

MEASURING FASHION

Environmental Impact of the Global Apparel
and Footwear Industries Study

Full report and methodological considerations

TABLE OF CONTENTS

I. INTRODUCTION	3
II. SCOPE & METHODOLOGY OVERVIEW	7
Scope of the study	8
Methodology Overview	9
Systems of analysis & system boundaries.....	10
III. FOOTPRINT BASELINE RESULTS	17
Total Baseline Footprint.....	18
Apparel Baseline Results	19
Footwear Baseline Results.....	26
IV. APPAREL INDUSTRY IMPACT GROWTH TRENDS	30
V. IMPACT REDUCTION SCENARIOS FOR 2030	35
VI. A SUSTAINABILITY FRAMEWORK FOR THE FUTURE	41
Goal Setting Framework.....	42
Future trends.....	43
Study Conclusion	45
VII. METHODOLOGICAL CONSIDERATIONS	46
Apparel Industry: Methodology & Assumptions	47
Assumptions	54
Footwear Industry: Methodology & Assumptions.....	59
Data uncertainty & gaps	62
Definition of impact indicators	63
References	65

I. INTRODUCTION



IT'S TIME FOR FASHION TO SET BOLD GOALS

The role of the global apparel and footwear industries has shifted far beyond meeting a basic human need. The relationship with fashion in our modern lives has had a collateral and significant impact on our planet's resources.

As we face urgent environmental and social challenges caused by climate change and resource depletion, the efficacy of solutions will depend on the creativity, innovation and boldness so characteristic of the fashion industry. It's time for players to change the trajectory.

This report encourages actors in the industry to set ambitious, evidence-based environmental impact reduction goals to drive meaningful change to secure a more sustainable future for fashion.

CORE OBJECTIVE AND GOALS OF THIS STUDY

With a view to drive bold Climate Action from the apparel and footwear industries, Quantis carried out a comprehensive study of the environmental impacts across both industries' value chains. The core objective is to inform on the current state of these industries' environmental performance and provide robust data to inform and empower them to use a science-based approach to reduce their impact (for example, by aligning with the Science Based Targets initiative or other leading initiatives). A special focus is put on greenhouse gas (GHG) emissions as well as water impact.

Stemming from this overarching ambition, the goals of the present study were defined as follows:

- Quantify the apparel industry's global environmental impacts across various indicators
- Assess data gaps to be addressed in further studies
- Study both historic and future data points to highlight trends and compare corresponding impact growth rates
- Provide key data-driven takeaways that can be used to promote industry-wide environmental progress of the apparel and footwear industries

The study ultimately delivers insights into the efforts necessary to reduce climate impact by the industry in the vicinity of 50% by 2030. The business potential is clear for key players in apparel and footwear businesses to drive ambitious sustainability efforts.

The present report, referred to in the topline report as the *full study*, contains the study's final results as well as provides more detailed information to readers of the topline report. The methodological considerations section provides background information on calculations and assumptions and also outlines data gaps and uncertainty estimates.

The audience of this study includes apparel and footwear brands and manufacturers as well as NGOs and think tanks. Conscientious consumers may also find it helps them to make more informed choices.

STEERING COMMITTEE AND STUDY CONTRIBUTORS

A steering committee representing industry experts and knowledge was put in place to review the data and assumptions used during the modeling phase of the study. According to their input and feedback, Quantis revisited and tested assumptions to ensure robustness. The steering committee met at the start of the project and during preliminary findings. Individual follow-ups were made to review final results.

Steering committee members included:

- Jason Kibbey, CEO, Sustainable Apparel Coalition
- Debera Johnson, Executive Director, Brooklyn Fashion + Design Accelerator, Pratt Center for Sustainable Design Strategies
- Megan McGill, Program Manager, C&A Foundation
- La Rhea Pepper, Managing Director, Textile Exchange

The Measuring Fashion study was based on data from the World Apparel & Footwear Life Cycle Assessment Database (WALDB). In addition, key WALDB members contributed to this study, including: Hugo Boss, Legero, Swiss Federal Office of the Environment, Sustainable Apparel Coalition, LVMH, Texaid, IKEA and Cotton, Inc.

This full study and summary report were developed and produced with the help of the following Quantis team-members, including: Pauline Chrobot, Mireille Faist, Lori Gustavus, Amanda Martin, Annabelle Stamm, Rainer Zah, and Michèle Zollinger.

II. SCOPE & METHODOLOGY OVERVIEW



SCOPE OF THE STUDY

The results presented in this study are based on the World Apparel Life Cycle Database (WALDB)¹, a collaborative initiative dedicated to collecting the latest Life Cycle Assessment (LCA) data of single processes across apparel and footwear supply chains. Using 2016 as its baseline year, this study first looks to the past, to quantify the apparel industry's impacts in 2005 and 2010, and then evaluates the results against future projections for 2020 and 2030.

The scope of the study was later extended to include footwear impacts from the year 2016 based on the best available data on material production, component manufacturing, assembly, distribution and disposal processes.

This study considers multiple fiber materials for both the apparel and the footwear industry (see *System of Analysis & System Boundaries* section). For this study, no distinction between conventional fiber material versus more sustainable fibers was made (e.g. conventional cotton vs. cotton using regenerative production practices). Today, the majority of cotton is produced conventionally, and the analysis required to account for more sustainable cotton fiber production rendered this activity out of the scope of the present study. As such, all fiber materials here are assumed to be conventional materials.

This scope does not include the issue and impacts of micro-plastic in the oceans. Furthermore, as mentioned above, the study does not include the topic of *preferred* fibers and materials that reduce impacts. Thus, it should be noted that **other factors not taken into account here can also influence recommendations for the industry and should be considered**. Finally, policy is likely to play a key role in the uptake of any solutions that help decarbonize the apparel industry. This study considers the projected quantitative impacts of changes in manufacturing processes themselves, rather than the policy or other decision-maker level changes required to achieve them and ensure a socially equitable outcome.

¹ See for more information: <https://quantis-intl.com/tools/databases/waldb-apparel-footwear/>

METHODOLOGY OVERVIEW

Impact assessment classifies and combines the flows of materials, energy, and emissions into and out of each product system by the type of impact their use or release has on the environment.

To evaluate environmental impact, the study used the peer-reviewed and internationally recognized life cycle impact assessment method IMPACT 2002+ vQ2.2 (Jolliet et al. 2003, adapted by Quantis). The metrics used in this analysis are as follows:

- Climate change (or GHG emissions), in kilograms of carbon dioxide equivalent (kg CO₂-eq)
- Freshwater withdrawal, in cubic meters (m³)
- Human health, in Disability Adjusted Life-Years (DALYs)
- Ecosystem quality, in Potentially Disappeared Fraction (PDF) of land per square meter per year (PDF*m²*y) which relates to the likelihood of species loss.
- Resource depletion, in megajoules (MJ)

IMPACT 2002+ uses the most current science with regard to climate change and offers the greatest consistency with data that might be presented elsewhere. Detailed information about the IMPACT 2002+ method and indicators is available [here](#), while a description of the impact categories evaluated and approach is provided in the methodological considerations section.

Data and assumptions used in footprinting

The quality of footprint results is dependent on the quality of data used in the evaluation. Every effort has been made to apply the most credible and representative information available. Where needed, assumptions were based on professional judgment, and sensitivity analyses were conducted to understand the influence of the parameter on reported results. The data applied and assumptions made for the footprint calculations were based on publicly available data and expert knowledge which characterize the product life cycle. Background processes were modeled using Ecoinvent 3.3 as provided by SimaPro. Data used to represent foreground processes came from WALDB as mentioned above.

SYSTEMS OF ANALYSIS & SYSTEM BOUNDARIES

Global apparel system

Using 2016 as its baseline year, the study looks into the apparel industry's impacts throughout its entire value chain, from raw material extraction and processing to end-of-life processes and transportation. The following figure illustrates the corresponding process:

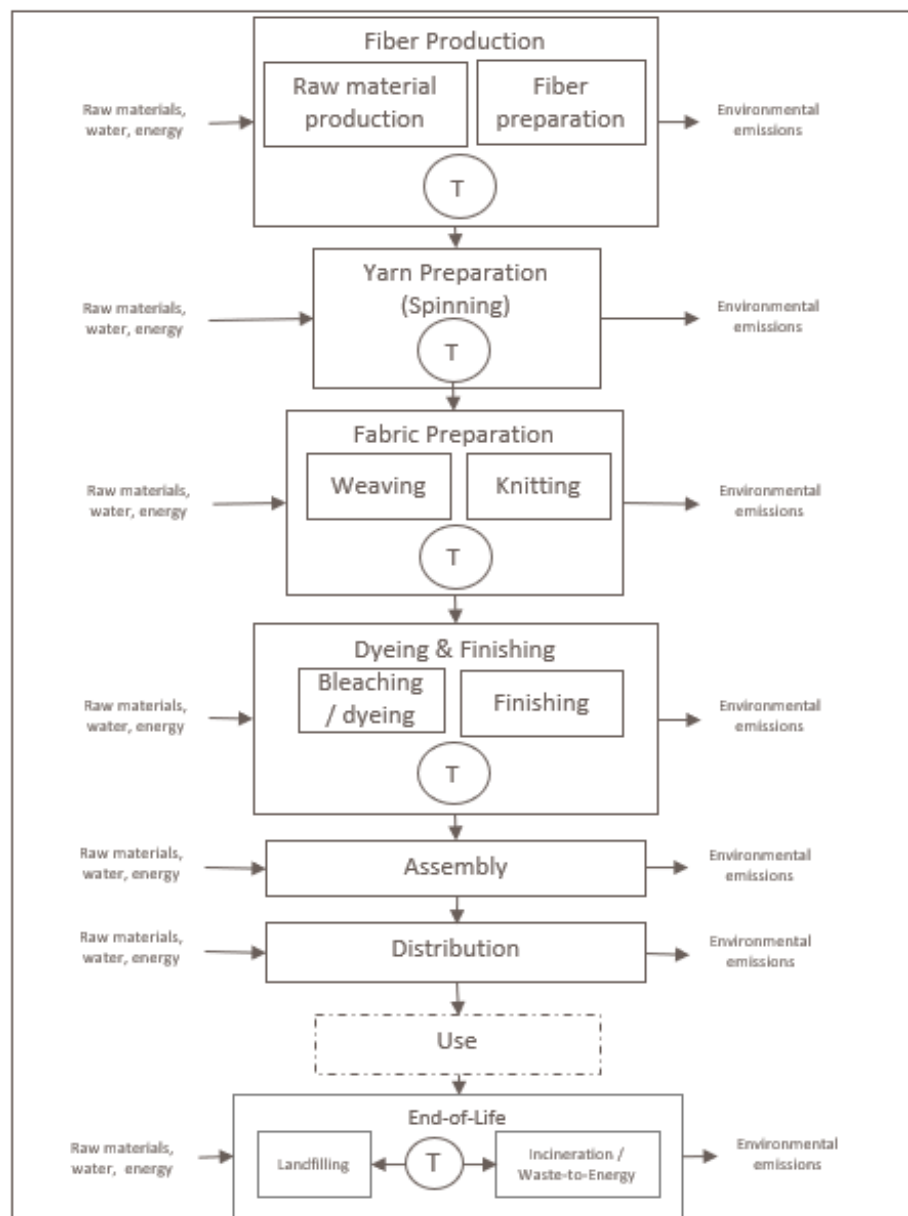


Figure 1: The life cycle of the global apparel system

(Note – the dotted line marks exclusions from the model. "T" refers to transport and was included where indicated)

Apparel Life Cycle Stages

For the purpose of the study, the apparel system was broken down into the following life cycle stages:

- The **Fiber Production** stage covers the extraction and processing of fibers. Transportation from raw material extraction location and between the processing and the yarn preparation stage was also included.
- **Yarn Preparation** includes the spinning of yarn from both filament and staple fibers. Different spinning techniques (wet spinning and cotton spinning) were taken into consideration, as were potential losses incurred from these processes. Transportation from the yarn preparation to fabric preparation stage is also included.
- **Fabric Preparation** corresponds to knitting and weaving yarn into fabric. Two different knitting techniques (circular and flat) were taken into consideration, as were losses incurred from these processes. Transportation from the fabric preparation to the dyeing and finishing stage is included here.
- The combined **Dyeing and Finishing** steps include bleaching and dyeing as well as fabric finishing. Transportation between dyeing and finishing to assembly is accounted for.
- **Assembly** refers to the cutting and sewing of fabric into apparel products. Potential losses incurred from these processes are accounted for.
- **Distribution** covers transportation from assembly location to retail stores, but not between retail stores and end-users.
- **End of life** processes involve the collection and management of apparel products at the end of their useful life (incineration and landfilling). Transportation to incineration and landfills is also accounted for.

In an effort to provide as comprehensive a system overview as possible, and following the standards and methods for LCA, the study takes into consideration all identifiable upstream inputs for every life cycle stage. For example, when considering the environmental impact of transportation, not only are the emissions associated with trucking or shipping considered, but also the impacts of additional processes and inputs corresponding to fuel production. This way, all inputs were traced back to the original extraction of raw materials.

Functional Unit

The functional unit used for this study is the global apparel annual production. Impacts were likewise calculated based on the global apparel yearly consumption per capita.

Materials covered

The study encompasses synthetics, cotton, cellulosic fibers and other natural fibers such as linen. See the methodological chapters for a detailed breakdown by fiber.

Exclusions and cut-off criteria

Processes considered negligible were excluded, notably, flows contributing less than 1% by mass or energy. The following items were also excluded from the scope of the study:

- **Use phase:** while the use phase of apparel products typically has a high impact, it was considered out of scope for this study as the objective was to focus on manufacturing processes. Use phase analysis involves assumptions about consumer behaviors, which vary widely in the real world. Due to the variability of consumer behavior assumptions in LCA, it was determined that such analysis would introduce marked uncertainties and detract from the key focus of this study. Likewise, transportation to the end customer (retail to end-customer) was excluded.
- **Packaging:** packaging was not accounted for in the study because it is expected to have a negligible impact on the industry's overall footprint.
- **Cleaning and ironing** during assembly were not included because they are similarly thought to play a minor role in apparel's overall global footprint.
- **Luxury materials:** furs and exotic leathers were not included in the study due to their minor mass flows, correlated with the resource investment required to access corresponding data.
- **Accessories** were not included in the study. With a relatively small share in the garment industry with regard to weight, they are considered to have a negligible impact on the industry's global footprint.

Footwear industry system

In addition to the initial focus on apparel's pollution impacts, the scope of the study was extended to include the footwear industry's contribution. The analysis was limited to the year 2016, based on the depth of the available data, essentially derived from the 2012 World Footwear Yearbook, in which the total volume of pairs of shoes under study was 23 billion. The following figure illustrates the general process:

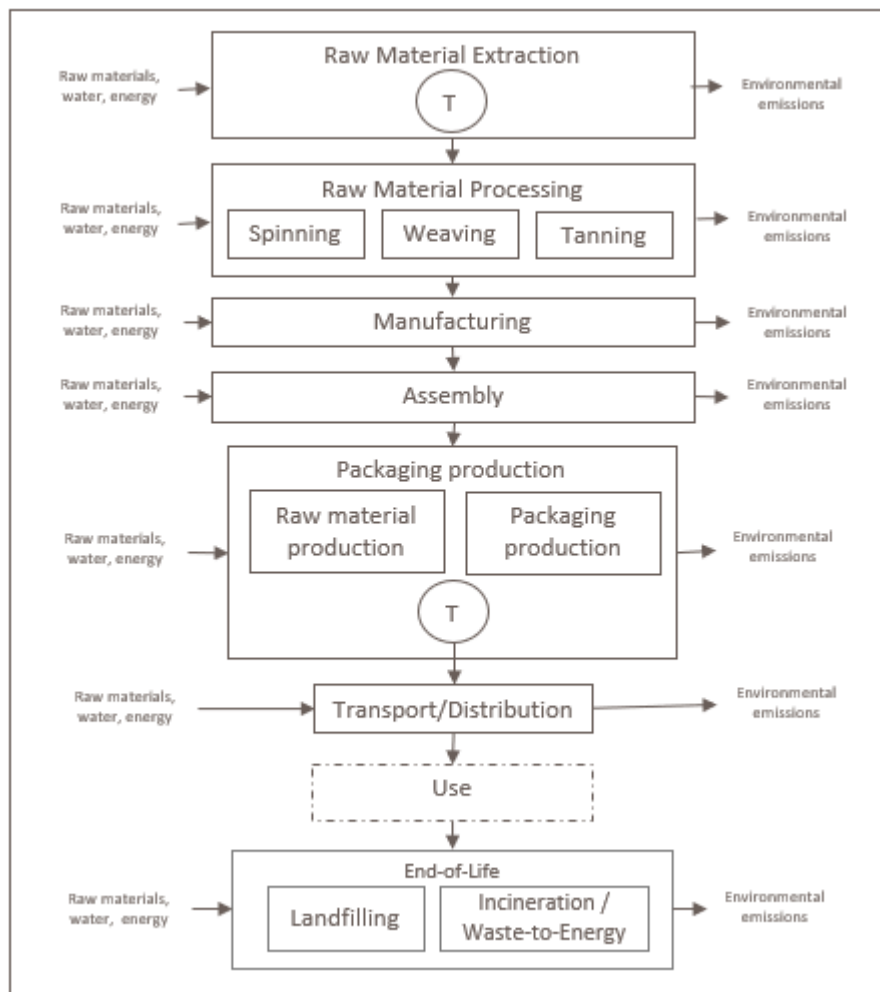


Figure 2: The life cycle of the global footwear system

(Note – the dotted line marks exclusions from the model. "T" refers to transport and was included where indicated))

Footwear Life Cycle Stages

For the purposes of the study, the global footwear system was broken down into the following life cycle stages:

- **Raw Material Extraction** includes the extraction of the materials required to manufacture shoes. Transportation between the raw material extraction location to raw material processing location is considered here.
- The **Raw Material Processing** includes material processing steps such as spinning and weaving for textile and synthetic shoes and tanning for leather shoes. No transportation is included in this stage.
- **Manufacturing** includes the production (cutting and linking) of mid- and outsoles for all shoe material types. No transportation is accounted for here.
- **Assembly** includes the assembly (sewing and gluing) of the different footwear parts. No transportation is included here.
- **Packaging Production** includes raw material extraction as well as manufacturing stages for secondary packaging. The packaging material used for this assessment is cardboard. Transportation is included here for the manufacturing steps as background data.
- **Transport** refers to distribution and includes transportation from the production location to the consumption location (retail), but not between retail stores and end-users. Both the footwear product and its packaging were considered here.
- **Disposal** involves the collection and management of footwear products at the end of their useful life (incineration and landfilling). Transportation to incineration and landfills is not accounted for here.

As for apparel, all identifiable upstream inputs for every life cycle stage were taken into consideration to provide as comprehensive a system overview as possible. Thus, all inputs are traced back to the original extraction of raw materials.

Functional Unit

The functional unit used for this study is the global footwear annual production. Impacts were likewise calculated based on the global footwear yearly consumption per capita.

Materials covered

The study focuses on 3 types of shoes: synthetic (57% of global footwear production), leather (25% of global footwear production) and textile (18% of global footwear production). Other materials used for the shoe soles were also taken into consideration. Regarding leather shoes, this study accounted for material losses from rawhide to leather. ***See methodological considerations for further detail.***

Exclusions and cut-off criteria

Processes considered negligible were excluded from the scope of the study, notably any flow contributing less than 1% of the industrial footprint, by mass or energy. The following items were also excluded from the scope of the study:

- **Use phase:** In line with the approach selected to assess apparel's footprint, the use phase was not included in the present study.
- **Laces and other accessories** were not included in the study. With a relatively small mass share in the footwear industry, they are considered to have a negligible impact on the industry's global footprint.
- **Refined packaging materials:** additional secondary packaging material (e.g. craft paper, tape) was not included in the study. With a relatively small share in the footwear industry, these materials are considered to have a negligible impact on the industry's global footprint.

Temporal and geographic boundaries of the study

The present analysis mostly concentrates on the apparel system, for which robust data was available. When possible, 2016 data was referenced, or otherwise supplemented with the best available proxy. This approach was further consolidated by a geographical reach spanning six continents (Asia, North America, Central and South America, Europe, Africa and the Middle East, Oceania). For more details, see the methodological considerations section.

Using the year 2016 as a baseline, pollution indicators across the above-mentioned geographies were compared to what they were in 2005 and then in 2010. For the past scenarios, the findings are based on The Fiber Year 2017 report published by The Fiber Year Consulting to account for shifts in material, consumption and production locations. Likewise, 2016 figures were assessed against 2020 and 2030 projections based on 2016 data and assumptions (described in the methodological considerations section) in relation to economic growth predictions. The study used available data to integrate considerations about shifts in material and consumption. Where no data was available, assumptions approved by the steering board were used, and fine-tuned as necessary.

III. FOOTPRINT BASELINE RESULTS



80%

TOTAL BASELINE FOOTPRINT

Together the apparel and footwear industries generated between 5 and 10% of global pollution impacts in 2016. Footwear alone represents approximately one-fifth the impact of the apparel industry, about 1.4% of global climate impacts (700 million metric tons CO₂eq), while apparel represents 6.7% of global climate impacts (3,290 million metric tons CO₂eq). **Combined, they account for an estimated 8.1% of global climate impacts (3,990 million metric tons CO₂eq).**

	%	MILLION METRIC TONS CO ₂ eq
Apparel	6.7%	3,290
Footwear	1.4%	700
Total apparel & footwear impacts	8.1%	3,990
Compared to:		
Total global CO ₂ eq impacts	100%	49,300

Table 1: Total apparel & footwear industries' impacts compared to total global impacts in 2016 (provided both in % and million metric tons CO₂eq)

The following section outlines hotspots for the apparel and footwear industries. An in-depth analysis of pollution impacts was done for the following five indicators: climate change, freshwater withdrawal, resources, ecosystem quality, and human health (see the methodological considerations section for a description of the impact categories).

APPAREL BASELINE RESULTS

Based on 2016 data, the study shows that global consumption of fiber materials reached 11.4 kg per capita². The United States has the highest demand for apparel fibers, amounting to 37.6 kg per capita, followed closely by Europe (31.21 kg) and China (1.08 kg)³.

The per capita emissions related to the estimated global consumption were 442 kg of CO₂eq in 2016. This is equivalent to a 4,100 km-long continental flight, or driving 2,400 km in a passenger car. Likewise, the apparel industry’s annual per capita water consumption tallies up to an estimated 23,900 liters, which is akin to taking about 150 baths.

In the United States, the per capita emissions were 1,450 kg of CO₂eq in 2016, while in Europe the per capita emissions were 1,210 kg of CO₂eq and in China just 41.8 kg of CO₂eq.

For all indicators, the Dyeing and Finishing, Yarn Preparation and Fiber Production life cycle stages appear to be the 3 main drivers of the industry’s global pollution impacts. Conversely, Distribution and Disposal appear to be negligible, regardless of the selected indicator.

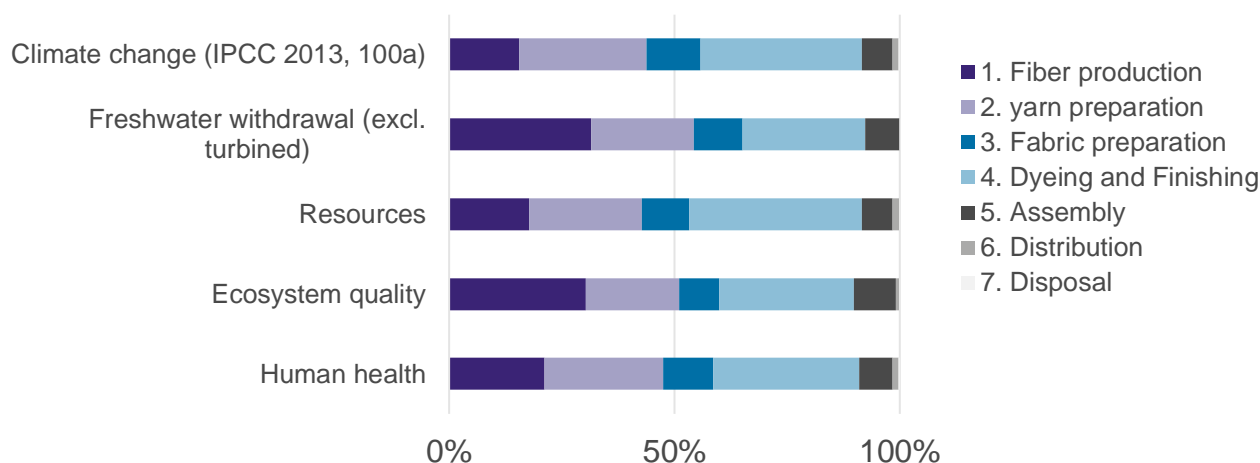


Figure 3: Contribution of each life cycle stage of the global apparel industry by each of the five impact indicators

² This represents approximately 11 pairs of jeans and 13 t-shirts per person (assuming that a pair of jeans weighs about 850g and a t-shirt about 150g).

³ Because consumption data was not available, this data was calculated using total impact numbers with the assumption that imports equal consumption (source: World Trade Organization).

While the Dyeing and Finishing stage has a high impact with regards to all indicators studied, Fiber Production has the highest impact on freshwater withdrawal and ecosystem quality due to cotton cultivation⁴. The high impact of the Dyeing and Finishing and Yarn Preparation stages is mainly due to the energy intensive processing and high dependence on fossil-based energy.

IMPACT CATEGORY	UNIT	TOTAL	FIBER PRODUCTION	YARN PREPARATION	FABRIC PRODUCTION	DYEING & FINISHING	ASSEMBLY	DISTRIBUTION	DIS
Climate change	Gigatons CO ₂ eq	3.29	0.51	0.93	0.39	1.18	0.22	0.04	
		100%	15%	28%	12%	36%	7%	1%	
Human health	10 ⁶ DALY	2.25	0.48	0.59	0.25	0.73	0.17	0.03	
		100%	21%	26%	11%	32%	7%	1%	
Ecosystem quality	10 ⁹ PDF.m ² .y	1,020	309	211	90.2	304	94.2	8.81	
		100%	30%	21%	9%	30%	9%	1%	
Resources	10 ⁹ MJ	40,900	7,250	10,300	4,280	15,700	2,800	624	
		100%	18%	25%	10%	38%	7%	2%	
Freshwater withdrawal	10 ⁹ m ³	215	67.7	49.2	23.1	58.4	16.2	0.25	
		100%	31%	23%	11%	27%	8%	0%	

Table 2: Impact category results by life-cycle stage

(Note – for each indicator, results are also provided in percentage relative to overall impact)

⁴ This study considered multiple fiber materials (cotton, natural fibers, synthetic, cellulosic - see methodological considerations section Calculation B for more detail). However, the study did not compare different fiber materials against one another because people wear multiple types of fibers usually based on their performance properties. Rather than comparing among fiber types, it is more important to promote the more sustainable fiber options within each typology. For example, when using cotton, it is preferable to use more sustainable solutions that use regenerative agricultural practices, and for synthetics, prioritize recycled fibers and work towards solutions that eliminate micro-plastics.

Climate Change

The energy-intensive processes in the Dyeing and Finishing stage are the primary drivers of the global apparel industry's total climate change impact. Yarn Preparation is also a key contributor, though to a lesser extent.

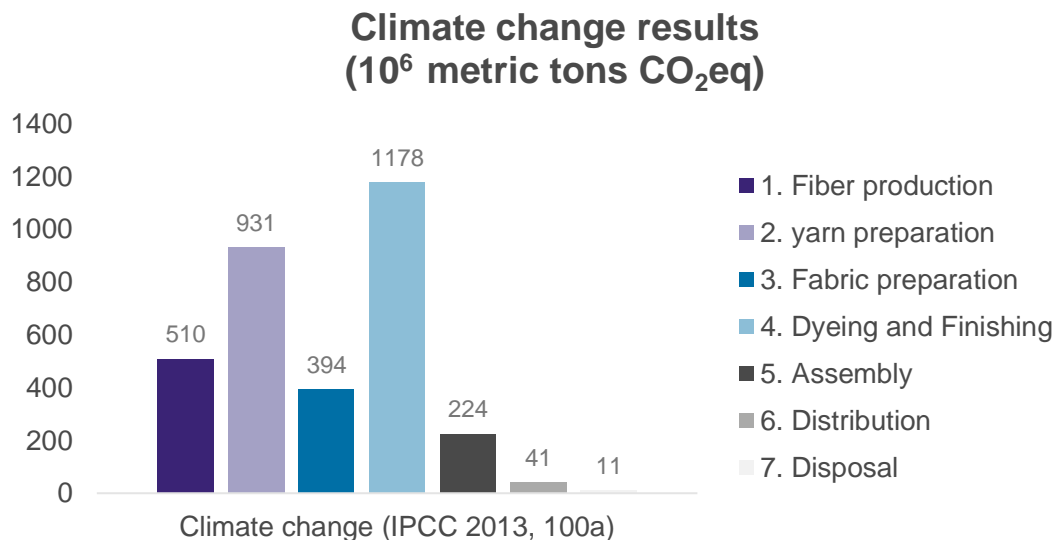


Figure 4: Climate change impacts by life cycle stage

Most of these impacts are a direct result of apparel's reliance on hard coal and natural gas to generate electricity and heat in key processing locations. Asian countries such as China, India and Bangladesh not only comprise the largest manufacturers, but also have heavily coal-based energy mixes⁵. Dyeing processes in particular have a high energy demand because of the wet processes used, resulting in heating high amounts of water. Fabric preparation (knitting and weaving) and yarn preparation (spinning) require mostly electricity and almost no additional heat, resulting in a lower climate change impact. Hard coal and natural gas show a share of 60% to 70% of the climate change impacts in the Dyeing and Finishing stage. The difference relates to different energy mixes in the various locations.

⁵ The apparel manufacturing industry in these countries can be characterized by numerous small- and medium-scale enterprises. For example, in China the top four players – Youngor Group, Heilan Group, Bosideng Corporation, and Septwolves Industry – together represent market share of just 4.5% of total industry revenue in 2017, while the remainder is generated by numerous smaller enterprises (IBIS World Industry Report, Apparel Manufacturing in China, 2017).

Dyeing & finishing (10⁶ metric tons CO₂eq)

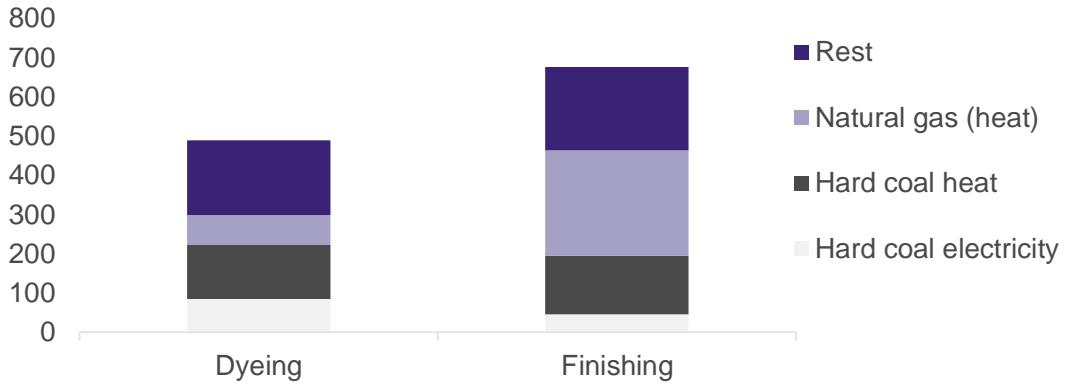


Figure 5:
Zoom in on

the use of hard coal and natural gas to power dyeing and finishing processes

	DYEING	FINISHING
Hard coal (electricity)	17%	7%
Hard coal (heat)	28%	22%
Natural gas (heat)	16%	40%
Other	39%	31%

Table 3: Process contribution in percentage for Dyeing and Finishing stage

(Note – for each type of energy, results are provided in percentage relative to overall impact)

For Distribution, transport was assumed to be 8% air freight and 92% shipping freight (for more details, see methodological considerations section). Distribution is proven to have a relatively low impact as far as climate change is concerned, although these results do not include final distribution from shop to end-customer. The study further shows that transportation accounts for only an estimated 3% of the apparel industry’s impact on climate change. This impact would however be significantly higher if businesses decided to switch from road transportation to air. For example, **shifting a single percent of transportation allocations from shipping to airfreight would cause a 35% increase in carbon emissions.**

Freshwater withdrawal

Fiber Production, Dyeing and Finishing and Yarn Preparation are the four largest contributors to freshwater withdrawal impacts. The impact from Fiber Production comes from the withdrawal of water from the ecosystem and then, after processing, returning polluted water back to the ecosystem. The Dyeing and Finishing steps are wet processes, especially dyeing, and accordingly consume sizeable quantities of water. Yarn Preparation requires a significant amount of water due to the wet spinning processes used for different fiber materials (e.g. synthetic fibers and natural fibers).

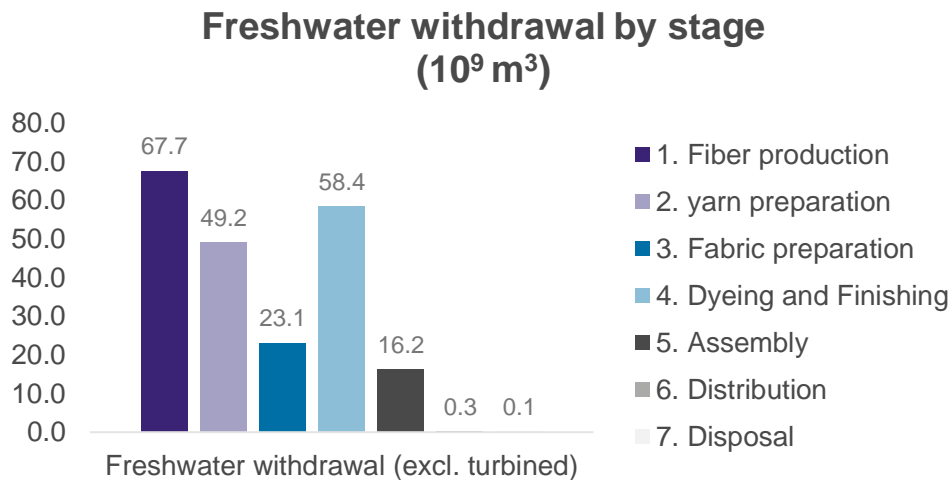


Figure 6: Freshwater withdrawal impacts

by life cycle stage

In Fiber Production, the main water withdrawal comes from cotton⁶ production despite its share of only 24% of total fiber consumption. In contrast, production of synthetic fiber, the most common textile material, consumes only about half as much.

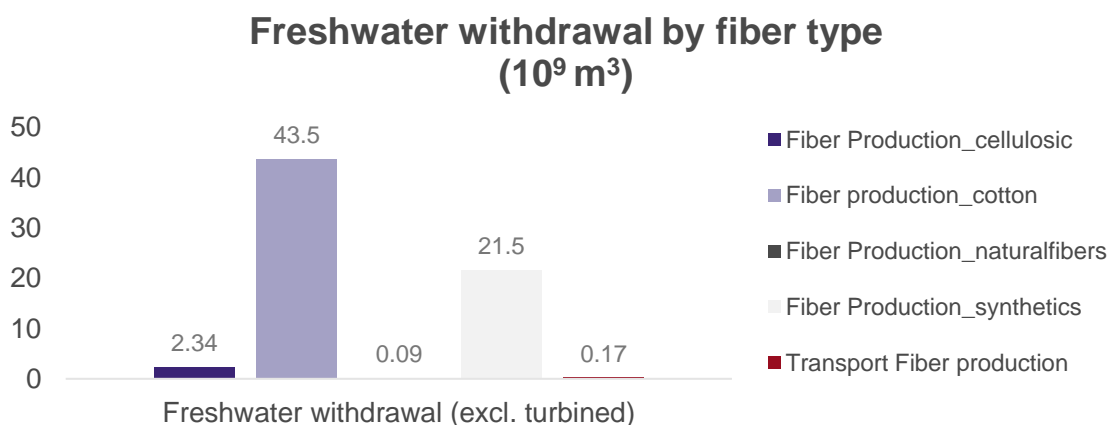
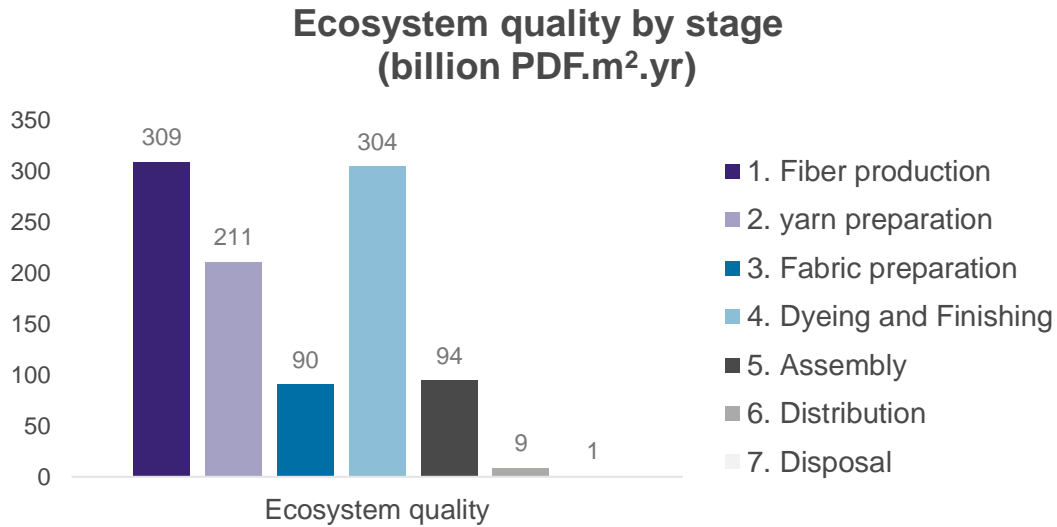


Figure 7: Freshwater withdrawal impact per type of fiber

⁶ This refers to conventional cotton. There are a number of more sustainable cotton solutions that reduce impacts on freshwater withdrawal and implementing regenerative practices. Thus, supporting the most responsible fibers, specifically cotton, is important and can lead to significant impact reductions.

Ecosystem quality

The Fiber Production, Dyeing and Finishing and Yarn Preparation stages have the highest impacts on ecosystem quality. With regards to the processing stages, the main drivers for ecosystem quality come from energy production.



Ecosystem quality impacts by life cycle stage

Figure 8:

For Fiber Production, the primary source of impact comes from cotton cultivation, which affects ecosystem quality primarily due to pesticides used in cultivation, and other field emissions such as nitrate (and other pollutants). In this stage, the second driver with regards to ecosystem quality comes from the production of synthetic resin for synthetic fibers.

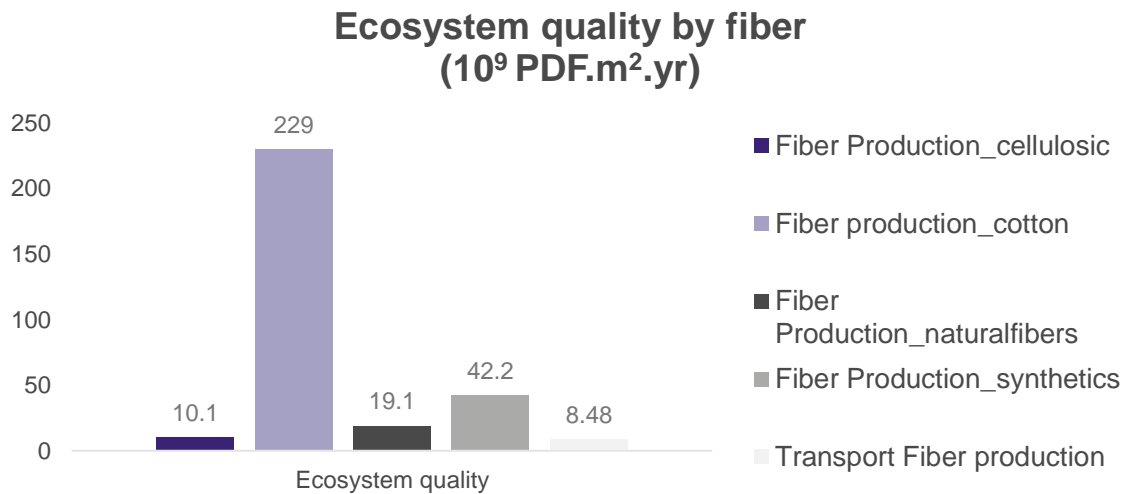


Figure 9: Ecosystem quality impact results breakdown per type of fiber

Human health

The Dyeing and Finishing, Yarn Preparation and Fiber Production stages have the highest impacts on human health. The main drivers are linked to the use of fossil fuel to power processes such as knitting, dyeing and spinning, as well as synthetic fiber production. Toxic impacts from dyeing wastewater are a trending topic, but difficult to characterize due to lack of data, and likely to be underestimated here.

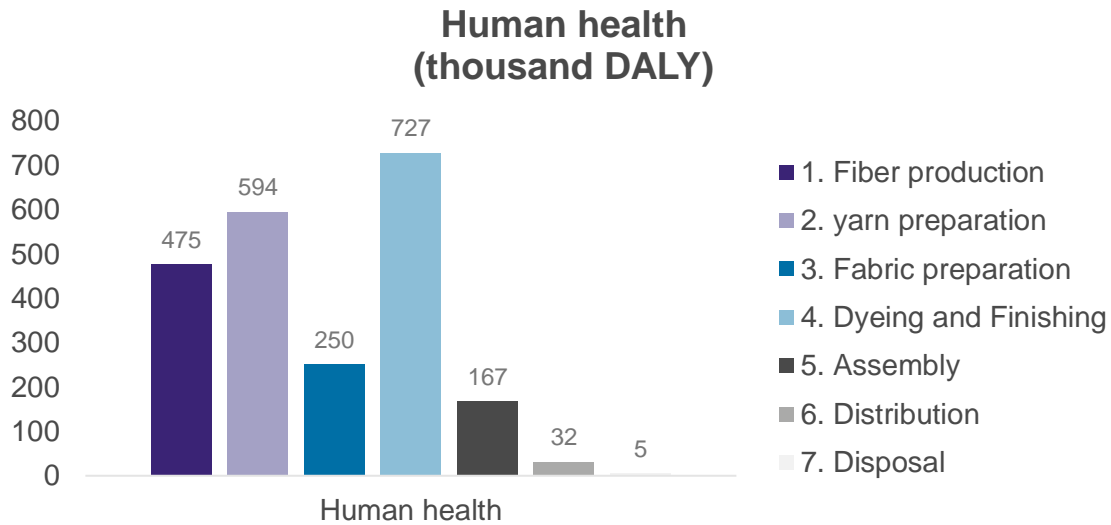


Figure 10: Human health impacts by life cycle stage

Resource depletion

The Dyeing and Finishing, Yarn Preparation and Fiber Production stages have the highest impacts on resource depletion. This is driven due to particularly energy-intensive processes which are based on fossil fuel energy.

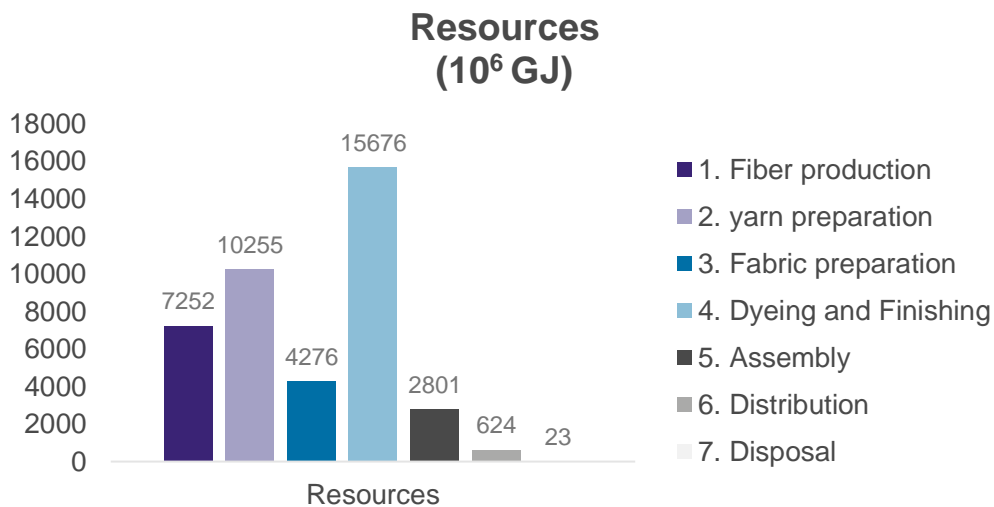


Figure 11: depletion

life cycle stage

Resource impacts by

FOOTWEAR BASELINE RESULTS

Based on 2012 World Footwear Yearbook data, the study shows that global consumption of shoes reached 2.86 pairs per capita. The United States has the highest demand for footwear with 6.98 pairs per capita. Europe consumed 2.1 pairs and China 1.97 pairs⁷.

The per capita emissions related to the estimated global consumption per capita is 94 kg of CO₂eq. This is equivalent to a 900km continental flight, or driving 2,350 km in a passenger car. Likewise, footwear’s annual water consumption tallies up to an estimated 4,000 liters, which is akin to taking 21 baths.

The United States per capita emissions related to consumption were 229 kg of CO₂eq in 2016 compared to 69.0 kg of CO₂eq in Europe and 64.7 kg of CO₂eq in China.

While footwear takes up an estimated 26% of available materials, it accounts for between 16% and 32% of the combined total pollution impacts of the apparel and footwear industries, depending on the indicator under consideration.

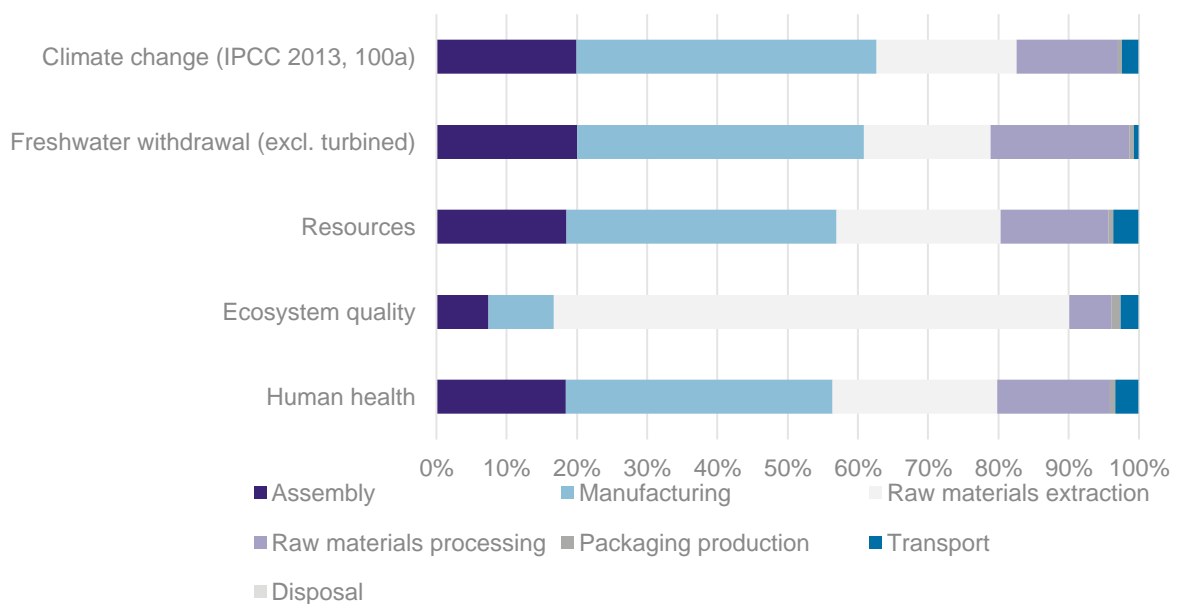


Figure 12: Contribution of each life cycle stage of the global footwear industry by impact category

⁷ Because consumption data was not available, this data was calculated using total impact numbers with the assumption that import is equal to consumption (source: World Trade Organization).

Overall, the Manufacturing as well as the Raw Material Extraction stages are the biggest drivers across all impact categories. Transport accounts for only 2.5% of footwear’s global impact. Packaging Production and Disposal appear to be negligible, regardless of the selected indicator.

DAMAGE CATEGORY	UNIT	TOTAL	RAW MATERIALS EXTRACTION	RAW MATERIAL PROCESSING	PACKAGING PRODUCTION	MANUFACTURING	ASSEMBLY	TRANSPORT	DISPOSAL
Climate change	million metric tons CO ₂ eq	700	140	101	3.86	299	140	16.9	0.136
		100%	20%	14%	1%	43%	20%	2%	0.02%
Freshwater withdrawal	10 ⁹ m ³	29.5	5.32	5.84	0.18	12.0	5.92	0.21	0.005
		100%	18%	20%	1%	41%	20%	1%	0.02%
Resources	10 MJ	7,740	1,810	1,190	56.6	2,980	1,430	277	3.66
		100%	23%	15%	1%	38%	19%	4%	0.05%
Ecosystem quality	10 ⁹ PDF.m ² .y	477	350	28.6	6.09	44.5	35.2	12.4	0.08
		100%	73%	6%	1%	9%	7%	3%	0.02%
Human health	10 ³ DALY	514	120	82.6	3.95	195	94.6	17.1	0.19
		100%	23%	16%	1%	38%	18%	3%	0.04%

Table 3: Impact category results by life-cycle stage

(Note – for each indicator, results are also provided in percentage relative to overall impact)

Footwear materials

The following breakdown by fiber material was used: synthetic shoes 57%, leather shoes 25%, and textile shoes 18% (*for more detail refer to the methodological considerations section*). These results should not be used to compare different fiber materials against each other to assess one fiber material's comparative footprint but instead inform on the total impact from the footwear industry in 2016.

While leather shoes only account for a quarter of the overall footwear production, they take up an estimated 30% to 80% (depending on the impact category) share of footwear's global impacts. Synthetic shoes contribute 12% to 54% (depending on the impact category) while textile shoes contribute between 6% and 21% (depending on the impact category) of the footwear industry's global impact.

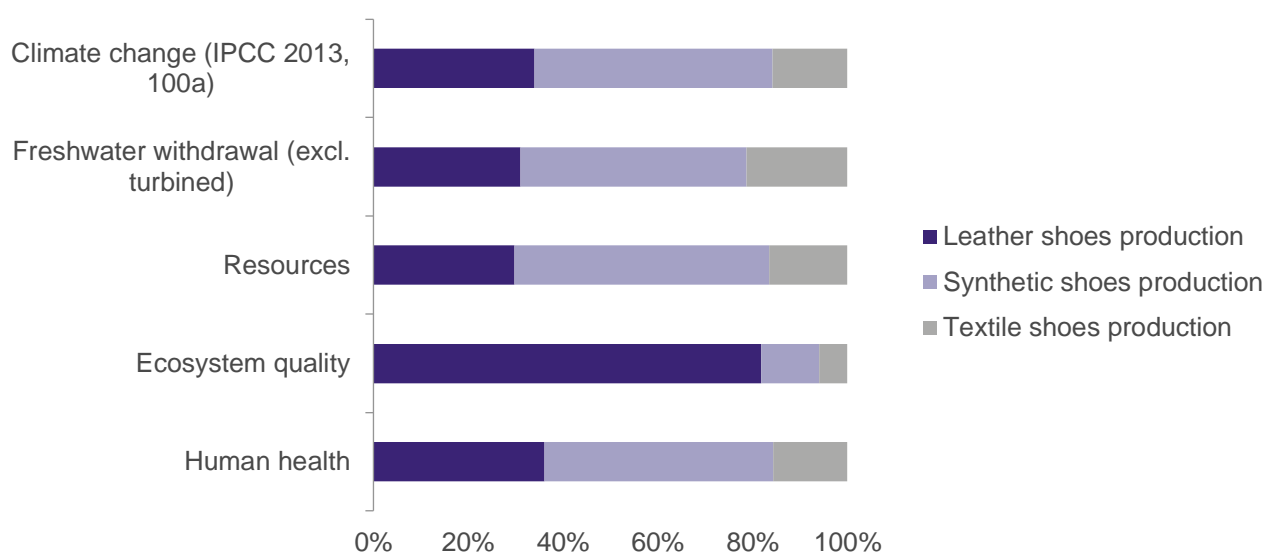


Figure 13: Impact result breakdown per type of shoe material

IMPACT CATEGORY	LEATHER SHOES (%)	SYNTHETIC SHOES (%)	TEXTILE SHOES (%)
Climate change	34%	50%	16%
Human health	36%	48%	16%
Ecosystem quality	82%	12%	6%
Resources	30%	54%	17%
Freshwater withdrawal	31%	48%	21%

Table 3: Percentage impact contribution by type of shoe material

When looking at Raw Material Extraction, leather shoes have the highest impact on ecosystem quality due to raw material processing (related to leather processing steps). Synthetic shoes have the highest impact on resource depletion mainly due to polyethylene and polyester production. This impact is linked to the overall number of synthetic shoes produced. Textile shoes primarily affect freshwater withdrawal, due to cotton cultivation, which depends heavily on irrigation.

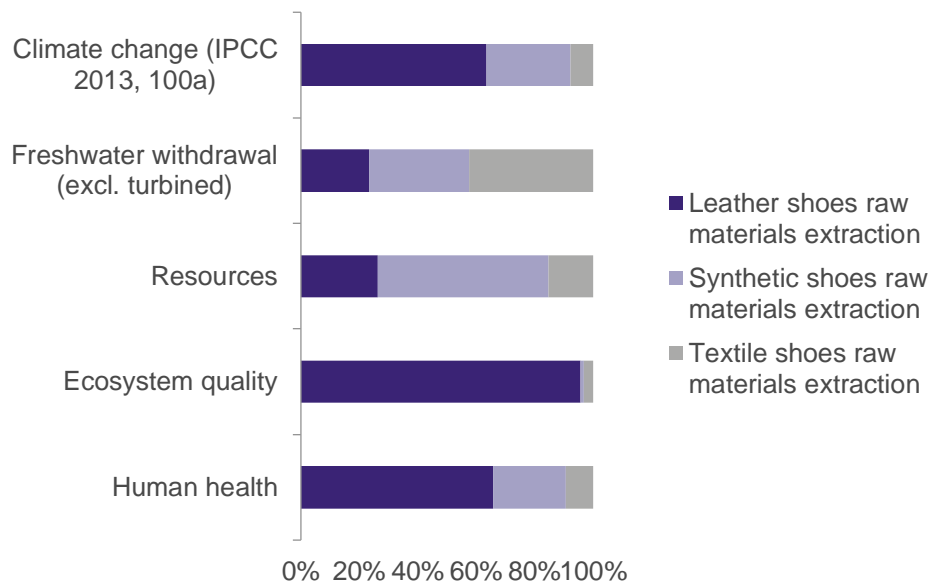


Figure 14: Raw material extraction impact breakdown per type of shoe material

Looking into detail at the impact of producing leather shoes, raw material processing accounts for around 50% of their impact. Within these processing steps, and depending on the impact category, tanning generates 5% to 35% of the carbon emissions emitted from leather shoes.

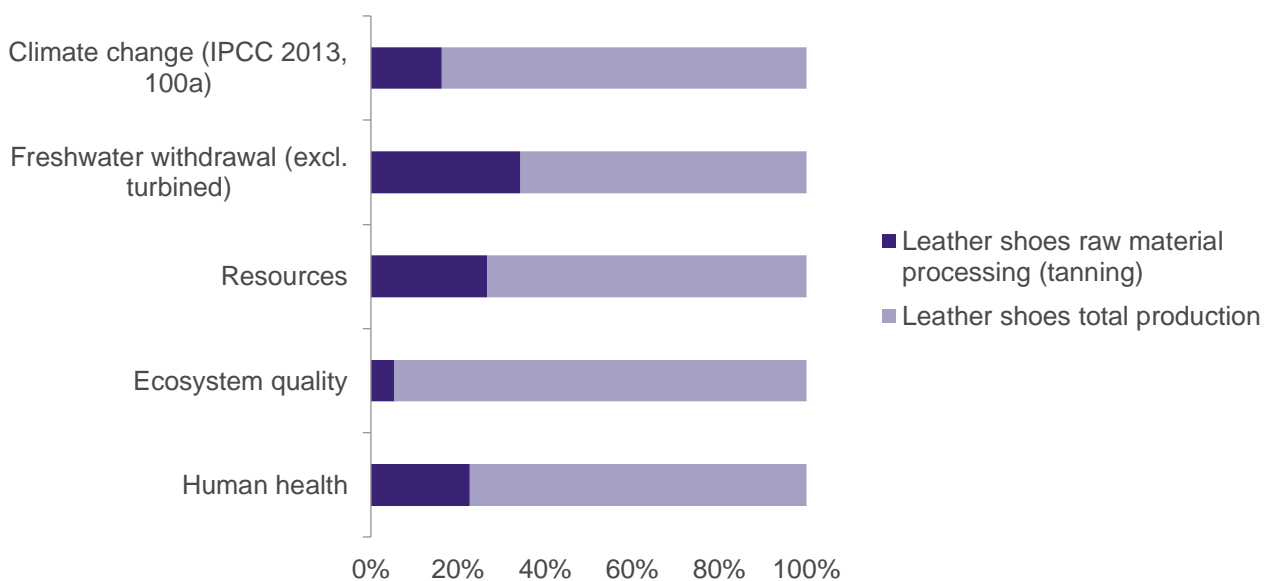


Figure 15: Zoom in on the impacts of leather shoes material processing and production steps

IV. APPAREL INDUSTRY IMPACT GROWTH TRENDS



Apparel industry impact analysis over time

Using the year 2016 as baseline, the apparel industry’s pollution impacts were compared to what they were in 2005 and in 2010. From there, 2016 figures were assessed against 2020 and 2030 projections (based on available data and assumptions in relation to economic growth predictions, as described in the methodological considerations section).

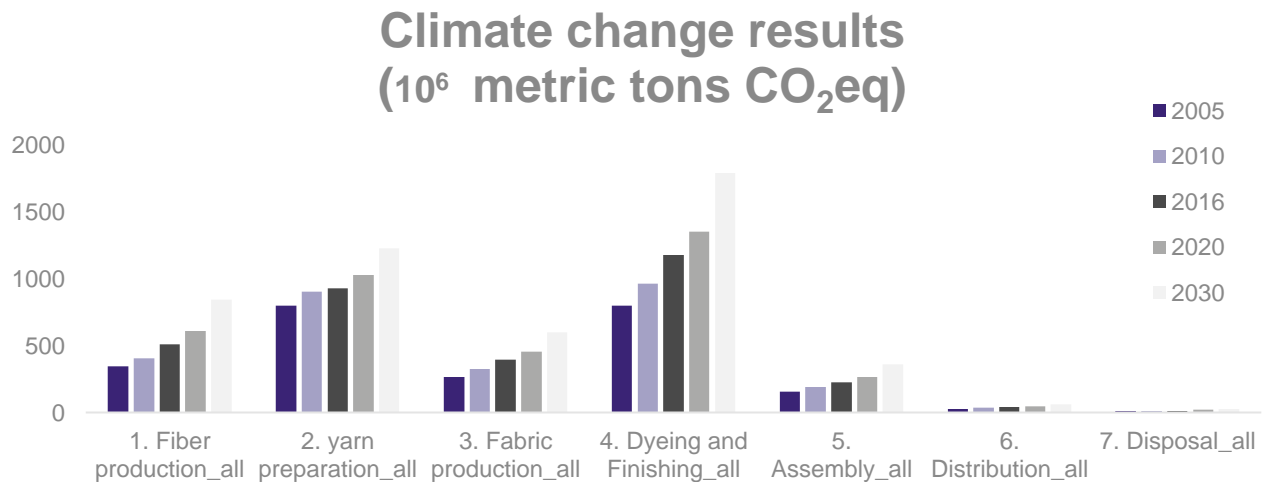


Figure 16: Comparative scenarios for projected climate change-related impacts per life cycle step

The apparel industry’s production impacts on climate change increased 35% between 2005 and 2016 and are projected to steadily rise in 2020 and 2030, if a business-as-usual scenario prevails. This increase reflects increasing consumption per capita while global population rises⁸, along with a shift in material use towards more synthetics and less natural fiber, cotton and cellulosic.

This trend would also affect all pollution indicators, from climate change to freshwater withdrawal, resource depletion, ecosystem quality and human health. This is manifest in the projected 49% increase from baseline (2016) in terms of projected climate change impacts for 2030, equally affecting resource depletion (49%) and human health indicators (47%).

The study also highlights that, as synthetics are expected to overtake cotton in the apparel fiber market, the degradation in ecosystems quality (111% in 2020 and 136% in 2030) and freshwater withdrawal (112% in 2020 and 139% in 2030) is likely to be more moderate.

⁸ Calculated based on an annual economic growth rate of 3.7% for the apparel fiber market (Orbichem, 2014).

	UNITS	2005	2010	2016	2020	2030
Climate change	Gigatons					
	CO ₂ eq	2.44	2.84	3.29	3.78	4.91
	%	74%	86%	100%	115%	149%
Human health	10 ⁶ DALY	1.69	1.94	2.25	2.57	3.31
	%	75%	86%	100%	114%	147%
Ecosystem quality	10 ⁹					
	PDF.m ² .y	829	908	1,018	1,127	1,388
	%	81%	89%	100%	111%	136%
Resources	10 ⁹ MJ	30,000	34,900	40,900	46,900	61,100
	%	73%	86%	100%	115%	149%
Freshwater withdrawal	10 ⁹ m ³	171	189	215	240	299
	%	80%	88%	100%	112%	139%

Table 3: past & future growth of pollution impacts by category

2005

DAMAGE CATEGORY	UNIT	TOTAL	FIBER PRODUCTION	YARN PREPARATION	FABRIC PRODUCTION	DYEING & FINISHING	ASSEMBLY	DISTRIBUTION	D
Climate change	Gigatons	2.44	0.34	0.82	0.27	0.81	0.16	0.03	0.
	CO ₂ eq	100%	14%	34%	11%	33%	7%	1%	0.
Human health	10 ⁶	1.69	0.35	0.52	0.17	0.50	0.12	0.02	0.
	DALY	100%	21%	31%	10%	30%	7%	1%	0.
Ecosystem quality	10 ⁹	829	289	198	62.2	210	64.5	6.08	0.
	PDF.m ² .y	100%	35%	24%	8%	25%	8%	1%	0.
Resources	10 ⁹ MJ	30,000	4,710	9,180	2,950	10,800	1,910	430	18
		100%	16%	31%	10%	36%	6%	1%	0.
Freshwater withdrawal	10 ⁹ m ³	171	59.7	44.2	16.0	40.3	11.0	0.18	0.
		100%	35%	26%	9%	24%	6%	0%	0.

Table 4: Impact category results by life-cycle stage for 2005

(Note – for each indicator, results are also provided in percentage relative to overall impact)

DAMAGE CATEGORY	UNIT	TOTAL	FIBER PRODUCTION	YARN PREPARATION	FABRIC PRODUCTION	DYEING AND FINISHING	ASSEMBLY	DISTRIBUTION	DISPOSAL
Climate change	Gigatons CO ₂ eq	2.84	0.41	0.91	0.32	0.97	0.19	0.03	0.02
		100%	14%	32%	11%	34%	7%	1%	0%
Human health	10 ⁶ DALY	1.94	0.39	0.57	0.21	0.60	0.14	0.03	0.01
		100%	20%	30%	11%	31%	7%	1%	0%
Ecosystem quality	10 ⁹ PDF.m ² .y	908	285	217	73.9	249	75.1	7.22	0.97
		100%	31%	24%	8%	27%	8%	1%	0%
Resources	10 ⁹ MJ	34,900	5,740	10,100	3,500	12,900	2,260	512	20.0
		100%	16%	29%	10%	37%	6%	1%	0%
Freshwater withdrawal	10 ⁹ m ³	189	60.8	48.7	19.0	47.9	12.8	0.21	0.02
		100%	32%	26%	10%	25%	7%	0%	0%

Table 5: Impact category results by life cycle stage for 2010

(Note – for each indicator, results are also provided in percentage relative to overall impact)

DAMAGE CATEGORY	UNIT	TOTAL	FIBER PRODUCTION	YARN PREPARATION	FABRIC PRODUCTION	DYEING AND FINISHING	ASSEMBLY	DISTRIBUTION	DISPOSAL
Climate change	Gigatons CO ₂ eq	3.78	0.61	1.03	0.45	1.36	0.27	0.05	0.02
		100%	16%	27%	12%	36%	7%	1%	1%
Human health	10 ⁶ DALY	2.57	0.54	0.65	0.29	0.84	0.20	0.04	0.01
		100%	21%	25%	11%	33%	8%	1%	0%
Ecosystem quality	10 ⁹ PDF.m ² .y	1,127	323	231	104	350	108	10.1	0.97
		100%	29%	21%	9%	31%	10%	1%	0%
Resources	10 ⁹ MJ	46,900	8,750	11,300	4,920	18,000	3,190	717	30.3
		100%	19%	24%	10%	38%	7%	2%	0%
Freshwater withdrawal	10 ⁹ m ³	240	72.8	54.4	26.6	67.1	18.4	0.29	0.08
		100%	30%	23%	11%	28%	8%	0%	0%

Table 6: Impact category results by life cycle stage for 2020

(Note – for each indicator, results are also provided in percentage relative to overall impact)

IMPACT CATEGORY	UNIT	TOTAL	FIBER PRODUCTION	YARN PREPARATION	FABRIC PRODUCTION	DYEING AND FINISHING	ASSEMBLY	DISTRIBUTION	DISPOSAL
Climate Change	Gigatons CO ₂ eq	4.91	0.84	1.23	0.60	1.79	0.36	0.06	0.02
		100%	17%	25%	12%	37%	7%	1%	0%
Human Health	10 ⁶ DALY	3.31	0.71	0.78	0.38	1.11	0.27	0.05	0.01
		100%	21%	24%	12%	33%	8%	1%	0%
Ecosystem Quality	10 ⁹ PDF.m ² .y	1,388	366	265	137	462	143	13.4	1.25
		100%	26%	19%	10%	33%	10%	1%	0%
Resources	10 ⁹ MJ	61,100	12,200	13,400	6,490	23,800	4,230	948	38.0
		100%	20%	22%	11%	39%	7%	2%	0%
Freshwater Withdrawal	10 ⁹ m ³	299	86.8	63.9	35.2	88.7	24.4	0.39	0.11
		100%	29%	21%	12%	30%	8%	0%	0%

Table 3: Impact category results by life cycle stage for 2030

(Note – for each indicator, results are also provided in percentage relative to overall impact)

V. IMPACT REDUCTION SCENARIOS FOR 2030



FOCUS AREA OVERVIEW

Based on the comparative and predictive approach, the study explored potential impact reduction actions and tested different hypotheses to determine necessary industry-wide emission reduction targets. This is particularly relevant for setting Science-Based Targets (SBT) for the industry, an initiative to which a number of apparel companies have recently committed, including Levi Strauss, Nike, and Gap⁹.

This study assessed three impact reduction action scenarios¹⁰: switching to renewable energy, promoting energy efficiency/productivity, and implementing circular economy measures (re-looping recycled fiber into the system)¹¹. The assumptions and approach used to perform these calculations can be found in the methodological considerations section.

The figure below illustrates the necessary GHG emission reduction action targets to achieve industry-wide emission reductions of 5%, 10%, 30% and 50% by 2030. For example, to achieve a 5% industry-wide emission reduction, any one of the following targets could be set: a renewable energy target of 8%, or an energy efficiency/productivity target of 9%, or a circular economy target (fiber recycling) of 34%. However, to achieve a 50% emission reduction, the industry would require either a 78% renewable energy target or a 72% energy efficiency target. In any case, a circular economy target alone would simply not achieve this industry-wide emission reduction target.

⁹ <https://www.greenbiz.com/article/growing-momentum-science-based-targets>

¹⁰ Another scenario that could have been studied is replacing conventional fiber materials with preferable fibers, e.g. a portfolio of more sustainable fibers that also reduce impact. For this study, no distinction in fiber material (conventional vs. best in class) was made, so the baseline represents all fiber materials as conventional fiber materials.

¹¹ In this document, a narrow working definition of circular economy is used which comprises re-looping recycled fibers into the system (closing the loop on fibers). Some circular economy advocates use a broad and progressive definition, including circular energy use (renewables), emphasizing the need to reduce, reuse and then recycle. Such approaches are welcomed, as a substantial decrease in the rate of consumption of fast fashion will be key for circular economy measures to truly achieve ambitious science-based targets.

Sector emission reduction goals by action
 (% reduction required for total GHG emission reduction target
 by individual action)

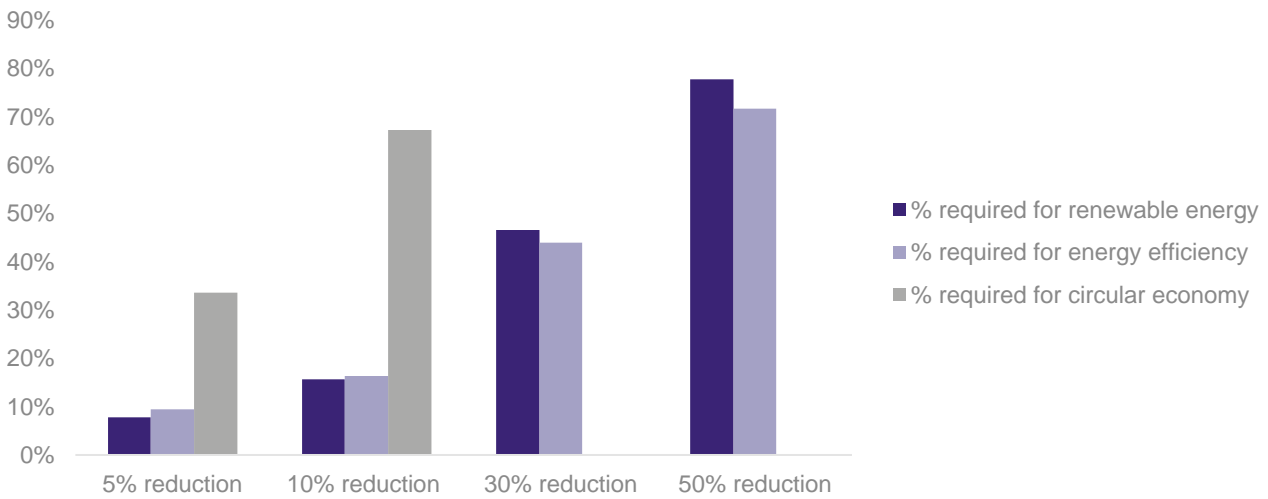


Figure 17: Projected emission reduction goals for the apparel industry in 2030, with a focus on renewables vs energy efficiency vs circularity action items
 (Note – for each action item, a target is indicated in % to achieve specified industry-wide GHG reductions)

Based on these results, **the most effective way the apparel and footwear industries can achieve an ambitious industry-wide emission reduction is to focus on renewable energy and energy efficiency across their supply chains** with particular emphasis on the highest impacting life cycle stages (Dyeing and Finishing, Fiber Production, Yarn Preparation, Fabric Preparation, and Assembly) to propel the value chain into a low-carbon future.

The study shows that when a company seeks to achieve greater emissions reductions, it is more effective to focus efforts on increasing renewable energy and energy efficiency rather than on implementing a circular economy approach. Although circular economy measures form a viable pathway for materials reduction, it does not have as significant an impact on emission reduction and may at best (as a stand-alone target) achieve an approximate 10% industry-wide emission reduction within the broader apparel value chain. Only a circular economy where multiple steps in the chain can be skipped, by reusing fabrics or even garments, can provide a relevant reduction in the indicators. Furthermore, to be effective, circular economy must not create more consumption, which may occur if there is a rebound effect of increased or ongoing fast fashion consumption. **Setting an industry-wide science-based target would therefore depend on making major efforts to reduce fossil fuel use and improve energy efficiency throughout the value chain.**

It is important to note that this is a global level study, and the feasibility of making a renewables switch is highly dependent on geography. We do not advocate the purchase of renewables credits as such schemes are often problematic in terms of economy-wide energy mix; at the very least such credits do not alleviate local pollution or health impacts.

ACTION ITEM 1: RENEWABLE ENERGY

When looking specifically at the renewable energy emissions reduction scenario, the study aimed to understand how other impact categories next to greenhouse gas emissions are affected. To assess the potential of mainstreaming renewables across the apparel industry, a variable percentage of renewable energy was applied to Yarn Preparation, Fabric Preparation, Dyeing and Finishing and Assembly processes. This modeling included a shift from fossil fuels to solar energy in addition to favoring wood pellets to their non-renewable alternatives (i.e. natural gas) in order to derive heat¹².

It was found that setting an industry-wide renewable energy target at 60%¹³ by 2030 would yield encouraging results in terms of climate change (39% reduction), and also freshwater consumption (16.9% reduction) and human health (11.5% reduction), which shows the value of a multi-indicator approach.

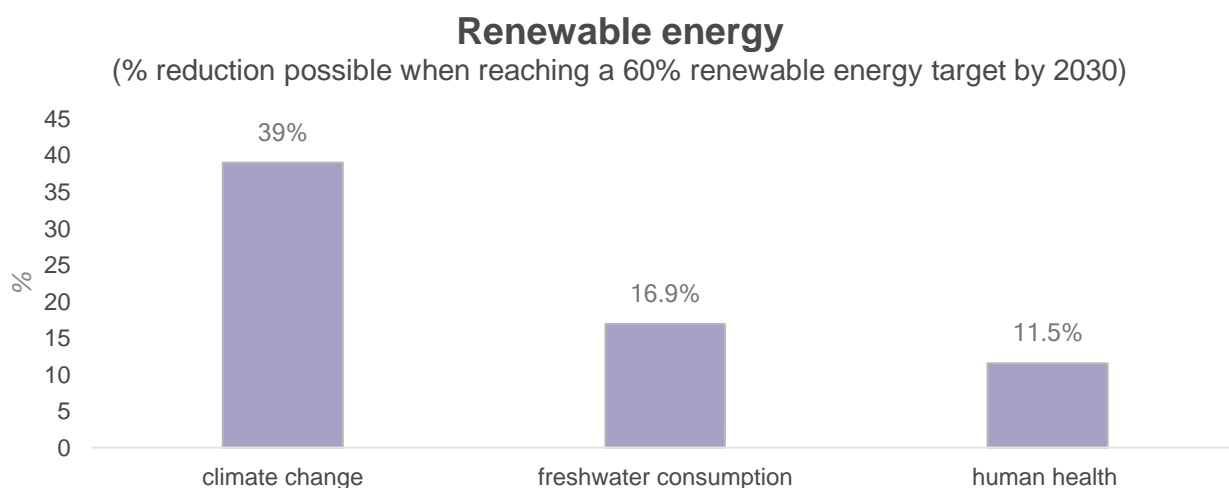


Figure 18: Projected climate change, freshwater and human health impact reduction possible if apparel achieves a 60% renewable energy target by 2030

¹² Wood pellets from wood residues are meant here. However even renewables and residues are limited in amount and can have other negative impacts (e.g. land use change or deforestation), so energy efficiency measures should always come first. The aim here was not to say that "wood pellets" is the best/right alternative when thinking about renewable solutions for heating. The study rather wanted to show what happens if an energy source other than fossil-based solutions is used (other considerations e.g. land use change impacts are as such not taken into account here). Finally, renewables should be vastly expanded to the maximum for the part of the industry's manufacturing that uses electricity, such as spinning, weaving and knitting.

¹³ A renewable energy target of 60% was chosen which would lead to an industry-wide GHG emission reduction of 30-50%. The target selected was based on a benchmarking exercise on existing commitments. Here, the renewable energy share was modeled as reaching 60% of the total electricity mix for the apparel sector for the processes/life cycle stages mentioned above.

ACTION ITEM 2: ENERGY EFFICIENCY/PRODUCTIVITY

When looking at the energy productivity action item, the study aimed to understand how other impact categories next to GHG emissions are affected. Different percentages of energy efficiency factors were applied for both heat and electricity generation during manufacturing processes of Yarn Preparation, Fabric Preparation, Dyeing and Finishing, and Assembly. Additionally, the study assumed a 10% fiber loss attributed to technological inefficiencies at the Fiber Production stage. For more detail see methodological considerations section.

With an energy productivity target set at 60%¹⁴, the industry may reduce its climate change and human health impacts by 41.6% and 40.8% respectively while also decreasing its freshwater consumption by 28.5%. These results show how other impact categories can also be positively influenced with such a target, showing the value of a multi-indicator methodological approach.

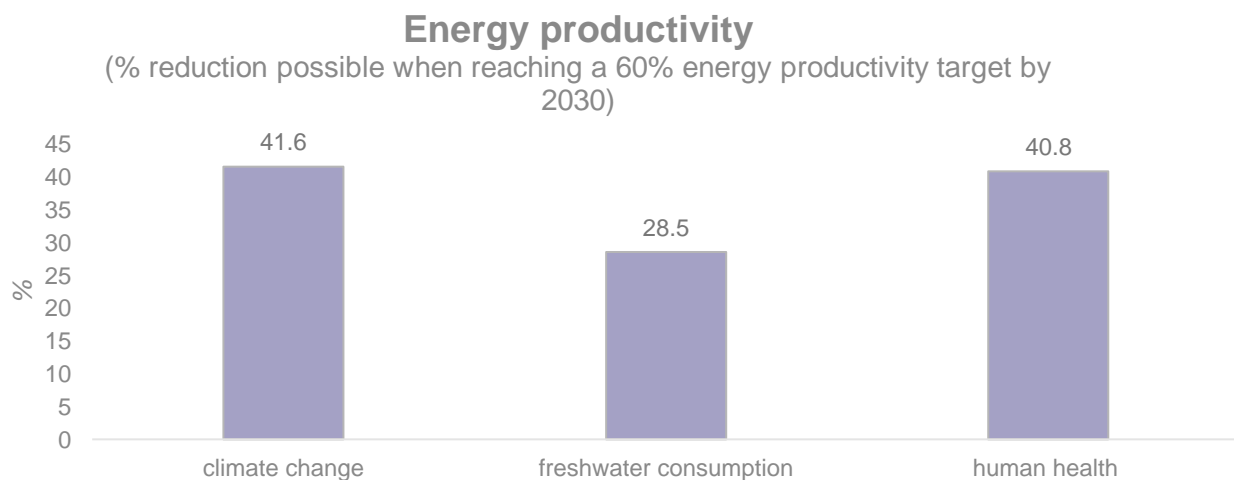


Figure 19: Projected climate change, freshwater and human health impact reduction, if apparel achieves a 60% energy efficiency/productivity target by 2030

¹⁴ An energy productivity target of 60% was chosen which would lead to an industry-wide GHG emission reduction of 30-50%. The target selected was based on a benchmarking exercise on existing commitments. Here, the energy productivity percentage was modeled as using 60% less energy to do the same thing.

ACTION ITEM 3: CIRCULAR ECONOMY

Designing fashion for the circular economy has been extensively debated, leading stakeholders to demand sound metrics on the apparel industry's potential for circularity. Here the study aimed to understand how other impact categories as well as GHG emissions are affected when setting an industry-wide circular economy target. A percentage of recycled fiber was applied to fiber production processes based on the assumption that 53% of disposal would go to recycling and 75% of the recycled output could be reused as recycled fiber. Furthermore, a 10% increase in the impact associated with Yarn Preparation was included to account for the new recycling technology such an approach would require. Neither land use change considerations nor the shift from fiber recycling to fabric recycling were accounted for. Both could allow for additional impact reduction. Furthermore, encouraging adoption of crops or production practices that reduce water use could also reduce additional impacts¹⁵. Finally, while beyond the scope of this report, equity considerations are a key part of any discussion on the circular economy. Recently, East African countries such as Rwanda banned the import of second-hand clothes because such imports undercut local manufacturing and are seen as undesirable and even undignified in an emerging economy.

Setting the circular economy target at 40%¹⁶, data highlights the potential in terms of impacts. A shift of this magnitude could lead the apparel industry to decrease its impacts on climate change by around 6% and freshwater consumption by 4%, while also reducing its negative influence on human health by 3%. Overall, the reduction potential for this action item is significantly lower than for renewable energy or energy efficiency/productivity. This means that closing the loop on fiber alone will not be enough to achieve ambitious industry-wide emission reductions.

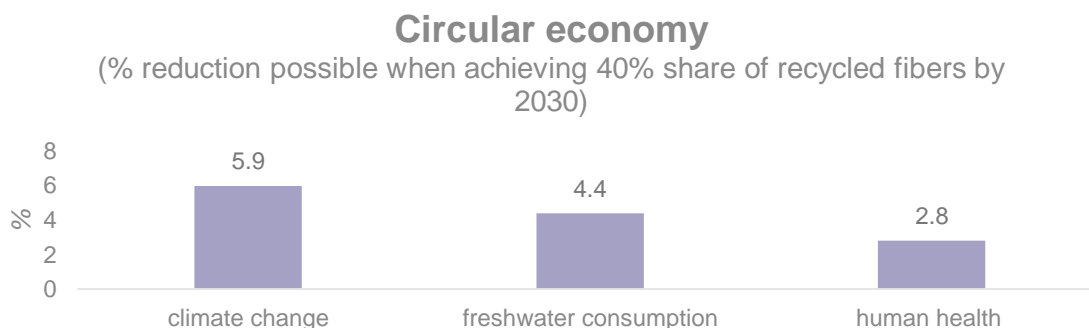


Figure 20: Projected climate change, freshwater consumption and human health impact reduction, if apparel achieves a 40% recycled fiber target by 2030

¹⁵ It cannot be automatically inferred that reducing cotton consumption reduces freshwater withdrawal in water-scarce regions. If cotton is not an economic option for farmers in those regions, they might switch to a food or bio-fuel crop which does not necessarily reduce freshwater use. Thus encouraging adoption of crops and production practices that reduce water use (e.g. replacing conventional cotton with more sustainable cotton fibers using regenerative production practices) can reduce additional impacts.

¹⁶ A circular economy target of 40% was chosen which would lead to an industry-wide GHG emission reduction of 5-10%. The target selected was chosen because it was considered to be reasonable yet ambitious. Here the 40% was modeled by using a recycled fiber rate of 53% multiplied by the recycling rate which can be used to replace new fiber which was 75%, thus $53\% \times 75\% = 40\%$. Hence, only 60% new fibers from total fiber material that would be required would need to be used.

VI. A SUSTAINABILITY FRAMEWORK FOR THE FUTURE



GOAL SETTING FRAMEWORK

The results in this study enable clear-sighted strategies on setting and achieving ambitious sectoral science-based targets thereby demonstrating sustainability leadership. Undeniably, fossil fuel dependency needs to be massively reduced while boosting energy efficiency throughout the value chain. A multi-indicator approach will facilitate emission reductions across multiple impact categories, such as GHG, freshwater withdrawal, and more.

Through gap analysis, the study found that an industry-wide science-based approach would require an 80% emissions cut by 2050 (for an alignment below 2 degrees Celsius), while full compliance with the limits of the planet would require the industry as a whole to return to its 2005 emissions levels with respect to water use, ecosystem conservation and human health impacts.

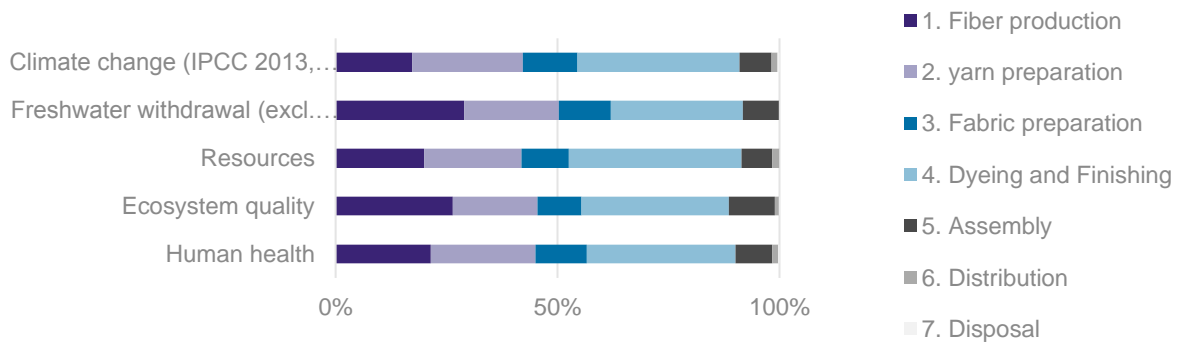


Figure 22: Recommended framework guiding the apparel industry to align with leading initiatives, per life cycle stage and impact indicator

FUTURE TRENDS

This framework also incorporates industry-impacting trends to allow for better and more informed decisions for sustainable fashion in the future. There are four main trends that have been assessed in this study based on *The State of Fashion 2017* report and ASEAN's 2016 report *Refashioning the future*: geographic shifts, digitalization, smart consumption, and preferred & new fiber materials.

Geographic shifts

This trend refers to the relocation of production sites from reshoring manufacturing locations in China to the US, or shifting from manufacturing locations from China towards Africa, due to reduced labor costs. To ensure this trend does not lead to a surge in GHG emissions, it is important to consider relocation to places where renewable energy forecasts support emission reduction opportunities for manufacturing processes like dyeing and finishing, fiber production, yarn production, etc. If this is not the case, relocation can lead to a significant increase in emissions instead of a reduction. Furthermore, the potential ecosystem impacts of such shifts have to be monitored. If production is relocated to high-level income countries like in Europe or the Americas that already have strong water pollution and toxicity prevention systems in place, the industry could benefit from a reduced environmental impact. Yet, the relocation of the manufacturing from low-income countries back into the consumer countries combined with an increased level of automatization (Industry 4.0) might induce a massive loss of jobs in countries such as Pakistan or Bangladesh. In the case of relocating to low-income countries like Ethiopia, the lack of infrastructure could lead to an increase of wastewater impacts or human toxicity, if not offset by a push for renewables for manufacturing.

Digitalization

This trend refers to new technology or technology-induced supply chain efficiencies along the value chain, such as lean manufacturing, digital energy management systems, automation and mass customization. Digitalization enables a reduction in impact by reducing industrial waste and thus reducing the amount of raw material input needed. In this context, it is also important to consider energy efficiency to ensure effective emission reduction. However, this trend can also lead to important social consequences (e.g. loss of jobs), which should be considered.

Smart consumption

This trend refers to new consumption patterns such as an increase in mass customization, e-commerce, and new business models. Smart consumption, such as clothing as a service (leasing clothes and take-back schemes), are an important element to reduce consumption and thus the environmental impact of the industry. Transitioning to new business models that support a sustainable economy will be a key driver for this.

Preferred & new fiber materials

This trend refers to the adoption of preferred fiber materials¹⁷, which have a lower environmental impact than their conventional alternatives. For example, cotton using regenerative organic agriculture practices can have a positive impact on carbon sequestration and significant positive impacts on climate change. It can also refer to the adoption of new fiber materials such as synthetics that are made from recycled material and work toward solutions that eliminate micro-plastics. Promoting these preferred and new fiber materials is important, as is having data from life cycle analysis that allow the industry to quantify benefits of using new materials and report the reduction of negative impacts.

¹⁷ Find more information about preferred fiber materials in the following report "Preferred Fibers & Benchmark - Sector Report 2016" by Textile Exchange <http://textileexchange.org/downloads/preferred-fiber-materials-benchmark-sector-report-2016/>

STUDY CONCLUSION

To comply with Science Based Targets (requiring an 80% reduction in GHG emissions by 2050) and Planetary Boundaries, different improvement measures must be applied in parallel: Higher energy efficiency and a shift to renewable energy as well as smart approaches for fiber and fabric recycling. It is important to understand that the implementation of single measures alone (e.g. circular economy) will not make the apparel sector sustainable in the long term. Only a broad approach that includes a range of measures will enable the apparel and footwear industries to achieve their sustainability goals.

Furthermore, additional trends (referred to in this study) and considerations (e.g. micro-plastics, social benefits of natural fibers in terms of agricultural work places, etc.) should be considered when exploring solutions for a more sustainable future of fashion.

VII. METHODOLOGICAL CONSIDERATIONS



APPAREL INDUSTRY: METHODOLOGY & ASSUMPTIONS

SUMMARY	2005	2010	2016	2020	2030	SOURCE
BASELINE						
Fiber production [million tons]						
Total fiber	70.0	83.0	101	116	153	The Fiber Year report 2017: 2005, 2010, 2016, Increase of 3.7% per year calculated from baseline year 2016 (Global Fibers Overview from Tecnon Orbichem): 2020, 2030
Total for apparel	58.5	69.7	85.0	97.6	129	Values from The Fiber Year report 2017 (Table A) multiplied by the share of fibers going to apparel production (Table C)
Cotton	21.3	22.9	20.4	20.4	21.4	Values from The Fiber Year report 2017 (Table B) multiplied by the share of fibers going to apparel production (Table C)
Natural Fibers	2.16	2.16	5.10	5.10	5.35	Same as above.
Synthetics	41.9	41.9	54.4	67.0	96.9	Same as above.
Cellulosic	2.71	2.71	5.10	5.10	5.35	Same as above.
Yarn preparation [million tons]						
Total fiber	58.3	68.1	85.3	-	-	The Fiber Year report 2017
Total for apparel	48.9	57.1	71.5	82.1	108	Values from The Fiber Year report 2017 multiplied by the share of fibers going to apparel production (Table C)
Filament yarn	22.1	20.4	33.2	32.4	46.0	Table F
Staple yarn	26.8	36.6	38.3	49.7	62.5	Table F
Losses (and co-product) of staple fibers	26.4	26.9	28.6	23.8	24.7	Calculated from the overall losses (see below). These losses apply only to staple yarn (cotton, natural fibers, synthetic, cellulosic).
Overall losses	16.5	18.1	15.9	15.9	15.9	Ratio between total yarn for apparel and total fiber for apparel (Table D)
Fabric preparation [million tons]						
Total fiber	74.0	85.0	101.0	-	-	The Fiber Year report 2017
Total for apparel	47.9	55.9	70.1	80.5	106	Overall losses for this step applied to the global number of yarn produced for apparel. Technologies taken into account: knitting (57%) and weaving (32%). Non-woven and spun bond products are not used in apparel. Values from The Fabric Year report. Fabric is knitted using a circular (60%) or flat (40%) knitting technique. Values from World Apparel Life Cycle Database.
Overall losses	2.00	2.00	2.00	2.00	2.00	Values from the World Apparel Life Cycle Database

Dyeing and Finishing [million tons]

Total fiber	-	-	-	-	-	
Total for apparel	47.9	55.9	70.1	80.5	106	Overall losses for this step applied to the global volume of fabric produced for apparel
Overall losses	0.00	0.00	0.00	0.00	0.00	Values from the World Apparel Life Cycle Database
Assembly [million tons]						
Total fiber	-	-	-	-	-	
Total for apparel	41.9	48.9	61.3	70.4	93.1	Overall losses for this step applied to the global volume of fabric for apparel undergoing dyeing and finishing step
Overall losses	12.5	12.5	12.5	12.5	12.5	Values from the World Apparel Life Cycle Database
Disposal [million tons]						
Total fiber	-	-	-	-	-	
Total for apparel	41.9	48.9	61.3	70.4	93.1	Overall losses for this step applied to the global volume of fabric for apparel being assembled. 20% goes to incineration and 80% to landfill (World Apparel Life Cycle Database).
Overall losses	0.00	0.00	0.00	0.00	0.00	Values from the World Apparel Life Cycle Database

Calculations

A = GLOBAL FIBER PRODUCTION FOR APPAREL					
Units	[Million tons]		[%]		[Million tons]
Metrics	Global fiber production	X	Share of fibers going to apparel production	=	Global fiber production for apparel
Baseline	101	X	0.84	=	85.0
Scenarios					
2005	70.0	X	0.84	=	58.6
2010	83.0	X	0.84	=	69.7
2020	116	X	0.84	=	97.6
2030	154	X	0.84	=	129
Source	The Fiber Year report 2017		Table C		

B = SHARES OF DIFFERENT FIBERS IN GLOBAL PRODUCTION

	Units	[Million tons]	[%]
	Metrics	Global fiber production	Share in global fiber production
BASELINE	Cotton	24.3	24
	Natural fibers	6.08	6
	Synthetic	64.9	64
	Cellulosic	6.08	6.0
2005	Cotton	26.0	37
	Natural fibers	5.05	7.0
	Synthetic	35.9	51
	Cellulosic	2.92	4.0
2010	Cotton	24	29
	Natural fibers	7.12	9.0
	Synthetic	47.7	58
	Cellulosic	4.15	5
2020	Cotton	20.4	21
	Natural fibers	5.10	5
	Synthetic	67.0	69
	Cellulosic	5.10	5
2030	Cotton	21.4	17
	Natural fibers	5.36	4
	Synthetic	96.9	75
	Cellulosic	5.36	4
Source	The Fiber Year report 2017		The Fiber Year report 2017

C = SHARE OF APPAREL IN FIBER PRODUCTION

Units	[Million tons]		[Million tons]		[%]
Metrics	World fiber production for apparel	/	World global fiber production	=	Share of fibers going to apparel production
Value 2005	58.6	/	70.0	=	0.837
Value 2010	69.7	/	83.0	=	0.840
Average value used in calculation			Average (2005,2010)	=	0.84
Source	FAO World Apparel Fiber Consumption Survey 2013		The Fiber Year report 2017		

D = OVERALL LOSSES DURING FIBER PRODUCTION

Unit	[Million tons]		[Million tons]		[%]
Metrics	Global yarn production for apparel	/	Global fiber production for apparel	=	Overall losses during fiber production step
2016	71.5	/	85.0	=	15.9
Scenarios					
2005	48.9	/	58.6	=	16.5
2010	57.1	/	69.7	=	18.1
2020	82.1	/	97.6	=	15.9
2030	108	/	129	=	15.9
Source	The Fiber Year Report 2017		The Fiber Year report 2017		

E = STAPLE AND FILAMENT FIBER

BASELINE	Unit	[%]	[Million tons]
	Metrics	Global fiber production	Global fiber production
	Staple fiber	55	46.8
	Filament fiber	45	38.3
Scenarios			
2005	Staple fiber	62	36.5
	Filament fiber	38	22.1
2010	Staple fiber	71	49.8
	Filament fiber	29	19.9
2020	Staple fiber	55	53.7
	Filament fiber	45	43.9
2030	Staple fiber	55	71.0
	Filament fiber	45	58.1
Comment	Filament fiber are used directly as yarn (= no losses transforming filament fibers into filament yarn)		
Source	The Fiber Year Report 2017	The Fiber Year Report 2017	

F = STAPLE AND FILAMENT YARN			
Units	[Million tons]	[Million tons]	[Million tons]
Metrics	Global yarn production	- Total filament yarn production for apparel	= Total staple yarn production for apparel
Value baseline	71.5	- 38.3	= 33.3
Scenarios			
Value 2005	48.9	- 22.1	= 26.8
Value 2010	57.1	- 19.9	= 37.2
Value 2020	82.1	- 43.9	= 38.2
Value 2030	108	- 58.1	= 50.5
Comment	Filament fibers are used directly as yarn (= no losses from filament fibers to filament yarn)		
Source	The Fiber Year Report 2017	Table E	

ASSUMPTIONS

Fibers & market use breakdown

- The breakdown for total fiber production by market use is 84% going to apparel, 12% to home textile, 4% to industrial textile (see Table A and the Fiber year report).
- Approximation used by fiber:
 - Synthetic fibers approximated with polyester fibers
 - Cellulosic fibers approximated with viscose fibers
 - Natural fibers approximated with linen fibers
- For cotton, blends are assumed to have similar production process as pure fibers.
- For all fibers, a conventional dataset was used (no distinction was made between different fiber materials e.g. cotton vs. organic cotton)

Assembly

- Exporting countries are assumed to be the assembling countries.
- Importing countries are assumed to be the countries consuming and sending cloths to disposal.
- An adjustment factor (AF) was used to determine each country's share (%) in the world cloth trading market (billion \$):

$$AF = \frac{\text{Gross Domestic Product GDP based on Purchasing Power Parity (PPP)}}{\text{Gross Domestic Product (GDP nominal)}}$$

Yarn preparation

- Cotton spinning was used as a proxy for yarn preparation of synthetics.
- Wet spinning was used for yarn preparation of natural fibers and cellulosic.
- Cotton spinning and mercerizing was used for cotton.

Fabric production

- Based on the The Fiber Year 2017 report a ratio of 64% going to knitting and 36 % going to weaving was used.
- Knitting was allocated between circular (60%) and flat (40%).

Dyeing & Finishing

- Bleaching and dyeing for cotton was used for cotton and natural fibers.
- Bleaching and dyeing diverse was used for all other fiber materials (synthetic, cellulosic, natural fibers)
- A general apparel finishing process was used for finishing of knitted fabric.
- Finishing for woven yarn was used for all woven fabric except for that made from natural fibers for which finishing of woven linen was used.

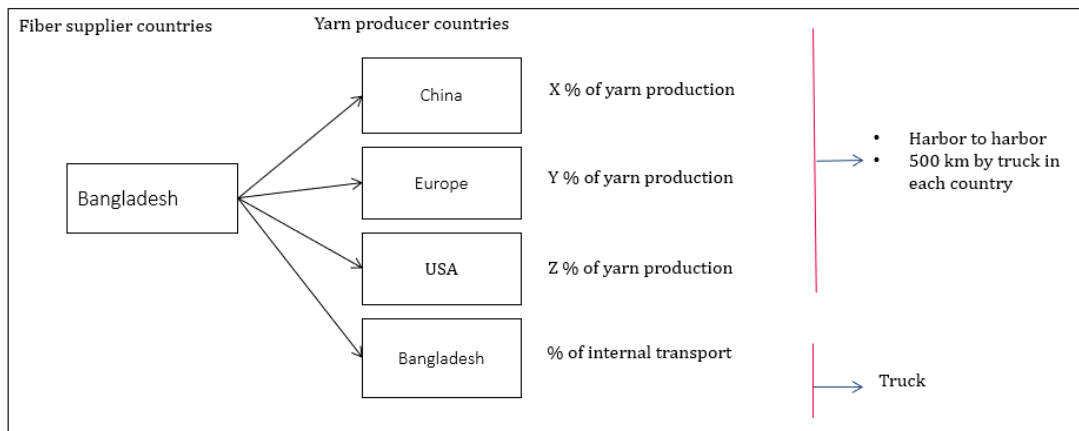
Disposal

- Locations of disposal used are: Europe, USA, and Rest of the World (RoW).
- No waste manufacturing processes were considered during manufacturing stages.
- Specific waste textile datasets were used for incineration.

Transport

Transport modelling was based on location data for each step. Each ton of goods produced (fiber, fabric, garment) from one country is transported to all the countries where the next step takes place. The calculations are then repeated for each supplier country. The following assumptions were applied:

- Transport by ship: distance harbor to harbor +500 km estimated to be carried by truck in both countries (sender and receiver)
- Internal transport is taken into account and is the same for all countries (1000 km by truck)
- Synthetic and cellulosic fibers are produced at the same locations
- For distribution, transport is 8% air freight and 92% ship freight based on the “Environmental Improvement Potential of Textiles” report (2014).
- Distance to waste disposal (landfill or incineration) is 55 km for Europe and 77 km for both USA and Rest of the World (RoW).



LIST OF COUNTRIES TAKEN INTO ACCOUNT IN THE CALCULATIONS

Bangladesh	Japan	Russia
Brazil	Korea	Taiwan
China	Malaysia	Thailand
EU (28)	Mexico	Turkey
India	Myanmar	USA
Indonesia	Pakistan	Vietnam

LIFE CYCLE STEP LOCATION DATA SOURCE

Fiber production	The Fiber Year report 2017
Yarn production	The Fiber Year report 2017
Fabric production	The Fabric Year report 2017
Dyeing and finishing	World Apparel Life Cycle Database
Assembly	World Trade Organization
Disposal	World Trade Organization

Geographical assumptions throughout the entire study

- Geographic allocations were adjusted according to production step:
 - For Fiber production, yarn preparation and fabric production, location data came from The Fiber Year report and The Fabric Year report and encompass Bangladesh, Brazil, China, EU (28), India, Indonesia, Japan, Korea, Malaysia, Mexico, Myanmar, Pakistan, Russia, Taiwan, Thailand, Turkey, USA, Vietnam and others.
 - For dyeing and finishing, location data was extracted from WALDB
 - For assembly and disposal, location data was issued by The World Trade Organization

- The following table illustrates the geographies broken down by life cycle stage for the apparel and footwear modeling. For all countries listed in the 80%, the datasets were adjusted to represent that region (e.g. electricity mix). For all countries listed as ROW, an average global dataset was used:

		Bangladesh	Brazil	China	EU (28)	India	Indonesia	Pakistan	Russia	Turkey	USA	Vietnam
FIBER PRODUCTION	2005		1%	41%	4%	11%	0%		2%		6%	
	2010		1%	53%	4%	15%	0%		1%		4%	
	B		1%	57%	7%	13%	2%		0.7%*		4%	
	2020		1%	59%	8%	11%	1%		1%		3%	
	2030		1%	62%	7%	10%	1%		1%		3%	
YARN PRODUCTION	2005	1%		51%	2%	7%		4%				
	2010	1%		58%	3%	10%		5%				
	B	3%		64%	1%	9%		4%				
	2020	2%		60%	3%	10%		6%				
	2030	2%		61%	3%	10%		5%				
FABRIC PRODUCTION	Past	3%	1%	60%		12%		2%		5%		
	B	3%	1%	60%		12%		2%		5%		
	Future	3%	1%	60%		12%		2%		5%		
DYEING & FINISHING	Past	28%		44%	11%					17%		
	B	28%		44%	11%					17%		
	Future	28%		44%	11%					17%		
ASSEMBLY	Past	5%		41%	0.3%	6%						4%
	B	7%		35%	11%	7%						6%
	Future	10%		50%	0.3%	6%						7%
DISPOSAL	Past				2%						38%	
	B				16%						20%	
	Future				1%						33%	
FOOTWEAR		4%	61%		10%							0.8%

Notes

Not all Rest of the World (RoW) countries (blank fields) are listed in this table. Please refer to geography reference to see the complete list of countries considered.

Locations were broken down by fiber materials.

For Yarn Production, EU(28) for the baseline scenario was approximated with Turkey.

For Fiber Production, Russia was approximated with Uzbekistan.

For both past and future scenarios for Assembly and Disposal, 2005 and 2020 had the same geographic distribution and 2010 and 2030.

For all scenarios in Dyeing and Finishing, the countries listed represent 100% of the geographic breakdown used in this life cycle stage.

Disposal represents less than 80% because the geographic breakdown used for this stage was EU, USA and RoW.

Scenarios and focus areas

- Changes in transport were not considered for scenario modeling
- Future scenarios:
 - Increase of total fiber, based on economic growth for apparel fiber market 3.7% per year (Orbichem, 2014)
 - Assumed shifts by material based on back-casting based on historical trends:

	2020	2030
Cotton	No change	5%
Natural fibers	No change	5%
Cellulosic	No change	5%
Synthetics	69%	78%

- Focus areas:
 - Renewable energy: calculated impact by category and indicator, based on ecoinvent v.3 from global and China-related values:
 - Impact of solar/fossil energy: 5% for climate change, 16% for freshwater withdrawal, 14% for human health.
 - Impact of wood pellets/fossil fuels: 18% for climate change, 96% for freshwater withdrawal, 161% for human health.
 - Energy productivity: energy productivity here is assumed to using selected percentage (%) less energy to do the same thing.
 - Assumed fiber loss during fiber production is 10%.
 - Same energy productivity percentage was applied to both heat and electricity in the scenarios.
 - Circular economy:
 - Impacts increase by 10% during the yarn preparation phase due to recycling technology.
 - Baseline assumption: 53% of disposal would go to recycling and 75% of the recycled output could be reused as recycled fiber

FOOTWEAR INDUSTRY: METHODOLOGY & ASSUMPTIONS

Calculations & Assumptions

PRODUCTION	LEATHER SHOES	SYNTHETIC SHOES	TEXTILE SHOES	TOTAL
[Million tons]	5.39	12.05	3.82	21.27
[Million pairs]	5395	12047	3825	21266
[%]	25	57	18	100
Comments	No losses assumed. Total number of shoes produced will be used in the entire life cycle stages (manufacturing -midsole, outsole production, cut and link- assembly and disposal). Assumption that 1 pair of shoes weigh 1kg.			
Source	World Footwear Yearbook Manufacturing-focused emissions reductions in footwear production - L. Cheah et al.			

MATERIALS					
Leather shoes	Materials	Value	Units	Comment	Sources
Raw material extraction	EVA (Ethylene vinyl acetate copolymer)	2.00	[Mt]	Material for midsole (37%)	World Footwear Yearbook Manufacturing-focused emissions reductions in footwear production - see L. Cheah et al.
	Rubber	0.97	[Mt]	Material for outsole (18%)	
	Raw hides	11.87	[Mt]	Material for upper part (40%)	
Raw material processing	Leather tanning	1541.35	[Million m2]	Conversion from raw hides to leather: 1m2 of leather equals 7.7kg of raw hides.	World Apparel Life Cycle Database

Synthetic shoes	Materials	Value	Units	Comment	Sources
Raw material extraction	EVA (Ethylene vinyl acetate copolymer)	6.87	[Mt]	Material for midsole (57%)	World Footwear Yearbook Manufacturing-focused emissions reductions in footwear production - see L. Cheah et al.
	Rubber	2.17	[Mt]	Material for outsole (18%)	
	Polyester	1.51	[Mt]	Material for upper part (25%)	
	Polyurethane	1.51	[Mt]		
Raw material processing	Polyester and polyurethane fiber spinning and weaving	3.01	[Mt]		

Textile shoes	Materials	Value	Units	Comment	Sources
Raw material extraction	EVA (Ethylene vinyl acetate copolymer)	2.18	[Mt]	Material for midsole (57%)	World Footwear Yearbook Manufacturing-focused emissions reductions in footwear production – see L. Cheah et al.
	Rubber	3.24	[Mt]	Material for outsole (18%)	
	Cotton fibers	0.96	[Mt]	Material for upper part (25%)	
Raw material processing	Cotton fiber spinning	0.96	[Mt]		

Transportation:

- The model is the same as the one used for textiles (same assumptions, locations and sources).
- Transportation for distribution represents 12% of overall transportation (same as in the textile model) with 8% achieved via air freight.
- The weight of shoe packaging is estimated at 178g, so that shoes and box combined weigh 1.178 kg.
- Transportation is assumed to be negligible between material production center and footwear manufacture.

Life Cycle steps:

- Shoe manufacturing and assembly are assumed to take place in the same location.
- Disposal: the same approach was used as for apparel

DATA UNCERTAINTY & GAPS

Data uncertainty: Fiber production

The main driver of uncertainty is the share of fibers used in apparel, which varies from 60% to 90% depending on the selected source. We opted for a rather conservative assumption of 84%. The uncertainty corresponding to overall fiber volume is estimated to be relatively small due to the reliability of our sources.

Data uncertainty: Textile processing

The uncertainty of the data concerns i) the specific fiber losses at every step, ii) the average material and energy requirements in the various processing steps as well as iii) the location of the processing countries.

- i. Fiber loss calculations are based on statistics on yarn preparation, and industry averages from the WALDB with regards to other processes. The highest losses occur during yarn preparation (about 16%, including by-products) and assembly stages (about 13%, including by-products). During yarn preparation, overall fiber losses can vary from 9 to 40% (including by-products). Losses corresponding to assembly stages depend to a high degree on the garment type and cut.
- ii. The WALDB data showcases great variability with regards to electricity consumption from one company to another. The amount of electricity that goes into spinning can vary between 3 kWh and 11 kWh per kg of yarn. Heat requirements for dyeing processes can vary between 10 MJ and 60 MJ per kg of dyed material. The data used is based on averages. As the sample is relatively small compared to the industry as whole, the level of uncertainty is quite high.
- iii. Geographic location of processing countries directly influences the energy mix and as a result, the environmental impacts of energy used in the process. For processes relying mainly on electricity, the uncertainty level averages 20%. For processes relying on heat, the uncertainty level falls to around 10%, as most of the energy for heating comes from fossil fuels.

Data gaps

The following list outlines current data gaps that were identified by the study:

- Share of fibers for apparel
- Quantified data on local water impacts in the dyeing process
- Consolidated averages for energy use in the processing industry (e.g. spinning technologies)
- Data reflecting the effect of blending on material losses, energy use and recycling
- Reliable data on transport mileage in footwear and apparel, especially for trucks and airplanes
- Detailed geographic breakdown for manufacturing locations

DEFINITION OF IMPACT INDICATORS

This study calculates midpoint and endpoint indicators, as well as inventory values and classes of metrics that differ by their intended purpose. Midpoints characterize processes caused by flows of substances to and from the natural environment, while the objective of an endpoint is to better illustrate the overall effect of these processes in terms of societal value — human health, ecosystems, and resources. Inventory data is the information used to compute midpoints and endpoints.

Inventory metrics summarize the flows of resources and wastes consumed and emitted by a system. While these flows may not be environmental impacts per se, measuring and comparing them nonetheless highlights the issues that an organization may directly influence (such as waste generation) and thus are of interest.

Midpoint indicators are the physical, chemical and biological processes triggered by the consumption or emission of a particular substance. For example, ozone depletion caused by the release of chlorofluorocarbons (CFC) and other compounds is a key midpoint indicator in the IMPACT 2002+ system. This type of result is generally calculated from the inventory of flows into and out of the environment, such as the consumption of crude oil or methane emissions (CH₄).

Endpoint indicators attempt to quantify damages to human health and the environment, generally as a result of the midpoints. For instance, the human health endpoint indicator in IMPACT 2002+ attempts to estimate the years of useful life lost due to all the human health impairments that can be quantified, using said methodology. Similarly, the ecosystem quality indicator delves into the loss of species that may occur. These calculations are performed using scientifically derived algorithms that require appropriate midpoints as data inputs.

It should be noted that while midpoints and endpoints are a recurrent theme in LCA science, specific indicators and the algorithms used to calculate them may vary — sometimes significantly — from one impact assessment method to another. The present document does not intend to explain the selected impact assessment methodology; however, it is important to understand what the underpinning indicators cover when referencing its conclusions. To that end, a brief description of the corresponding indicators is provided in the following table:

Impact indicator	Description
Climate change or global warming potential (midpoint)	Climate change or global warming potential (also referred to as carbon footprint) measures the potential impact on climate change from greenhouse gas emissions associated with a product, process or organization. It takes into account the capacity of a greenhouse gas to influence radiative forcing, expressed in terms of a reference substance and specified time horizon.
Ecosystem quality (endpoint)	The health of an ecosystem can be impaired by the release of substances that cause acidification, eutrophication, toxicity to wildlife and land occupation in addition to various other mechanisms. An evaluation of the overall impact of a system on ecosystem health is carried out using the ecosystem quality endpoint of the IMPACT 2002+ methodology (Jolliet et al., 2003), in which substances are weighted based on their ability to cause each of various damages to wildlife species. These impacts are measured in units of potentially disappearing fractions (PDFs), which relate to the likelihood of species loss.
Human health (endpoint)	Damage to human health due to pollution is caused by the release of substances that affect human beings through acute toxicity, cancer-based toxicity, respiratory effects, increases in UV radiation and other processes. An evaluation of the overall impact of a system on human health is carried out using the human health endpoint of the IMPACT 2002+ methodology, in which substances are weighted based on their ability to cause a variety of damages to human health. These impacts are measured in units of disability-adjusted life years (DALY), which combine estimations of morbidity and mortality from a number of causes.
Resources (endpoint)	Resource depletion is the result of the consumption of non-renewable resources or renewable resources at a rate greater than they can be renewed. Materials are weighted based on their abundance and difficulty to obtain. An evaluation of the overall impact of a system on resource depletion is carried out using the resources endpoint of the IMPACT 2002+ methodology, which combines nonrenewable energy use and an estimate of the increased amount of energy that will be required to obtain an additional amount of that substance from the earth, based on the Ecoindicator 99 method (Goedkoop, Spriensma 2000). Such impacts are measured in megajoules (MJ).
Freshwater withdrawal (midpoint)	Freshwater withdrawal measures the potential impact related to water withdrawal associated with a product, process or organization. It takes into account water (whether it is evaporated, consumed or released again downstream) without turbined water (i.e., water flowing through hydropower generation). It considers drinking water, fresh water, irrigation water and water for industrialized processes (including cooling water).

REFERENCES

- Asean in transformation - textiles, clothing and footwear: refashioning the future (2016). J. Chang et al., International Labour Office. <http://www.voced.edu.au/content/ngv:74515>
- Environmental Improvement Potential of textiles (IMPRO Textiles) (2014). European Commission.
- Global Fibers Overview – Synthetic Fibers Raw Materials Committee Meeting at APIC 2014, Tecnon OrbiChem
http://www.orbichem.com/userfiles/APIC%202014/APIC2014_Yang_Qin.pdf
- The Fiber year 2017 (2017). Fiber Year Consulting
- The Fabric year 2017 (2017). Fiber Year consulting
- Manufacturing-focused emissions reductions in footwear production (2013) L. Cheah et al.
<http://www.sciencedirect.com/science/article/pii/S0959652612006300>
- The state of fashion 2017 (2016). The Business of Fashion and McKinsey & Company.
- World Apparel Data Base (WALDB) (2016). Quantis International. See more information here: <http://quantis-intl.com/WALDB>
- World Apparel Fiber Consumption Survey (2013). FAO
https://www.icac.org/cotton_info/publications/statistics/world-apparel-survey/FAO-ICAC-Survey-2013-Update-and-2011-Text.pdf
- World footwear yearbook (2012). APICCAPS.
<https://ia600607.us.archive.org/2/items/WorldFootwearYearbook2012/2012WorldFootwearYearbook.pdf>