CTUh	CTUh	kg PM2.5 eq
Cotton production	0.412	kg	1.19E-02	1.80E+01	9.81E-03	1.58E+00	1.51E-07	1.04E-01	7.09E-08	2.24E-07	2.19E-03
Sweater creation	0.412	kg	1.97E-01	2.09E-01	4.34E-03	1.86E+01	4.01E-10	1.15E+00	3.36E-09	1.29E-07	3.16E-02
Packaging	0.018	kg/sweater	2.23E-06	2.65E-03	2.41E-06	6.92E-04	NA	2.41E-05	2.44E-11	1.03E-10	4.75E-07
Transportation	1	sweater	1.54E-01	1.67E-02	1.42E-02	1.45E+00	1.88E-08	1.26E+00	1.58E-04	2.64E-01	3.37E-02
Use	28	cycles	8.30E-02	7.09E-01	3.47E-03	2.88E+01	1.09E-08	4.91E-01	2.59E-09	8.71E-08	5.12E-03
Total	1	sweater	4.46E-01	1.89E+01	3.18E-02	5.04E+01	1.81E-07	3.01E+00	1.58E-04	2.64E-01	7.26E-02

Table 1. Complete life cycle of a 100% cotton sweater. The environmental impacts, as described by the nine TRACI impact categories, are displayed for cotton production, sweater creation, packaging, transportation, and the use of this sweater. Total impacts of the sweater are also displayed in the bottom row.

100% Wool		Impact category	Acidification	Ecotoxicity	Eutrophication	Global warming	Ozone depletion	Photochemical oxidation	Carcinogenics	Non-carcinogenics	human health respiratory effects, average
		Units	kg SO_2 eq	CTUe	kg N eq	kg CO_2 eq	kg CFC-11 eq	kg O_3 eq	CTUh	CTUh	kg PM2.5 eq
Wool production	0.35	kg	1.61E-02	2.11E-01	5.46E-03	1.34E+00	1.10E-08	3.42E-02	3.40E-09	1.22E-10	6.24E-04
Sweater creation	0.35	kg	3.82E-02	2.08E+00	3.23E-03	1.10E+01	8.69E-07	3.37E-01	3.29E-08	1.45E-07	1.82E-02
Packaging	0.018	kg/sweater	2.23E-06	2.65E-03	2.41E-06	6.92E-04	NA	2.41E-05	2.44E-11	1.03E-10	4.75E-07
Transportation	1	sweater	9.77E-03	8.43E-03	2.45E-03	1.15E+00	9.48E-09	3.44E-01	7.99E-05	1.33E-01	8.86E-04
Use	28	Washes	2.48E-02	2.12E-01	1.04E-03	8.63E+00	3.27E-09	1.47E-01	7.75E-10	2.61E-08	1.53E-03
Total	1	sweater	8.89E-02	2.51E+00	1.22E-02	2.21E+01	8.92E-07	8.62E-01	8.00E-05	1.33E-01	2.13E-02

Table 2. Complete life cycle of a 100% wool sweater. The environmental impacts, as described by the nine TRACI impact categories, are displayed for wool production, sweater creation, packaging, transportation, and use. Total impacts of the sweater are displayed in the bottom row.

60% cotton/40% polyester		Impact category	Acidification	Ecotoxicity	Eutrophication	Global warming	Ozone depletion	Photochemical oxidation	Carcinogenics	Non-carcinogenics	human health respiratory effects, average
		Units	kg SO2 eq	CTUe	kg N eq	kg CO2 eq	kg CFC-11 eq	kg O3 eq	CTUh	CTUh	kg PM2.5 eq
PET production	0.218	kg	9.44E-03	4.66E-02	7.78E-03	1.25E+00	1.20E-07	8.26E-02	5.63E-08	1.78E-07	1.74E-03
Cotton production	0.327	kg	1.38E-03	1.43E+01	1.35E-04	1.08E+00	2.59E-11	1.60E-02	3.12E-10	1.61E-08	6.83E-05
Sweater creation	0.545	kg	8.49E-02	5.73E-01	3.06E-03	2.09E+01	7.51E-12	7.42E-01	8.51E-09	1.84E-07	4.91E-02
Packaging	0.018	kg/sweater	2.23E-06	2.65E-03	2.41E-06	6.92E-04	NA	2.41E-05	2.44E-11	1.03E-10	4.75E-07
Transportation	1	sweater	9.18E-03	8.61E-03	3.81E-03	1.07E+00	9.69E-09	3.19E-01	8.17E-05	1.36E-01	8.46E-04
Use	28	cycles	1.10E-01	9.38E-01	4.58E-03	3.81E+01	1.44E-08	6.49E-01	3.42E-09	1.15E-07	6.78E-03
Total	1	sweater	2.15E-01	1.58E+01	1.94E-02	6.24E+01	1.44E-07	1.81E+00	8.18E-05	1.36E-01	5.86E-02

Table 3. Complete life cycle of a 60% cotton, 40% polyester sweater blend. The environmental impacts, as described by the nine TRACI impact categories, are displayed for PET production, cotton production, sweater creation, packaging, transportation, and use. Total impacts of the sweater are displayed in the bottom row.

100% acrylic		Impact category	Acidification	Ecotoxicity	Eutrophication	Global warming	Ozone depletion	Photochemical oxidation	Carcinogenics	Non-carcinogenics	human health respiratory effects, average
		Units	kg SO2 eq	CTUe	kg N eq	kg CO2 eq	kg CFC-11 eq	kg O3 eq	CTUh	CTUh	kg PM2.5 eq
Acrylic fiber and sweater creation	0.445	kg	NA	NA	NA	5.39E+01	NA	NA	NA	NA	NA
Packaging	0.018	kg/sweater	2.23E-06	2.65E-03	2.41E-06	6.92E-04	NA	2.41E-05	2.44E-11	1.03E-10	4.75E-07
Transportation	1	sweater	8.21E-02	1.00E-02	2.71E-03	7.83E-01	1.13E-08	2.26E-01	1.59E-01	3.02E-04	4.13E-04
Use	28	cycles	8.96E-02	7.66E-01	3.74E-03	3.11E+01	1.18E-08	5.30E-01	2.80E-09	9.41E-08	5.53E-03
Total	1	sweater	1.72E-01	7.79E-01	6.45E-03	8.58E+01	2.31E-08	7.56E-01	1.59E-01	3.02E-04	5.95E-03

Table 4. Complete life cycle of a 100% acrylic sweater. The environmental impacts, as described by the nine TRACI impact categories, are displayed for acrylic fiber and sweater creation, packaging, transportation, and use. Total impacts of the sweater are displayed in the bottom row. Fiber production and sweater creation data was unable to be disaggregated from Beton et al. (2014), who only studied global warming potential as an impact.