Life Cycle Analysis Assessment by Maakola

Comparison of the environmental impact of an organic Maakola T-shirt on demand and for rent, versus a regular T-shirt.

Maakola has put sustainability at the core of its business practices and products from the beginning. A proprietary life cycle assessment (LCA) methodology and tool was developed to calculate and assess the carbon footprint of Maakola's products. Independent environmental consultants developed the initial LCA tool in alignment with ISO 14040-14044 and it was further fine tuned and finalized by Engineer Drs. K. Herdewyn.

This LCA tool as well as the resulting estimates of global warming potential and water depletion, first and foremost guide Maakola's mission to maximally drive down climate impact through identifying and reducing emissions. The purpose of this document is to provide transparency by sharing the details behind the carbon footprint calculations, including assumptions, data sources, and potential improvements. It also guides us in our data-driven approach at every stage, from design to product development, to production towards becoming carbon neutral, and hopefully one day carbon positive.

Maakola's LCA tool and the footprints that were calculated from it are a work in progress with the ultimate goal of continually reducing the carbon footprint of Maakola's products over time. The LCA tool and results will continue to evolve and improve over time as we optimize our products for lower impact, the assumptions are replaced with actual data, and the methodology and data sources are updated.

1 BACKGROUND

This Carbon Footprint Assessment for Apparel aims to cover the lifecycle assessment (LCA) by a combination of a review of academic studies published in scientific journals and also calculating the LCA based on industrial processes and raw materials products available in attributional databases built based on ISO14040 and ISO14044, such as Ecoinvent 3 (Wernet et al., 2016) and Sardin et al., 2019.

2 LCA METHODOLOGY OUTLINE

The increasing awareness of the importance of sustainability and the potential environmental consequences associated with products and services has sparked the innovation of methods to better understand, measure, and reduce this impact. The leading tool for achieving this – and the only tool that can make a full evaluation of all sources and types of impact over the entire life cycle of a product – is life cycle assessment (LCA), a methodology defined by the International Organization for Standardization (ISO) 14040-14044 standards.

LCA is an internationally recognized approach that evaluates the potential environmental and human health impact associated with products and services throughout their life cycle or considering a portion of their lifecycle, beginning with raw material extraction and including transportation, production, use, and end-of-life treatment. Among other uses, LCA can identify opportunities to improve the environmental performance of products at various points in their life cycle, inform decision-making, and support marketing and communication efforts. Table 1 depicts the main lifecycle impact assessment (LCIA) indicator to be considered in this LCA.

At Maakola, we created an LCA tool to estimate the carbon footprint of the garments and accessories we develop. By doing so, we are able to identify critical processes in our supply and value chain and work towards reducing greenhouse gas emissions. At Maakola we developed the initial LCA, the methodology behind it, and validated the data used to calculate the carbon footprint of our garments. The chosen software was OpenLCA version 1.10.2 from GreenDelta and the data used was largely based on Ecoinvent 3.7. The chosen life cycle impact assessment (LCIA) method was ReCiPe 2016 Midpoint with an Hierarchist perspective.

The purpose of this methodology document is not only to disclose the carbon footprint (GWP) calculation formula and the other indicators described in Table 1 but also to give more insight and details on the assumptions that were made, the literature consulted, and sources of our data. The results of this study were achieved by combining quantitative life cycle analysis and reviewing literature in the field.

The LCA tool that we present here, and the resulting carbon footprints for our Maakola products, will continue to evolve and improve over time as more accurate data becomes available and we put continuous effort towards reducing the carbon footprint by optimizing our products, production, and business model. As always, we welcome your feedback.

Indicator	Unit	Method	Justification
Climate Change or Global Warming Potential (GWP)	kg CO_2 eq.	IPCC 2013 100y v1.02	This indicator is key in any human activity and is currently under the spotlight.

Table 1 Indicator and impact assessment method

3 STANDARD SUSTAINABILITY PRACTICES AT MAAKOLA

The impact on the planet and society drives our business practices at Maakola. The methods used to calculate the environmental impact of what we make, how we make it, and how our products are used, reflect that: the LCA study models and compares the carbon footprint of a garment that is either bought or rented. Both consumer models are applied to the same Maakola product, by the same product suppliers with specific quality demands on the developed products. For benchmarking purposes, we also used the calculated quantitative carbon footprint data as a base for understanding how similar garments with various life cycles, like fast fashion, affect climate change.

The practices listed below are applied across all Maakola products with the main goal to reduce their carbon footprint:

- We always select the raw materials with the lowest impact for the application. In most cases, this means fabrics made from natural fibers like cotton, wool, silk, Tencel, etc., or recycled materials. Our refined material selection methodology is geared towards natural materials, in contrast to synthetic or petroleum-based materials like polyester. When grown organically, these natural materials not only have a lower initial carbon footprint to produce, they can also act as a carbon sink.

- Everyone we work with along our supply chain obtained the necessary certifications attesting to their commitment towards humane and environmentally friendly production.
- We prefer working with local and small-scale manufacturers with whom we have a personal connection. This allows us not only to guarantee transparency but also to collaborate with them on implementing improvements for more efficient and green production methods, like for example the conversion to renewable energy.
- We don't measure the carbon footprint of our products alone. From trims to packaging, at each step, we try to make the best decision possible. And we are transparent about it by publishing every detail on the blockchain, which can be consulted at any given time by our customers or partners.

4 FUNCTIONAL UNIT, BOUNDARIES AND RAW MATERIALS

The described LCA methodology for Maakola products calculates the equivalent kilograms of carbon dioxide emitted. The resulting value includes emissions associated with (raw) materials, supply and demand manufacturing (either on-demand production or fast fashion), transportation, product use, and end of life to the extent that it is possible to estimate those.

4.1 Life Cycle Stage Overview

The overview of the processes included in the model at each step of the life cycle analysis is herein presented.

1. Textile and Garment Production

1.1 Growing and extraction of raw materials for textile production.

1.2 Manufacturing of garment

Turning fabric into a finished garment. This includes the energy that is needed to complete cutting, stitching, pressing, adding trimmings, sewing, etc. Mending apparel was assumed to require the same energy demand as assembly.

1.3 Transportation

Transportation of finished goods to the Maakola warehouse and/or atelier.

2. Product Usage

2.1 Washing of product over its lifetime.

Assumed lifetime of the products

- 30 washes for a bought on demand garment.

- 45 washes for a rented on demand garment.

- 7 washes for a fast fashion garment.

2.2 Transport

Due to the fact that Maakola's products are made-to-order, returns – an important source of carbon emissions - can be excluded from our analysis.

3. End of Life

Disposal of the product at the end of its life in landfill or buried, assuming full use of the product in accordance with the above-mentioned assumed lifetime.

4. General:

A cut-off was implemented in the model.

4.1 Product Units

Depending on the pattern and complexity of the garment, more or fewer assembly steps are needed. The carbon footprint is also determined by the produced size. To simplify the analysis, we have used averages based on our production quantities and agreed on the boundary condition that all garments have the same mass. Thus, the functional unit considered was 1 garment.

4.2 Boundaries

It was considered the cradle-to-grave boundary from raw material production to apparel production, usage, and end of life. The primary (first) production of materials was always allocated to the primary user of a material.

To simplify calculations, we had to exclude some parameters:

- Emissions at the company level (office space, business travel, energy for computers, etc.) – even though everyone at Maakola incorporates sustainable living in their lifestyle and this is reflected in the decisions we make in and around the office as well.
- Emissions associated with threads and trimmings used in the garments.
- Emissions associated with the processing of the raw materials into finished textiles. This includes spinning of yarn, weaving, coloring or dyeing, etc. as well as the transportation of raw materials to textile manufacturer.
- Emissions associated with the implementation of Vechain blockchain technology.
- Emissions associated with shipping between the Maakola warehouse and consumer, as well as from the consumer to landfill – as this is not possible to estimate accurately in the global market we operate in.
- Emissions associated with physical retail locations. At the moment we sell only online and small batches to popup stores.

5 ACADEMIC LITERATURE REVIEW OF LCA

A literature review was conducted to properly understand and model the life cycle of a cotton garment. All information was obtained from either scientific peer-reviewed sources, unbiased industry organizations, or unbiased NGOs.

The carbon footprint was calculated using primary and secondary data sources, including other life cycle assessments, material databases, and scientific literature reviews. Primary data is used when available and where appropriate, substantiated with industry-specific data. The credibility of any non-peer-reviewed source was discussed in the study when it was brought up.

To this day, the amount of available literature and research is still relatively limited, especially when it comes to specificity to geographical locations. While all our assumptions were made based on acknowledged research or literature, the results are largely obtained from using averages and will be further fine-tuned as more specific data becomes available. Below is a list of assumptions applied in the analysis:

- As stipulated throughout this document, it is difficult to make accurate estimates when we, as a manufacturer, are no longer in control of the product and production, for example during the use phase and end of life. Even though these phases are very important in the carbon footprint of a garment. We used conservative assumptions based on averages for the number of washing and drying cycles, as well as our garment's lifetime. We hope to refine these estimates as we continue to collaborate with manufacturers to measure and share real data, as research on these topics becomes more widespread, and we can use our own customer data (i.e. blockchain applications WearMe30Times).

- For some parts of the supply chain, due to a lack of data, we used industry averages instead of data from our specific supply chain.

- Finally, we also have the ambition to not just calculate the carbon footprint of our garments but follow a holistic approach that not only looks at carbon emissions, but also water, waste, social impact, etc. as standards become available for those.

A systematic academic review of the state of the art in LCA applied to production of cotton garments was performed to have a full picture of previous studies following a scientific method. Thus, a systematic academic review was conducted using articles published and available in ScienceDirect, SCOPUS, ResearchGate, and MDPI, world-class scientific repositories. Different articles were identified searching for the following character strings: "LCA" + "cotton"; "Lifecycle assessment" + "cotton"; "Lifecycle" + "organic cotton". From this point, articles were read, analyzed, and selected in case they provided useful information for the study.

5.1 LCA Data Sources

Corresponding to the outlined methodology under section 4, the different steps in the LCA are:

1. Cotton Textile & Garment Production
2. Use Phase, mostly driven by washing and mending
3. End of Life

Cotton Textile & Garment Production

The step "cotton textile production" in this analysis is limited to the cradle-to-gin phase which focuses on the growth of the (organic) cotton through the harvest into bales. At this point, we are unable to include the part of the textile production from gin to the (organic) cotton textile because of three main reasons. First of all, the consumption of resources (water and energy) as well as carbon emissions are heavily dependent on the yarn size and processing techniques (weaving, knitting, dying, etc.) on which we don't have accurate information. Secondly, at this time we cannot obtain enough detailed information from our suppliers on the geographical origin of the fabrics we are using. Finally, literature and databases cover mostly the first phase of textile production included in our analysis and only very limited - because of the dependencies outlined above - for the stages afterward. As we are performing comparative analysis, we chose to omit the gin-to-fabric stage and use more updated, documented (and thus reliable) data from cradle-to-gin instead. We highlight that our LCA assessment is a work in progress and we aim to work closer to the source so we can access more accurate data in next iterations and avoid making too many assumptions.

Cotton Garment Production and Distribution

The making of a garment is a time and labor-consuming process that often involves manual labor at some point. After the textile material has been woven or knitted, the next step is to ship it to a clothing production facility to finalize the product. The process from spinning yarn to producing the clothing is sometimes carried out in the same spot. Regardless of if the clothing assembly is carried out in a factory or not, the actual sewing of garments is done using a sewing machine. The average T-shirt is done in 5 to 6 minutes (Howlander, Islam, & Prasad, 2015), which is assumed to be the effective time and use of sewing machines and any other equipment surrounding the assembly process. According to Palamutcu (2010), power usage from clothing production is roughly equal to the power usage from other equipment surrounding the actual production process.

A sewing machine in industrial settings was assumed to use 490 W implying an estimate of 49 Wh of energy consumption. This data comes from manufacturers and resellers and is considered accurate enough for the purposes of this analysis.

Model	Power (W)
Juki DDL-8700	450
Consew 206RB-5	550
Juki DDL-550N	500
Singer 191D-30	400
Juki LU-2810S	550

Table 2 Industrial grade sewing machines

The step "cotton garment production" was modeled with three input product flow types: (1) material, (2), electricity for sewing machines as described above, and (3) transport, and one output product flow type: (1) cotton garment. We analyzed the two business models (selling and renting) implemented at Maakola and included the impact of a similar fast fashion garment for comparison purposes. The inputs and outputs for the different apparels are summarized in the table below.

A systematic academic review in Scopus scientific repository was performed with the aim of collecting the carbon footprint and water depletion corresponding to conventional cotton (depicted in Table 3). It was found enormous variability in the environmental impact associated with cotton fiber production due to different factors: production country, type of climate, and irrigation and technology considered for cotton farming. Thus, the carbon footprint of cotton fibers is often calculated to be in the range of 0.5 to 4 kg CO_2 equivalents per kg fibers (excluding CO_2 sequestered in the fiber), frequently described with results up to about 6 kg CO_2 equivalents – so the variations span about one order of magnitude.

Eventually, based on review by Sardin et. al using data from Textile Exchange, Ecoinvent databases, and scientific publications, conventional cotton fiber production averaged a carbon footprint of 2.2 kgCO2e/kg and water depletion of

4.8 m3 per kg of cotton fiber production, while organic cotton averaged 0.98 kgCO2e/kg and 0.182 m3, for carbon footprint and water depletion, respectively.

Table 3 and 4 depict the carbon footprint and water depletion of different used processes for apparel lifecycle, while Table 5 describes the process requirements for manufacturing the apparel.

Process	Input Unit	Carbon Footprint (GWP)	Output unit
Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, S - Copied from Ecoinvent	1 kg.km	0.00016406	kg CO2 eq
Electricity, low voltage {RER}| market group for | Cut-off, S - Copied from Ecoinvent	1 kWh	0.52104	kg CO2 eq
Transport, freight, sea, transoceanic ship {GLO}| market for | Cut-off, S - Copied from Ecoinvent	1 kg.km	0.00001156	kg CO2 eq
treatment of inert waste, sanitary landfill | inert waste | APOS, S	1 kg	0.01089	kg CO2 eq

Table 3 Carbon footprint for processes from ecoinvent 3.7

Process	Input Unit	Water Depletion (WD)	Output unit
Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, S - Copied from Ecoinvent	1 kg.km	1.62E-04	m3
Electricity, low voltage {RER}| market group for | Cut-off, S - Copied from Ecoinvent	1 kWh	5.46	m3
Transport, freight, sea, transoceanic ship {GLO}| market for | Cut-off, S - Copied from Ecoinvent	1 kg.km	2.08E-05	m3
treatment of inert waste, sanitary landfill | inert waste | APOS, S	1 kg	0.02307	m3

Table 4 Water Depletion for processes from ecoinvent 3.7

Apparel	In-/output	Flow name	Flow unit	Quantity
Rented	Input	Textile, woven cotton {GLO}| market for | Cut-off, S - Copied from Ecoinvent	Kg	0.15
	Input	Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, S - Copied from Ecoinvent	kg*km	620.58
	Input	Electricity, low voltage {RER}| market group for | Cut-off, S - Copied from Ecoinvent	Wh	49

	Output	Cotton garment, quality	Nr of items	1
Bought	Input	Textile, woven cotton {GLO}| market for | Cut-off, S - Copied from Ecoinvent	Kg	0.15
	Input	Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, S - Copied from Ecoinvent	kg*km	620.58
	Input	Electricity, low voltage {RER}| market group for | Cut-off, S - Copied from Ecoinvent	Wh	49
	Output	Cotton garment, quality	Nr of items	1
Fast fashion	Input	Textile, woven cotton {GLO}| market for | Cut-off, S - Copied from Ecoinvent	Kg	0.15
	Input	Electricity, low voltage {RoW}| market for | Cut-off, S - Copied from Ecoinvent	Wh	81.667
	Input	Transport, freight, sea, transoceanic ship {GLO}| market for | Cut-off, S - Copied from Ecoinvent	kg*km	3333.6
	Input	Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, S - Copied from Ecoinvent	kg*km	150.00
	Output	Cotton garment, fast fashion	Nr of items	1

Table 5 Inputs and outputs of Cotton garment production

All transport between production spots by land was assumed to be carried out with a lorry of Euro class 5. All transport by sea was assumed to be carried out with a transoceanic freight ship.

In the above analysis, Maakola is selling its products from Italy and Ghana, while getting its textile fabric from Italy, Portugal, the Netherlands, and Turkey, exclusively. The average distance between any of Italy, Turkey, the Netherlands, or Portugal, and Italy or Ghana, is roughly 4,137 km. Since the EU is the largest textile market today, fast fashion garments are assumed to be sold in the EU and imported from China (Niinimäki et al., 2020). The distance from the port of Shanghai to the port of Rotterdam is 22,224 km by seaway. Shanghai and Rotterdam were chosen as they are the largest export and import ports respectively in their regions. Besides, it was assumed truck transportation to a central warehouse of 1,000 km for fast fashion.

Besides, transactions were performed considering Vechain system, considered one of the least polluting blockchain systems with a strikingly low energy expenditure per transaction of 0.000216 kWh (Vechain, 2021). Considering that blockchain servers are in China, a very carbon and water-intensive electricity market, with a carbon footprint of 1.19 kgCO_2/kWh and water depletion of 9.23 m^3/kWh (Ecoinvent 3.7), this implies that the impact per transaction (considering one t-shirt per transaction) is as low as 2.57e-4 kgCO_2e and 1.99e-3 m^3.

Use Phase

The “Washing & Mending” phase will account for the user phase and was modeled with two input product flow types: (1) cotton garment and (2) electricity for mending and washing, and one output product flow type: (1) cotton garment. For all types of garments, the washings were assumed to be conducted in a washing machine that holds an EU Class A energy mark. This type of washing machine is assumed to use 50 kWh for 100 cycles when fully loaded with 12 kg (The European Commission, 2019). This entails that every 1 kg of garment in a fully loaded washing machine uses roughly 41.667 Wh for a washing cycle. Fast fashion apparel was assumed to average a use 7 cycles (Klepp et al., 2020). Water use for laundry averages about 6 liters per kg of apparel.

The inputs and outputs for a model cotton garment are summarised in the table below.

Apparel	In-/output	Flow name	Flow unit	Quantity
Rented	Input	Cotton garment, quality	Nr of items	1
	Input	Electricity, low voltage {RER}| market group for | Cut-off, S - Copied from Ecoinvent	Wh	285.4
	Output	Cotton garment, quality, rented, W&M	Nr of items	1
Bought	Input	Textile, woven cotton {GLO}| market for | Cut-off, S - Copied from Ecoinvent	Nr of items	1
	Input	Electricity, low voltage {RER}| market group for | Cut-off, S - Copied from Ecoinvent	Wh	187.5

	Output	Cotton garment, quality, bought, W	Nr of items	1
Fast fashion	Input	Textile, woven cotton {GLO}| market for | Cut-off, S - Copied from Ecoinvent	Nr of items	1
	Input	Electricity, low voltage {RoW}| market for | Cut-off, S - Copied from Ecoinvent	Wh	62.5
	Output	Cotton garment, fast fashion, W	Nr of items	1

Table 6 Inputs and outputs of washing, mending and drying

Since it was not known where the garments are sold or what type of transport customers use, it was not possible to include and was therefore excluded in the LC model. This entails any transport made by customers buying the garment was perceived as being generally the same, regardless of which type of garment they bought.

According to the Australian Circular Textile Association, roughly 30% of all produced clothes, globally, are never sold (Reed, 2019). Since this is information from a biased source, we assumed the real number to be slightly lower, closer to 25%, which entails that for every 4th garment produced, only three reach the customer. In this study, the rented garment lifecycle was used as the basis for the other two lifecycle models. The assumptions included in the model are:

1. 1 out of 4 fast fashion garments never reaches the customer.
2. All on-demand garments from Maakola reach the customer. Besides, any bought garment from Maakola will last 3 times longer than any fast fashion garment.
3. Any on-demand garments rented from Maakola reach the customer and will last 1.5 times longer than the equivalent on-demand garments purchased from Maakola due to proper care, mending, and delicate washing.

This leads to the following ratios used in the LCA: 1 rented garment life cycle = 1.5 bought garment life cycle = 6 fast fashion garment life cycles.

End of Life

The life span of a garment is often measured by the number of washes it can go through before losing its quality. When the quality of the garment is lost, it is assumed to be discarded. A fast-fashion garment is assumed to withstand roughly 10 washes (Morgan & Birtwistle, 2009) whereas we guaranteed that our Maakola products withstand a minimum of 30 washes without losing quality. Furthermore, if a garment is rented and brought back, Maakola ensures that proper care, mending, and gentle washing will further increase the lifespan of the garment by 50%.

To simplify the analysis, it was assumed that all garments were discarded only at the end of their life, but in the same way, i.e. landfill. However, Maakola's rented and bought on-demand T-shirt are in effect biodegradable and when buried in an open space (backyard), the fabric will decompose easily in 12-18 weeks and the threads in about 4 years. At this point, we can claim a carbon footprint of 0.

Apparel	In-/output	Flow name	Flow unit	Quantity
Rented, Purchased, Fast Fashion	Input	Textile, woven cotton {GLO}| market for | Cut-off, S - Copied from Ecoinvent	Kg	0.15
	Input	Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, S - Copied from Ecoinvent	kg*km	7.50
	Input	treatment of inert waste, sanitary landfill | inert waste | APOS, S	Kg	0.15
	Output	Cotton garment, quality	Nr of items	1

Table 7 Inputs and outputs of Cotton End of Life

6 RESULTS

Based on the afore-described LCA methodology, this chapter aims to compute the carbon footprint corresponding to different settings of garments, supply and demand, and materials.

APPAREL WITH CONVENTIONAL COTTON

The carbon footprint of one apparel of 0.15 kg of conventional cotton was addressed considering average carbon footprint values for conventional cotton textile production according to Sardin et al, 2019. Results of Tables 8 and 9 show the carbon footprint estimation considering both on-demand rented and purchased apparel and also fast fashion apparel with a lifespan of 10 cycles. The study approached the carbon footprint equivalent to 45 cycles of on-demand rented apparel compared to the equivalent lifespan with on-demand purchased and fast fashion. While on-demand rented apparel accounted for 0.61 kgCO_2e, considering the same on-demand apparel on a purchased scheme rose to 0.84 kgCO_2e and with fast fashion to 4.04 kgCO_2e, the latest showing a striking increase in carbon footprint.

Regarding the share of each process related to carbon footprint, cotton textile production (focused on cotton fiber production) accounted for the largest part, ranging from 54-70% of the total footprint. The garment production ranged 21-23% and the use phase accounted 7-25%. Regarding the end of life, its impact on the total carbon footprint was negligible at below 1%.

Table 10 depicts the water depletion, in which fast fashion accounted as 5.8 to 8.2 times more water-consumptiong than on-demand apparel rental and purchase, respectively. In this line, the embodied water in on-demand rented apparel was as low as 1.36 m^3, while the equivalent for an on-demand purchased apparel was 1.91 m^3.

Stage	On-demand Purchased	On-demand Rented	Fast Fashion
Cotton Textile Production (kg CO2eq)	0.49500	0.33000	2.82857
Garment Production (kg CO2eq)	0.19101	0.12734	0.90598
Product Use (kg CO2eq)	0.14654	0.14870	0.27913
End of Life (kg CO2eq)	0.00430	0.00286	0.02455
Total (kg CO2eq)	0.84	0.61	4.04

Table 8 Carbon footprint estimation adjusted to equivalence of 45 cycles of use with conventional cotton

Stage	On-demand Purchased	On-demand Rented	Fast Fashion
Cotton Textile Production	59.15%	54.20%	70.04%
Garment Production	22.83%	20.91%	22.44%
Product Use	17.51%	24.42%	6.91%
End of Life	0.51%	0.47%	0.61%
Total (kg CO2eq)	100%	100%	100%

Table 9 Carbon footprint share adjusted to equivalence of 45 cycles of use with conventional cotton

Stage	On-demand Purchased	On-demand Rented	Fast Fashion
Cotton Textile Production (m3)	1.08000	0.72000	6.17143
Apparel Production (m3)	0.55239	0.36826	4.62559
Product Use (m3)	0.27000	0.27000	0.27000
End of Life (m3)	0.00702	0.00468	0.04010
Total (m3)	1.91	1.36	11.11

Table 10 Water Depletion adjusted to the equivalence of 45 cycles of use with conventional cotton

APPAREL WITH ORGANIC COTTON

Organic cotton has been reckoned to reduce the carbon footprint of cotton textile production by 3.5 times compared to conventional cotton textile production (Niiniamki et al., 2020). The average carbon footprint found in the scientific review by Sardin et al. was used to compute the carbon footprint of a 0.15 kg organic cotton garment considering the same scenarios built in the previous subsection (on-demand rented, on-demand purchased, and fast fashion). Results showed that the total carbon footprint was significantly reduced by using organic cotton versus conventional cotton: from 0.61 kgCO_2 to 0.43 kgCO_2, respectively for on-demand rented garment. The same also applied for an on-demand purchased garment that lowered its carbon footprint from 0.84 kgCO_2 to 0.56 kgCO_2. Besides, it was addressed the impact of fast fashion garments with conventional cotton and organic cotton, obtaining an enormous reduction from 4.04 kgCO_2 to 2.47 kgCO_2.

Furthermore, the reduction in carbon footprint observed between conventional and organic cotton made the share of processes decrease, especially for the impact of cotton textile production, whose importance reduced from 54-70% to 35-51%. Variations in the other processes were observed for garment production and use phases.

Stage	On-demand Purchased	On-demand Rented	Fast Fashion
Cotton Textile Production (kg CO2eq)	0.22050	0.14700	1.26000
Clothe Production (kg CO2eq)	0.19101	0.12734	0.90598
Product Use (kg CO2eq)	0.14654	0.14870	0.27913
End of Life (kg CO2eq)	0.00430	0.00286	0.02455
Total (kg CO2eq)	0.56	0.43	2.47
Stage	On-demand Purchased	On-demand Rented	Fast Fashion
Cotton Textile Production	39.21%	34.51%	51.02%
Clothe Production	33.97%	29.90%	36.68%
Product Use	26.06%	34.91%	11.30%
End of Life	0.76%	0.67%	0.99%
Total (kg CO2eq)	100%	100%	100%

Table 11 Carbon footprint estimation adjusted to equivalence of 45 cycles of use with organic cotton

Regarding the water depletion organic cotton also contributed to a striking reduction compared to the values obtained with conventional cotton: a reduction of 51% for on-demand rented, 54% for on-demand purchased and 53% for fast fashion.

Stage	On-demand Purchased	On-demand Rented	Fast Fashion
Cotton Textile Production (m3)	0.04095	0.02730	0.23400
Apparel Production	0.55239	0.36826	4.62559

(m3)			
Product Use (m3)	0.27000	0.27000	0.27000
End of Life (m3)	0.00702	0.00468	0.04010
Total (m3)	0.87	0.67	5.17

Table 12 Water Depletion adjusted to equivalence of 45 cycles of use with organic cotton

7 CONCLUSIONS

While these calculations are specific to one particular design or product type, general conclusions can be drawn. The analysis made clear that the most environmentally friendly option for a consumer is to rent the desired garment from Maakola as it results in the lowest possible carbon footprint. This is not counting in any traveling done by the customer at any point in the lifecycle model. The option of buying from Maakola has the second-lowest carbon footprint, and the option of buying similar fast fashion apparel has the highest carbon footprint. This was calculated according to the lifespan of the rented garment, which equates to 1.5 life cycles of a bought apparel from the product supplier with specific quality demands, and 10 life cycles of the fast fashion apparel. In this line, this LCA study has been performed according to the guidelines and assumptions provided by Aurora Chiste for considering the lifespans of on-demand rented and purchased apparel. Table 13 collates the energy and water considerations for the LCA modeling.

Table 13 depicts the carbon footprint associated with a t-shirt manufactured on-demand (rented or purchased) versus fast fashion and considering conventional and organic cotton. It is remarkable that organic cotton with the on-demand scheme achieved the lowest indicators not only for carbon footprint but also for water depletion, with a carbon footprint of 0.44-0.58 kgCO$_2$e and water depletion of 0.97-1.33 m^3, strikingly lower than the equivalent with conventional cotton. Overall, it is notable that the scheme of on-demand production combined with a higher quality of materials in on-demand apparel lead to a striking reduction in the carbon footprint by 12.26 folds comparing fast fashion with the on-demand production & rent scheme. Likewise in other LCA studies covering the lifecycle of apparel, cotton textile production, and apparel production accounted for the major component in the carbon footprint.

Scheme	Fabric	Carbon Footprint (kgCO$_2$e)	Water Depletion (m^3)	Electricity (kWh)

On Demand	Rented	Conventional Cotton	0.61	1.36	0.33
		Organic Cotton	0.43	0.67	0.33
	Purchased	Conventional Cotton	0.84	1.91	0.24
		Organic Cotton	0.56	0.87	0.24
Fast Fashion		Conventional Cotton	4.04	11.11	1.15
		Organic Cotton	2.47	5.17	1.15

Table 13 Summary of LCA for apparel. It must be noted that Electricity considers the apparel production and use phases

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