Extended Abstract
6th PLATE 2025 Conference
Aalborg, Denmark, 2-4 July 2025

Environmental Impact factors for Apparel Products: Generalizing LCAs with Statistical “Market-mix” Modeling

Tamar Makov[a], David Font Vivanco[b]
a) Management Department, Ben Gurion University of the Negev, Israel
b) Eco Intelligent Growth SL, Spain

Keywords: Apparel; LCA; Reuse; second-hand; macro-level; GHG emissions; land use; water

Introduction

Life Cycle Assessment (LCA) is a bottom-up approach widely considered the gold standard for assessing the full lifecycle environmental impacts of products or services (Guinée, 2002). In the apparel sector, process-based LCA is commonly used to quantify the environmental impacts associated with a particular product, and identify environmental hotspots along the full lifecycle. For example, in their seminal paper on fast fashion, Niinimäki et al., 2020 use LCA results for a specific cotton T-shirt and a pair of jeans to highlight how much GHG and water a single fashion item is associated with. As they demonstrate, production typically dominates the full lifecycle impacts of clothing, accounting for roughly 75% of GHG emissions, and 92% of water depletion. Yet while LCA is an extremely useful tool, preforming product base analyses tends to be costly and time-consuming even when the system boundaries focus on production and cradle-to-gate life stages. In practice, the public availability of apparel LCAs is limited and the variety of product types covered is narrow.

As a result, studies exploring the potential benefits of alternative business models in apparel (e.g. clothing libraries), policies (e.g. EPR) or consumption pattern shifts at the mosso or macro level, often base their environmental modeling on specific case studies extrapolating results (Sandin et al., 2019; Roichman et al., 2024; EEA, 2023). For example, Zmani, Sandin, and Peters (2017) use results for three specific garments, to study the potential environmental benefits of collaborative consumption across the entire Swedish population. Similarly, Roichman et al. (2024), use LCA results for two garment types to shed light on the GHG emissions associated with consumer returns more generally. Yet while such efforts help to understand the scope of potential impacts, drawing on specific case studies as the basis for more general analyses may be problematic.

LCAs are typically specific to the products modeled, their weight, material composition, supply chain specifications and modeling assumptions and choices such as the impact assessment methods used. As apparel product weights material composition etc. can vary substantially both within and between product categories, the specificity inherent to LCA makes it challenging to generalize findings from one product to another similar one, let alone draw insights across product categories (see for example Munasinghe, Druckman, and Dissanayake 2021, and differences between Roichman 2024; Niinimäki et al., 2020 and Moon, 2024). The generalizability challenge is particularly relevant in macro level analyses where there is need to assess environmental impacts of entire product populations, or when detailed product specific data is unavailable, too time consuming or too costly to collect. Such instances include, for example, analyses of sustainable business models including sharing or leasing, international trade in second-hand apparel where items are often sold in bulk, or analyses based on Material Flow Analysis (MFA) (Moon, 2024).

In other sectors, such as transport, a market mix approach is often used to estimate typical emissions per passenger-km in a specific region. Put simply, the market mix carbon intensity factor is a weighted average calculated based on the region’s automobile fleet composition, the relative frequency of different vehicles within it, and the respective GHG emissions associated with each type of vehicle.

As such a market mix approach allows for a more generalized analysis by considering the typical characteristics and market share of various products within the segment. Here we operationalize the idea of an apparel market mix, to provide robust, data driven impact factors for common apparel product categories (e.g. tops, bottoms, sportswear etc. See Table 1).

	GWP 100 (kg CO_2e)				Land use (m^3)				Water deplation			
Category	Mean	std.	Min	Max	Mean	std.	Min	Max	Mean	std.	Min	Max
Tops	10.71	1.41	6.54	14.48	9.093	1.300	5.626	12.881	4.413	0.649	2.628	6.564
T-shirts, shirts and blouces	3.08	0.20	2.48	3.65	2.134	0.136	1.703	2.467	1.606	0.104	1.319	1.917
Bottoms (full)	10.47	0.81	7.85	12.69	7.544	0.609	5.872	9.114	5.009	0.385	3.954	6.136
Bottoms (short)	4.64	0.29	3.77	5.36	2.953	0.219	2.342	3.555	2.013	0.155	1.564	2.399
Dresses	11.19	2.58	4.78	18.81	4.265	1.122	1.410	7.214	2.999	0.811	0.955	4.973
Accessories (gloves)	1.33	0.22	0.77	1.91	1.428	0.233	0.842	2.016	0.266	0.046	0.151	0.381
Jackets and blazers (anoraks, ski jacktes, raincoats etc.)	15.51	3.02	8.57	23.96	13.608	3.037	5.351	22.210	2.190	0.392	1.214	3.269
Overcoats, car coats, capes, etc.	34.19	4.33	21.75	44.76	34.948	4.477	21.557	47.236	5.606	0.714	3.459	7.423
Scarves, shawls, ties etc.	3.31	0.38	2.26	4.31	3.467	0.440	2.263	4.550	0.781	0.089	0.517	1.053
Sportswear	8.74	0.79	7.02	10.76	5.155	0.479	4.083	6.313	3.906	0.362	3.112	4.799
Suits & ensembles	29.64	2.65	23.26	37.48	33.157	2.982	26.031	42.354	4.682	0.423	3.753	5.911
Swimwear	1.75	0.27	1.06	2.43	0.766	0.130	0.450	1.084	0.598	0.106	0.352	0.848

Table 1: Environmental impacts associated with the production of a single generic unit (i.e. product) by product category.

Methods and results

To generate representative, general cradle to gate environmental impact factors for a typical, generic item in each apparel product category (e.g. tops, underwear, jackets), we constructed a modular, open access LCA tool using Brightway (https://docs.brightway.dev/en). Specifically, for each product category (e.g. Tops) we first modeled the distributions of product sub-categories (e.g. blouse, T-shirts) based on their market frequency. Next for each sub-category, we modeled per item weight distributions and typical material compositions based on a comprehensive report on apparel in the EU (Beton, 2014). Drawing from these distributions using a series of Monte Carlo simulations, we randomly sampled an item weight and used it along with the sub-category's respective material composition to calculate the mass of each material (e.g. silk, cotton, viscose). Next, we modeled all relevant production inputs and processes including weaving, knitting, washing, drying, and finishing according to their relative production prevalence, and calculated the cradle-to-gate impacts associated with materials and item manufacture according to the specified impact category (i.e., GWP100 (IPCC2021), water depletion, and land use (ReCiPe2016(H) midpoint)). We then repeated the process 10^4 times, to generate the typical impact distributions and calculate the mean, standard deviation, and min and max ranges for each product category's market mix. Environmental impact factors per item in each product category are presented in Table 1.

As reflections of the market mix of items, our results can be used as general impact factors for different apparel product categories, in cases where one needs to model the entire population or when detailed, product level data is unavailable. Importantly, all parameters of materials, weights, and relative frequency can be adjusted and updated by users, to reflect aspects such as localize parameters for to a particular region or changes in apparel product populations over time as these become available.

Conclusions

Interest in the environmental impacts of fashion and appeal is rising (EPRS, 2019), and there is growing need for general benchmarks at the product category level and impact factors that can be used for scenario analyses or with aggregate datasets lacking detailed product descriptions. Here we develop a dedicated open access Brightway tool and generate impact factors which represent the market mix of different apparel product categories. By simplifying complex systems, our approach and results enable actionable insights without relying on exhaustive, product-specific analyses.

Acknowledgments

This work is partially funded by GIF and the Sloan foundation through the nDEE

References

Beton, A., Dias, D., Farrant, L., Gibon, T., Le Guern, Y., Desaxce, M., Perwuelz, A., Boufateh, I., Wolf, O., Kougoulis, J., Cordella, M., & Dodd, N. (2014). *Environmental improvement potential of textiles (IMPRO Textiles)*. European Commission Joint Research Centre, Institute for Prospective Technological Studies. https://doi.org/10.2791/52624

European Environment Agency. (2023). The destruction of returned and unsold consumer goods in the EU: A legal analysis of possible approaches to prevent waste. *https://www.eea.europa.eu/publications/the-destruction-of-returned-and*

Guinée, J. B. (Ed.). (2002). *Handbook on life cycle assessment: Operational guide to the ISO standards.* Kluwer Academic Publishers.

Moon, D. (2024). Promoting sustainable practices: Exploring secondhand clothing consumption patterns and reductions in greenhouse gas emissions in Japan. Sustainable Production and Consumption, 45, 294–305. https://doi.org/10.1016/j.spc.2024.01.0154o

Munasinghe, P., Druckman, A., & Dissanayake, D. G. K. (2021). A systematic review of the life cycle inventory of clothing. *Journal of Cleaner Production, 318,* 128559. https://doi.org/10.1016/j.jclepro.2021.128559

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment, 1*(4), 189–200. https://doi.org/10.1038/s43017-020-0039-9

Roichman, T., Sprecher, B., Blass, V., Meshulam, T., & Makov, T. (2024). The convenience economy: Product flows and GHG emissions of returned apparel in the EU. *Resources, Conservation and Recycling, 210,* 107811.https://doi.org/10.1016/j.resconrec.2024.107811

Sandin, G., Roos, S., Spak, B., Zamani, B., & Peters, G. (2019). Environmental assessment of Swedish clothing consumption: Six garments. *Sustainable Futures*. Mistra Future Fashion. Retrieved from http://mistrafuturefashion.com/wp-content/uploads/2019/08/G.Sandin-Environmentalassessment-of-Swedish-clothing-consumption.MistraFutureFashionReport-2019.05.pdf

Zamani, B., Sandin, G., & Peters, G. (2017). Life cycle assessment of clothing libraries: Can collaborative consumption reduce the environmental impact of fast fashion? *Journal of Cleaner Production, 162,* 1368–1375. https://doi.org/10.1016/j.jclepro.2017.06.128

European Parliamentary Research Service. (2019). *Environmental impact of the textile and clothing industry*. Retrieved from https://www.europarl.europa.eu