

What's the Real Environmental Impact of Your Wardrobe? A Life Cycle Assessment Approach

Xingqiu Lou, Kent State University
Victoria Gonzalez, Washington State University
Ting Chi, Washington State University

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Introduction. The general population is increasingly becoming more environmentally conscious, and this trend has extended to various professional industries, including the textile and apparel industry, which is considered one of the most polluting industries worldwide (Jia et al., 2020). The manufacturing of textiles emits 1.2 billion tons of carbon emissions annually (Ellen MacArthur Foundation, 2017). Fashion has become one of the most prominent players in the climate change contribution game, responsible for nearly 4% of global GHG emissions (McKinsey & Global Fashion Agenda, 2020). As environmental awareness in the textile and apparel industry has expanded, various tools have been developed to evaluate sustainability performance throughout the product lifecycle. Life cycle assessment (LCA) is a well-established method, which provides a standardized framework to quantitatively evaluate the potential environmental impacts from the raw material stage to end disposal.

Literature Review. Apparel products undergo a series of different stages in their lifecycle, including raw material extraction, processing, manufacturing, and end-of-life (Mu, Xin, & Zhou, 2020). Each stage of the apparel lifecycle yields different environmental impacts due to different production and consumption practices. Furthermore, the type of fiber utilized for apparel products has different sources and production requirements and yields different environmental impacts across the product's lifecycle. For example, cotton cultivation requires substantial amounts of fertilizers, pesticides, and energy, resulting in adverse effects on the environment and human health (Jin et al., 2011). Other fibers such as flax and jute have environmental advantages over cotton, as they require much less water to grow and have lower environmental impacts in production processes (La Rosa & Grammatikos, 2019; Moazzem et al., 2021).

There are several LCA studies evaluating the environmental impacts of textile products. However, most of them have focused on limited product life cycle stages. Other LCAs have concentrated on one specific type of fiber or a limited number of fibers (e.g., cotton/polyester, cotton/organic cotton). The purpose of this study is to analyze and quantify six commonly used fibers in the textile and apparel industry by comparing their potential environmental impacts created at each stage of the supply chain. The six fibers analyzed in this study include 100% conventional cotton, 100% organic cotton, 100% polyester, 100% jute, 100% flax, and 100% silk. These fibers were selected due to their significant market share size.

Methodology. The study employed a life cycle assessment methodology with a cradle-to-gate system boundary and analyzed the stages of agriculture, spinning, weaving, and dyeing. The

functional unit is 1 kg of each fiber. Input and output data were obtained from the Ecoinvent v3.8 database. The results were then evaluated based on the impact categories in the ReCiPe (2016) methodology, which is one of the most commonly utilized methodologies in LCA academic research. The impact categories include climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionizing radiation, agricultural land occupation, urban land occupation, natural land transformation, depletion of fossil fuel resources, depletion of minerals, and depletion of freshwater resource.

Results and Discussions. In agriculture production, silk has the highest impacts across all impact categories, except for human non-carcinogenic toxicity. Its production results in significant terrestrial ecotoxicity and global warming, mainly due to activities such as emissions of phosphorous to water and soil during soil maintenance, emission of metals to soil, transportation of mulberry leaves, production of Kraft paper used for covering silkworms, and electricity generation (Barcelos et al., 2020). Conventional cotton consistently generates more environmental impacts than organic cotton, except for certain categories such as freshwater eutrophication, land use, marine eutrophication, and stratospheric ozone depletion. Organic cotton seeds are not genetically modified. As a result, more land is needed to produce the same amount of fiber as conventional cotton, resulting in a significant difference in land use values between the two fibers. Flax generally has a higher environmental impact than jute, but its impact is lower than that of cotton varieties. Polyester has a lower impact on stratospheric ozone depletion compared to natural fibers due to its synthetic origin, but it significantly impacts terrestrial ecotoxicity and global warming. Polyester fabric is often treated with sulfuric acid and petroleum products (Veolia, 2021), leading to a greater terrestrial ecotoxicity impact. The creation of polyester fibers involves energy and heat-intensive processes, which contributes to its high impact on the global warming impact category.

Conventional cotton, silk, and jute were included in the comparison for yarn preparation and spinning and weaving stages due to data availability. Among these three fibers, silk has the most significant impact, while jute has the least significant impact in most categories. The constant temperature required in the silk spinning process and the energy-intensive process of transferring silk fiber to reels are potential contributors to its significant impact (Astudillo et al., 2014). Additionally, advanced shuttle-less looms used in modern silk weaving contribute to the significant impact on global warming and fossil resource scarcity. Conventional cotton has the second leading impact in most categories, primarily due to electricity and water use during fiber acquisition. Data for the dyeing stage was only available for conventional cotton batch dyeing techniques. Global warming is one of the most significant impacts, with direct CO₂ emissions from burning hard coal to generate steam for this stage contributing to this impact (Zhang et al., 2015). Terrestrial ecotoxicity is also high, with the release of nickel and zinc from dyes being a significant contributor (Yacout et al., 2016).

Implications and Future Research Directions. The study highlights the importance of considering the entire product lifecycle when evaluating the sustainability of textile and apparel products and emphasizes the significant impact the choice of fiber type can have on the environment. These findings provide stakeholders with a deeper understanding of LCA research in the textile and apparel context, assisting them in identifying more sustainable fibers. Furthermore, the study's results can help consumers make informed decisions when purchasing textile and apparel products, facilitating the transition towards more sustainable fashion supply chains.

Future research can expand the scope of this study to include other fibers and their blends as well as sub-stages of the apparel lifecycle to enhance the understanding of the environmental impacts of textile and apparel production. It is also essential to explore the social and economic impacts of different fibers and production processes in addition to their environmental impacts.

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