LIFE CYCLE ASSESSMENT (LCA)

FOR UNSPUN'S 3D WOVEN PANTS

unspun

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GLOSSARY

Allocation: "Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006, section 3.8).

Background System: "Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good." (European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2010, pages 96-97). Generally, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Foreground System: "Those processes of the system that are specific to it and/or directly affected by decisions analysed in the study" (European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2010, pages 96-97). This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a rule, specific (primary) data should be used for the foreground system.

Functional Unit: "Quantified performance of a product system for use as a reference unit" (ISO 14040:2006, section 3.2).

Life Cycle: A view of a product system as "consecutive and interlinked stages from raw material acquisition or generation from natural resources to final disposal" (ISO 14040:2006, section 1). This includes all material and energy inputs as well as emissions to air, land, and water.

Life Cycle Assessment (LCA): "Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, section 1).

Life Cycle Impact Assessment (LCIA): "Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product" (ISO 14040:2006, section 5).

Life Cycle Interpretation: "Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040:2006, section 5).

Life Cycle Inventory (LCI): "Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 14040:2006, Annexures A1 and A2).

System boundary: "Set of criteria specifying which unit processes are part of a product system." (ISO 14044:2006, section 3.5).

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EXECUTIVE SUMMARY

The study ultimately delivers key data driven insights, that can be used by Unspun to mitigate the environmental impacts associated with the production 3D woven pants (Vega) hereinafter referred to as '3D woven pants'.

The following goals are set to deliver the above mentioned insights:

1. Quantify the environmental impacts associated with the production of (1) 100% 3D woven conventional cotton pants, and (2) 100% 3D woven virgin polyester pants. Key hot spots are identified in the respective supply chains (SCs).

2. Estimate the potential environmental impacts/benefits of 3D woven pants over pants produced via the air-jet weaving technique.

3. Estimate the potential environmental benefits/impacts associated with circularity of 3D woven pants for different return rates.

4. To build a scenario using a different final distribution option: supplier to warehouse/outlets and then to the end-customer, and explore how this scenario might influence the overall environmental impacts of 3D woven pants.

Environmental impacts are quantified using Life Cycle Assessment (LCA) methodology following ISO standards 14040:2006 and 14044:2006. Impacts are expressed using three key indicators: Global Warming Potential (GWP), Primary Energy Demand (PED), and Blue Water Consumption (BWC). The Functional Unit (FU) of this study is production of 'one pair of Unspun's 3D woven pants' made from two different fibers and produced in different supply chains mentioned in this study. This study covers the apparel manufacturing stages within the SCs, starting from fiber/raw material production to the production of 3D woven pants and delivery to the consumers. Air-jet weaving serves as the baseline for comparison with 3D weaving.

Unspun aims to remake garments returned by customers at the end of their life into new garments, by unweaving the pants into yarn and weaving them again into new garments, thus keeping the resources in circulation instead of downcycling. Unspun aims to achieve 100% circularity. But waste is bound to be generated even while using high end-state of art technology to unweave used pants into yarn. So, 90% circularity, meaning the process efficiency of unweaving equipment is 90%, and 10% fabric waste was assumed for this analysis. It should be noted that a 100% return rate (RR) is an ideal scenario and may not be practically feasible. So, environmental

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impacts associated with circularity of 3D woven pants, estimated for five different return rates: 20%, 40%, 60%, 80% and 100% are reported here. Currently, supplier directly ships the 3D woven pants to customers. A scenario is built to understand the impacts of shipping the pants from the supplier to the warehouse/retail outlet via ship and then to the customer via truck.

Table 1 presents impact savings of one pair of Unspun's 3D woven pants made from 100% conventional cotton (SC 1) and 100% virgin polyester (SC 2) over similar pants produced via air jet weaving.

TABLE 1: IMPACT SAVINGS (%) OF ONE PAIR OF UNSPUN'S 3D WOVEN PANTS PRODUCED IN TWO DIFFERENT SCS

Supply chain (fiber)	Global Warming Potential	Primary Energy Demand	Blue Water Consumption
SC 1 (100% conventional cotton 3D woven pants)	**-23.93%**	**-25.00%**	**-1.41%**
SC 2 (100% virgin polyester 3D woven pants)	**-19.02%**	**-17.84%**	**-2.58%**

* + SIGN INDICATES HIGHER IMPACT AND - SIGN INDICATES IMPACT SAVINGS RELATIVE TO THE BASELINED

Baselining shows savings for GWP, PED and BWC impact categories for both conventional cotton and virgin polyester 3D woven pants (Table 1). This is because (1) the electricity requirement of 3D weaving is significantly lesser than air jet weaving. Also, the fabric waste generated at cut & sew is considerably eliminated as the pants are directly woven from yarn in tubes and sent to the sewing area for attaching pockets/buttons/trims. Fabric loss at cut and sew determines the amount of fiber needed in the cultivation stage and the process energy/materials needed in the yarn/fabric/apparel production processes. So higher fabric waste means lower process efficiency, more fiber and process energy/materials are needed to produce the required output, resulting in higher environmental impacts across the life cycle of the pants.

Note that the ooverall water savings of 3D woven pants is lower than savings in energy and carbon because, 3D weaving and air jet weaving are both power driven, so more savings are realized in the PED and GWP categories.

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By-stage impacts are summarized as follows:

100% conventional cotton 3D woven pants (SC 1)

- 3D weaving process is the key contributor to the overall GWP and PED impacts followed by cultivation of conventional cotton and fiber production. Impacts are mainly driven by the energy (electricity) used in 3D weaving process.
- Conventional cotton cultivation and fiber production stages are found to be the highest contributors to BWC impacts. Impacts can be linked to the irrigation needs of the cotton crop.

100% virgin polyester 3D woven pants (SC 2):

- Granulate production is the highest contributor to GWP and PED impacts, followed by 3D weaving process. Impacts predominantly come from the production of monomers like purified terephthalic acid and ethylene glycol used in PET fiber production, and the electricity used in the 3D weaving process.
- Finishing process that refers to the attachment of accessories like lining fabric and fusible interfacing made from cotton, is found to be a clear dominant contributor to BWC impacts. Due to the water-intensive cotton cultivation process required in the production of these accessories, even though their share in the fiber composition of pants is negligible, their impacts are significant. In contrast, production of polyester, the dominant fiber in the pants (almost 100%), hardly has any BWC impact.

Table 2 presents impacts of the two types of 3D woven pants produced: (1) from 100% virgin resources, and (2) from used 3D pants returned by customers assuming 90% circularity, and a 100% return rate. Impact reduction is observed across all the three categories for conventional cotton and virgin polyester 3D woven pants remade from 3D woven pants returned by customers at the end of their life. One key assumption made here is that only 3D woven pants are returned, unwoven into yarn and then woven again into 3D pants, other garments are not considered.

TABLE 2: IMPACT RESULTS OF 3D WOVEN PANTS (1) MADE FROM 100% VIRGIN RESOURCES AND (2)

Impact Category	90% circularity (100% return rate)	No circularity (100% virgin resources)
100% CONVENTIONAL COTTON PANTS		
Global warming potential (kg CO2 eq.)	**4.01**	**6.23**
Primary energy demand (MJ)	**76.20**	**114.00**
Blue water consumption (Liters)	**764.00**	**4910.00**

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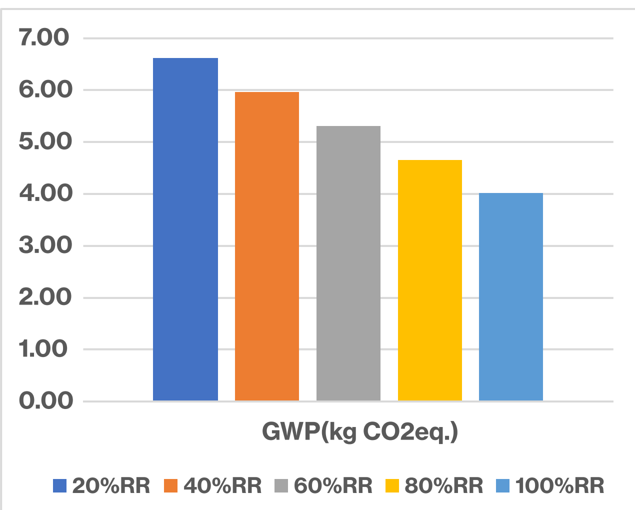
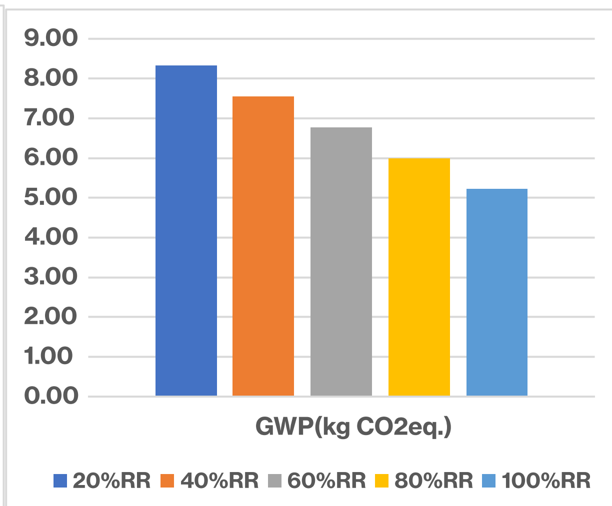
Impact Category	90% circularity (100% return rate)	No circularity (100% virgin resources)
100% VIRGIN POLYESTER PANTS		
Global warming potential (kg CO2 eq.)	5.22	8.26
Primary energy demand (MJ)	97.40	175.00
Blue water consumption (Liters)	342.00	378.00

Figure 1 presents the GWP impacts of 3D woven pants for five different return rates, while keeping 90% circularity. Similar trends can be observed for PED and BWC impacts. Environmental impacts are found to be inversely correlated with 3D woven pants' return rates, meaning as return rates rise, the impacts reduce. This is because a greater return rate causes more waste/returned pants to be turned into yarn, which lessens the demand for virgin yarn production and related fiber production, as a result has reduced environmental impacts.





RR-RETURN RATE

FIGURE 1: GWP IMPACTS OF ONE PAIR OF 100% COTTON (LEFT) AND ONE PAIR OF 100% POLYESTER (RIGHT) 3D WOVEN PANTS FOR FIVE RETURN RATES, WITH 90% CIRCULARITY.

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Key insights from the study:

- Baselining 3D woven pants with air jet woven pants made from similar fibers resulted in savings for 3D woven pants in all the three impact categories: GWP, PED, and BWC.
- Overall water savings of 3D woven pants (3%) is lower than savings in energy (18%) and carbon (19%) because, 3D weaving and air jet weaving are both power driven, so more savings are realized in the PED and GWP categories.
- Considering by-stage impacts, 3D weaving process is the highest contributor to the GWP and PED impacts of 100% cotton 3D woven pants.
- PET granulate production followed by 3D weaving process are the key contributors to GWP and PED impacts of 100% polyester pants.
- 3D woven pants remade from returned 3D woven pants were found to have lesser environmental impacts compared to 3D pants made from 100% virgin raw materials, while assuming 90% circularity and 100% returning rate. The higher the return rates, lesser the environmental impacts of the 3D woven pants remade from returned pants
- Shifting the final distribution, from direct shipping to customers, to transporting the pants to a warehouse/retail outlet from factory and then to a customer, would cause an increase in energy and emissions, consequently, reduce impacts savings.

Currently, the impacts reported here are mainly based on secondary data i.e., published literature and ecoinvent/ Sphera datasets for all the life cycle stages except 3D weaving and finishing. To validate the findings reported here, Green Story recommends conducting an onsite data validation and a complete process-level primary data-based LCA study. This can help Unspun's management to better understand the environmental profile of their SCs and identify the inefficiencies in their existing production processes.

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1. INTRODUCTION

The range of products being produced for varied applications each day is beyond measurement (Muthu & Li, 2021). Life of a product begins with the extraction of raw materials, production, distribution, use, and finally its disposal (Jacques et al., 2010). Each of these life cycle stages of a product has likely negative environmental impacts (Pajula et al. 2017). Certain life cycle stages may have more impacts than others. To reduce these impacts, it is necessary to quantify these environmental impacts, identify the hotspots across the life cycle of these products that cause these impacts (Muthu & Li, 2021). The necessity to lessen the environmental impacts of products has become even more urgent now (Yang et al. 2023).

In recent years, there has been growing concern about the environmental impact of the fashion industry, particularly the production and consumption of apparel (McNeill and Moore, 2015). The increasing demand for fast fashion, combined with unsustainable practices throughout the apparel life cycle, has raised concerns about the industry's contribution to resource depletion, pollution, and climate change. To gain a holistic understanding of the environmental footprint of apparel throughout its life cycle, Life Cycle Assessment (LCA) is considered a powerful tool (Buxel et al., 2015).

By using LCA, companies can identify hotspots in their supply chain, develop strategies to reduce environmental impacts, make informed decisions about raw materials, fiber selection, design, and apparel manufacturing processes to decrease the environmental impacts (Pelton and Smith, 2015). In this study, LCA was used to identify the key hotspots across the life cycle stages of Unspun's apparel (3D woven pants) that influence Global Warming Potential (GWP), Primary Energy Demand (PED) and Blue Water Consumption (BWC) impact categories.

Unspun is a textile innovation studio and custom denim label. Unspun is building solutions that will help the fashion industry fulfil the promise of a decarbonized economy. Unspun's approach is to develop and apply innovative hardware and software toward smarter apparel production. Unspun's mission is to reduce global human carbon emissions through automated, localized, and intentional manufacturing for apparel. This study is aligned with Unspun's sustainability strategies and initiatives.

Unspun's 3D weaving technology usage is one such sustainable intervention, with a potential to decrease the footprint of their apparels. 3 dimensional or 3D weaving, compared to the traditional two-dimensional weaving, reduces weight, fabric wastage, lowers production time and energy. Unspun also aims to circularise resources, by converting garments returned by customers by unweaving them into yarn and then weaving them back into new garments.

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Purpose of The Study

The purpose of this study is to analyse environmental performance of Unspun's 3D woven pants, provide data-driven insights that can be used by Unspun to reduce their products' environmental impacts across GWP, PED and BWC impact categories.

1.1. Introduction to Life Cycle Assessment

The production of any product has beneficial and adverse effects on the environment and subsequent generations (Chen et al., 2021). The comprehensive examination of these implications is referred to as the product's Life Cycle Assessment (LCA). LCA is compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle. The systematic life cycle (cradle to gate/grave) approach aids stakeholders to compare products/processes and identify hotspots in a product's life cycle. According to ISO standards 14040:2006 and 14044:2006, LCA consists of four phases: Goal and Scope definition, Life Cycle Inventory (LCI) analysis, Life Cycle Impact Assessment (LCIA), and Interpretation (Figure 2).

Phases of LCA

1. Goal and scope definition: Defining purpose, scope (boundaries, conceptual, geographic, and temporal), the quality of the data used, limitations, intended application and main hypothesis

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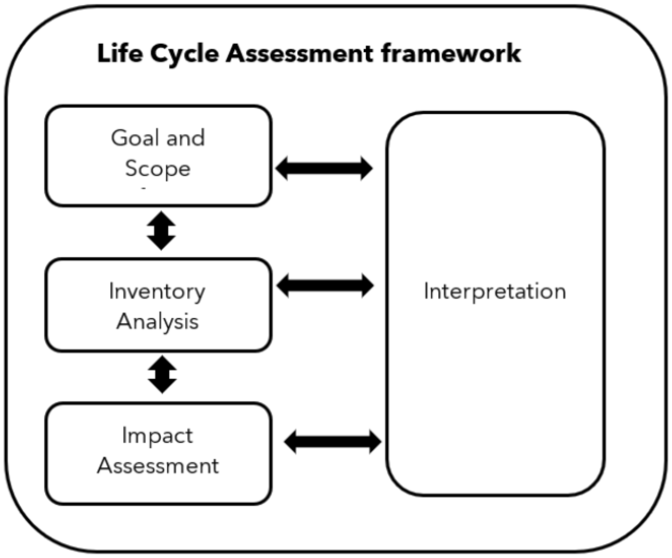
ISO 14040 and ISO 14044



ISO 14040: 2006 Environmental management - Life cycle assessment- Principles and framework

FIGURE 2: LIFE CYCLE ASSESSMENT (LCA) FRAMEWORK

2. Life Cycle Inventory (LCI) analysis: Collecting data, in order to quantify the inputs (energy and raw materials consumed) and outputs (emissions to air, water, soil, and solid waste) of the studied system, according to the functional unit defined in the scope.

3. Life Cycle Impact Assessment (LCIA)

- Classification – Grouping the inventory data.
- Characterization – Quantify how much impact a product has on the selected impact categories.
- Normalizing (optional) – Relating the characterized data to a broader data (country's total emissions).
- Weighting (optional) – Impact assessment results converted into scores for easy understanding

Note: Normalisation and weighting are excluded from this analysis, only characterised results are presented.

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4. Interpretation: In this phase, the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope to reach conclusions and recommendations.
In this report, goal of the study can be found in section 2, scope in section 3, LCI in section 4 and LCIA (results & interpretation) in section 5.

Note: Normalisation and weighting are excluded from this analysis, only characterised results are presented.

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2. GOAL OF THE STUDY

Stemming from the overall purpose stated above, the following goals are defined:

- Quantify the environmental impacts associated with the production of (1) 100% 3D woven conventional cotton pants, and (2) 100% 3D woven virgin polyester pants, across three indicators: GWP, PED and BWC. Key hot spots are identified in the respective supply chains (SCs).
- Estimate the potential environmental impacts/benefits of 3D woven pants over pants produced via air-jet weaving technique.
- Estimate the potential environmental benefits/impacts associated with circularity of 3D woven pants for different return rates.
- To build a scenario using a different final distribution option: supplier to warehouse/outlet and then to the end-customer, and explore how this scenario might influence the overall environmental impacts of 3D woven pants.

3. SCOPE OF THE STUDY

This section describes the scope of the study defined to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s) and functional unit, the system boundary, allocation procedures, and cut-off criteria used in this study.

3.1 Product systems

The product system to be analyzed is Unspun's finished 3D woven pants. The 3D woven pants are studied from cradle to gate, starting from the extraction of raw materials to finishing (attachment of accessories), till distribution to Unspun's costumers. In addition to this, Unspun also employs a circularity approach wherein they remake the returned garments from their customers at the end of its life, into new garments, by unweaving the products into yarn, and then weaving into a new product. In this study, it is assumed that only returned 3D pants are remade into 3D pants again. Two types of 3D woven pants are produced using two different fibers: (1) 100% conventional cotton hereinafter referred to as cotton and (2) 100% virgin polyester hereinafter referred to as polyester. The weight of the apparel included in the scope of this study

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is listed in Table 3. Accessories (such as buttons, zippers, lining fabric, fusible interface, rivets and sewing thread) were also included in the life cycle analysis.

Though Unspun aims for 100% circularity, this study does not account for that ideal scenario, instead a 90% circularity was assumed. The process efficiency of the unweaving equipment was taken as 90%, the remaining 10% is assumed to be fabric waste. Also, 100% return rate for the used pants may be an ideal scenario, so impacts linked to the 3D woven pants are estimated for different return rates: 20%, 40%,60%,80% and 100%, while keeping the circularity at 90%.

Currently, supplier directly ships the 3D woven pants to customers. A scenario is built to understand the impacts of shipping the pants from the supplier to the warehouse/retail outlet via ship and then to the customer via truck. Table 4 provides an overview of the 3D woven pants, its manufacturing stages, and the corresponding supplier locations.
Table 3: Weight of the 3D woven pants included in the scope of this study

TABLE 3: WEIGHT OF THE 3D WOVEN PANTS INCLUDED IN THE SCOPE OF THIS STUDY

Product Type	Weight (Kilograms
3D woven pants	**0.8**

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TABLE 4: OVERVIEW OF SUPPLY CHAINS ANALYZED IN THIS STUDY

Supply Chain No.	MANUFACTURING STAGES							Finished Apparel/ Product
	Fiber Name	Cultivation	Fiber/ Granulate Production	Yarn Production	Yarn Dyeing	Fabric Production (3D Weaving)	Finishing	
SC1	Cotton	USA*	USA*	USA*	USA*	Emeryville, CA		100% cotton 3D woven pants
SC1	Polyester	NA	USA*	USA*	USA*	Emeryville, CA		100% polyester 3D woven pants

*Note- Supplier location was not provided by Unspun and hence assumed by GS.

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3.2 Product Function and Functional Unit

The Functional Unit (FU) provides a reference to which the inputs and outputs are related/converted (basis for the calculation of environmental impacts) and is necessary to ensure comparability of results. All environmental impacts are expressed in terms of the FU defined. The Functional Unit (FU) of this study is production of 'one pair of Unspun's 3D woven pants made from two different fibers and produced in different supply chains mentioned in this study' The corresponding reference flow is one pair of 3D woven pants that weights 0.8 kg (See Table 3)

3.3 Baselining Methodology

In this study, 3D weaving is baselined with air-jet weaving for the two selected Unspun's 3D woven pants. The baselined LCIA results showcase the benefits/impacts of Unspun's 3D woven pants over similar pants produced via air-jet weaving process. It should be noted that the baselined results would be influenced by the data quality of the secondary datasets and Green Story (GS) confidential data used in this study to model cotton cultivation & fiber production, PET granulate production, yarn production, and yarn dyeing. Data quality refers to the technological/geographical/time representativeness, reliability & completeness of the data used.

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3.4 Selection of impact categories

The life cycle inventory data are analysed based on the following three impact categories (Table 5) chosen after discussion with Unspun.

TABLE 5: ENVIRONMENTAL IMPACT CATEGORIES ANALYZED IN THIS STUDY

Indicator	Description	Reference
Global warming potential (kg CO2 eq)	Potential for climate change based on the radiative forcing of chemicals. The GWP is expressed in kg or tons CO2 equivalents in proportion to CO2. Converts LCI data to carbon dioxide (CO2) equivalents by adding the emissions of greenhouse gases (CO2, N2O, CH4, and VOCs) multiplied by their appropriate GWP factors.	IPCC 2013
Primary energy demand (MJ)	PED is expressed in MJ energy equivalents and indicates the entire amount of primary energy (renewable and non-renewable) utilized during the life cycle of a product, including all direct and indirect energy usage.	Sphera,2014
Blue water consumption (Liters)	Blue water is defined as water sourced from surface or groundwater resources. Irrigated agriculture, industry and domestic water use can each have a blue water footprint. Only blue water consumption is used and not blue water use, as it measures the water removed from its source that cannot be replaced, leading to water scarcity.	Sphera, 2014

3.5 System boundary

The system boundary of the present study is from 'cradle to gate'. Figure 3 and Figure 4 illustrate the production process flow of Unspun's 3D woven pants with and without circularity.

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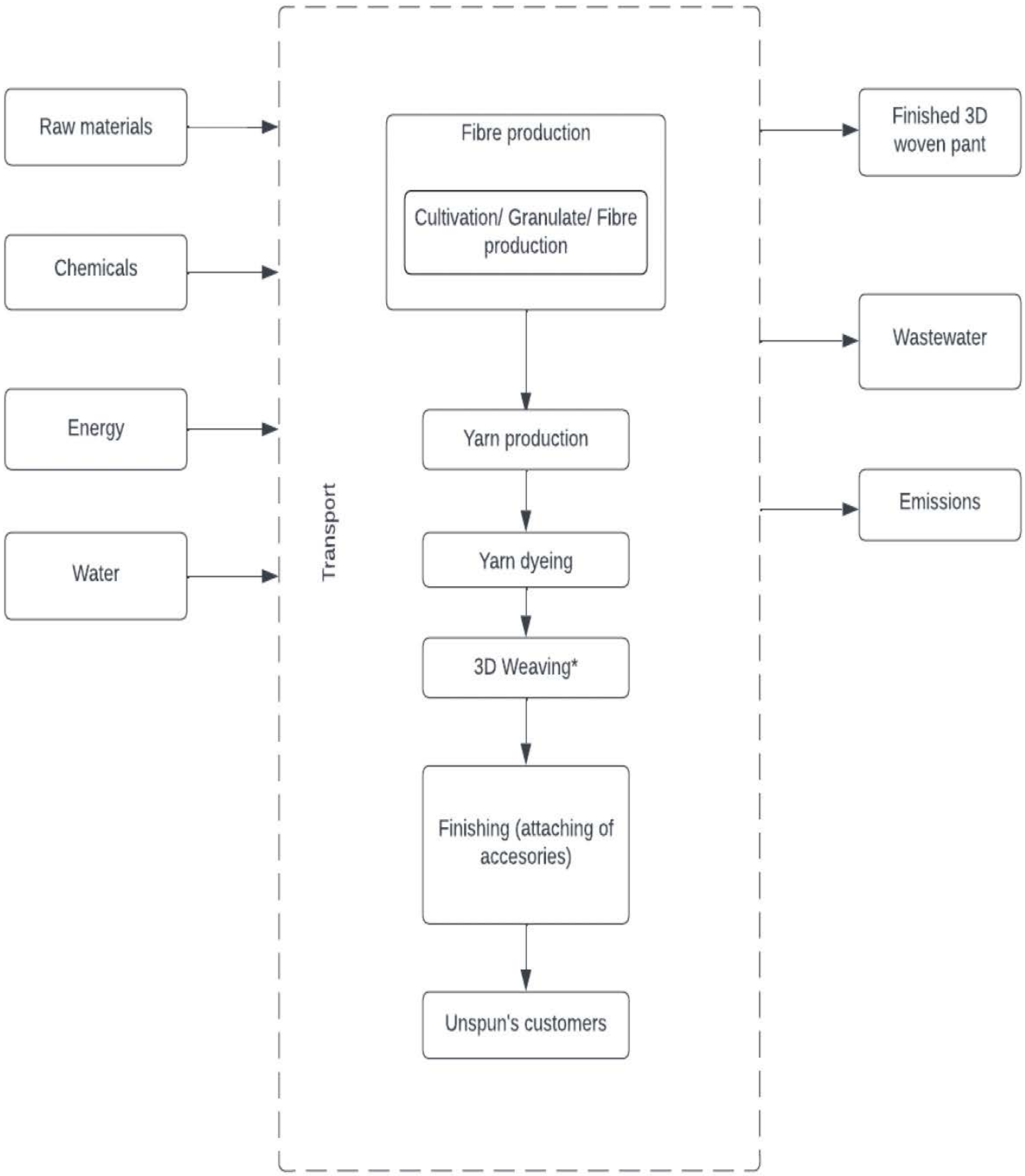

FIGURE 3: SYSTEM BOUNDARY – LIFE CYCLE OF UNSPUN'S 3D WOVEN PANTS

Notes:

- *The 3D weaving process mentioned in the system boundary is replaced with air-jet weaving for baselining

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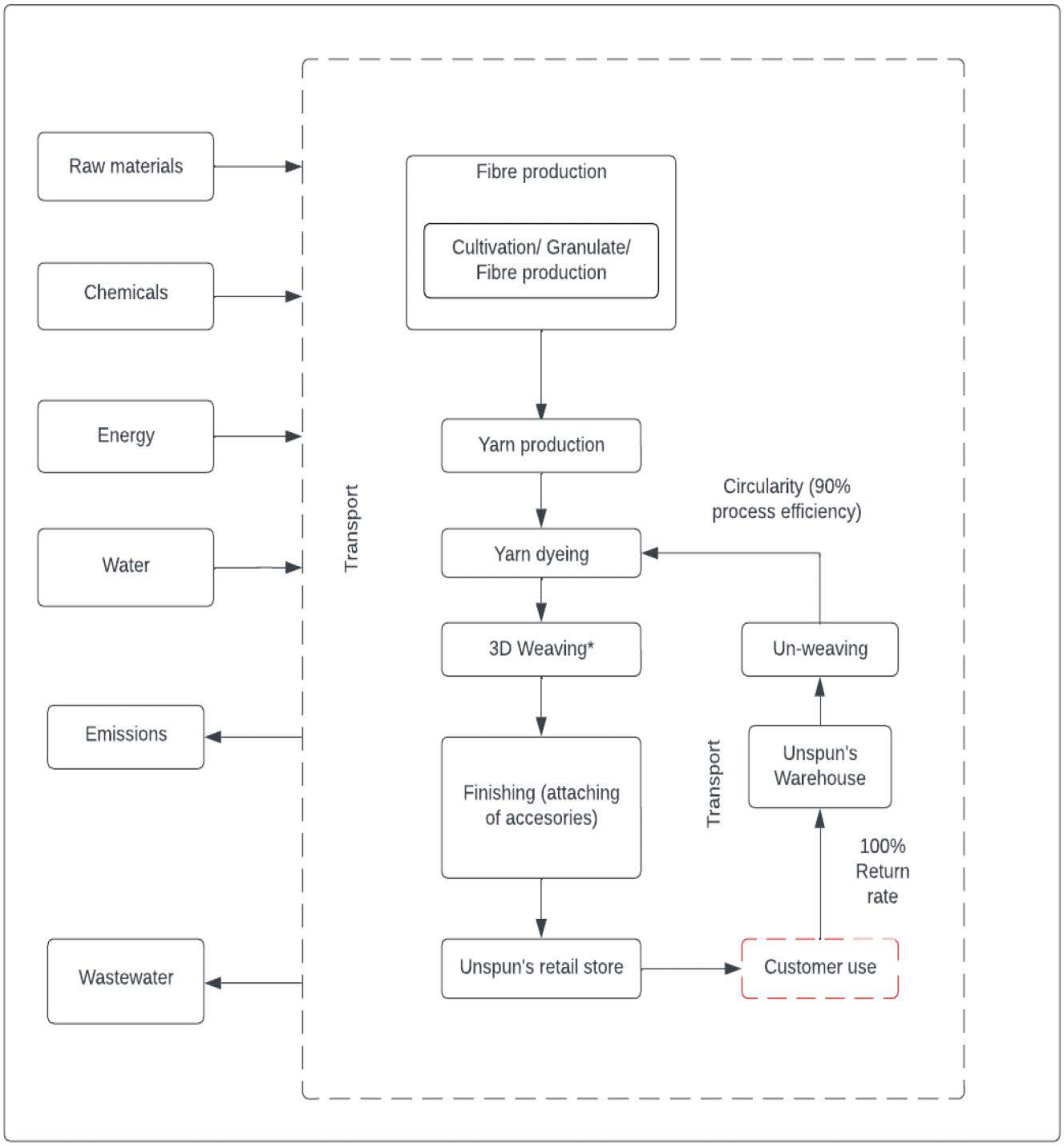

FIGURE 4: SYSTEM BOUNDARY – LIFE CYCLE OF UNSPUN'S 3D WOVEN PANTS WITH CIRCULARITY

Notes:

- The life cycle stage marked in red dotted line is excluded from the study.
- The fiber production process in the figure refers to cotton cultivation, harvesting and ginning in case of cotton pants and in case of polyester pants refers to oil extraction and granulate production.
- The yarn production process refers to ring spinning in case of cotton and melt spinning in case of polyester
- *The 3D weaving process mentioned in the system boundary is replaced with air-jet weaving for baselining

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3.5.1 System description

In this study, 3D woven pants production is broken down into following life cycle stages. Different datasets used to model each of these stages can be found in Annexures A1 and A2.

Fiber/ Raw material production: Covers the extraction of raw-materials and production of fibers. For cotton, this stage includes cotton cultivation, harvesting and ginning. For polyester, this stage includes granulate/fiber production of granulate from ethylene glycol and terephthalic acid. Transportation from raw material extraction location to the fiber production location was included.

Yarn production: Includes spinning to produce yarn from fibers. For synthetic fiber like polyester, this process begins with the granulate production, melt extrusion, drawing, and texturing to produce polyester yarn. In case of cotton, this process includes ring spinning. Transportation from yarn production location to yarn dyeing location was included.

Yarn Dyeing: This stage refers to dyeing of yarns. In case of cotton, yarn is dyed using reactive dye, while disperse dye is used for polyester yarn. Transportation and packaging from yarn dyeing location to 3D weaving & finishing location was included.

3D weaving: This stage refers to the 3D weaving of yarn to produce pants. Potential losses incurred in the processes were accounted.

Finishing (attachment of accessories): In this study, according to Unspun, this stage refers to stitching/sewing the accessories with the pants. Potential losses incurred from these processes were also accounted.

Distribution: Distribution includes transportation from finishing facility location to Unspun's customers.

Un-weaving: This stage refers to un-weaving the 3D pants to yarns using splicing process. Potential losses incurred in the process was assumed to be 10%.

Excluded Stages: Consumer use and End of Life (EoL).

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3.5.2 Supply chain overview:

For cotton 3D woven pants production, manufacturing stages like cotton cultivation, harvesting, ginning, ring spinning, yarn dyeing, 3D weaving, finishing (attachment of accessories) and distribution to warehouse are included.

3.6 Data Representativeness

This study used data from both primary and secondary sources. Primary foreground data collected for 3D weaving and finishing processes include, manufacturing locations, modes of transportation, electricity consumption, and few packaging details. Electricity consumption of the un-weaving device was also provided by Unspun.

Secondary data were taken from peer reviewed literature and LCA databases, like GaBi (GaBi Solutions, 2022), ecoinvent 3.8. (Wernet et al. 2016) datasets and GS confidential data from industry sources. Ensuring data quality is essential to calculate reliable results that can be communicated to involve stakeholders and consumers. Data quality was checked for precision (estimated/calculated/quantified), consistency (method was uniformly applied to various life cycle stages considered in the analysis), representativeness (geography/technology/time) and completeness. The technological/ geographical representativeness and temporal coverage are discussed in more detail below.

- Technological coverage

The technology reference is taken from Unspun's 3D woven pants and their key processing locations i.e., supplier locations. In the absence of an exact technological configuration in the datasets, the most recently available and industrially accepted alternative technology is chosen and used, so that the results are reliable. While using secondary data, it is assumed that the technology used is comparable with that of the primary data. The datasets used for secondary data are documented in Annexures A1 and A2.

- Geographical coverage

The intended geographical reference for 3D woven pants is USA. Unspun shared the geographical locations for 3D weaving and finishing processes, reasonable assumptions were made for the rest of the process locations (See Section 3.10). In the absence of a dataset for a particular geography, Global/European/Rest of World (RoW) datasets were used and are clearly stated in Annexures A1 and A2.

- Temporal coverage

Information about the supplier locations is compiled from Unspun's operations for the year 2022 and 2023. Secondary datasets from GaBi (GaBi Solutions, 2022) and ecoinvent 3.8 were used in this study.

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3.7 Cut-off criteria

No cut-off criteria for the foreground system are defined for this study within the primary data collection based on mass, energy, or environment. As presented in section 3.5, the system boundary was defined based on the goal of the study. For the processes within the system boundary, all available energy and material flow data have been included in the LCA models.

3.8 Allocation procedures

Multi-output allocation-

Multi-output allocation follows the requirements of ISO 14044:2006. Allocation refers to the distribution of environmental burden between co-products in a studied product system. The materials, energy and environmental burdens are allocated to the different co-products created.

- Cotton ginning: For cotton ginning process, mass allocation has been applied to output flows, i.e., between the main product fiber bales and the co-product cotton-seed as detailed in Table 6. The mass allocation data is taken from ICAC (2021).

TABLE 6: ALLOCATION FOR COTTON GINNING PROCESS

Products	Mass allocation (%)
Cotton fiber bales	**40.3%**
Cotton-seed	**59.7%**

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3.9 Software and database

The LCA models are created using the GaBi 10.6.1 software system for life cycle engineering, developed by Sphera (Life Cycle Assessment: GaBi Software, 2023). The GaBi professional extension database (GaBi Solutions, 2022) and ecoinvent 3.8 database provided the upstream life cycle inventory data for most of the raw materials extraction and production processes.

3.10 Assumptions & Limitations

Several transportations, raw material, energy consumption, and waste generation related assumptions had to be made during this study because of data unavailability or other limitations. Such process specific assumptions are listed below:

- Locations for cultivation, fiber production, yarn production and yarn dyeing were not provided by Unspun. The location of 3D weaving and finishing unit was provided as USA, hence it was assumed that the other manufacturing processes like cotton cultivation, polyester fiber production, yarn production, yarn dyeing, also take place in USA for both SCs 1 and 2. Transportation between these life cycle stages was assumed to 30 km by truck.

- Waste from the 3D weaving process was assumed to be mechanically recycled to produce cotton/polyethylene terephthalate (PET) granulate, based on the product type. System expansion was applied, which means credits are given for the cotton/PET fiber production that is avoided because of the recovered fibers, by looping back into the system.

- The plastic material used for packaging of yarn is assumed as high density polyethylene (HDPE). The spools used for yarn packaging are assumed to be made from virgin corrugated board. These assumptions are taken based on general industry practices used for packaging of yarn.

- The electricity bills provided by Unspun are for both the 3D weaving and finishing units. Data validation was not carried out in this study, and the collected data was assumed to be accurate. Also split between electricity demands for 3D weaving and finishing could not be calculated, so all the electricity numbers provided were assumed to be for 3D weaving. So, going forward, Green Story recommends data validation for these processes.

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- Unspun informed that 100% renewable energy is used in their units, but due to lack of renewable energy certificates, US electricity grid mix was used.

- Exact dataset for recycled kraft paper production was not available, hence a closest alternative i.e., recycled graphic paper production was used.

- The weight of the sewing thread is taken from GS confidential source.

- There was no information provided on the material used for production of rivets, hence was assumed that rivets made from brass are used.

- Unspun aims at 100% circularity of 3D woven pants. Since it's an ideal scenario and may be unachievable, 90% circularity is considered, meaning a 10% fabric loss is assumed from the un-weaving process, and is assumed to be landfilled with energy recovery. System expansion was applied, which means credits are given for the electricity production that is avoided because of the by-products. For the avoided electricity production, "US: market group for electricity, low voltage ecoinvent 3.8" was used.

- For all scenarios except for the 100% return rate, unreturned pants are assumed to be sent to landfill with energy recovery by the customers. System expansion was applied, which means credits are given for the electricity production that is avoided. For the avoided electricity production, "US: market group for electricity, low voltage ecoinvent 3.8" was used.

3.11 Interpretation to be used

The results of the LCIA are interpreted according to the goal and scope. The interpretation addresses the key findings, such as main process, material (s), and/or emission(s) contributing to the overall results.

3.12 Data validation

No internal or external audit of resource utilization data provided by Unspun and its suppliers is performed by Green Story for this study. It is assumed that the data provided by Unspun and its suppliers are factual and accurate.

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3.13 Critical review

No third-party critical review has been performed for this study. This study has been peer reviewed by Green Story's LCA review team.

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4. LIFE CYCLE INVENTORY (LCI) ANALYSIS

The Life Cycle Inventory (LCI) provides a detailed account of all the flows entering and leaving the studied product system. It consists of all the inputs such as raw materials, energy, water, and outputs such as products, co-products, emissions and waste for the defined FU.

4.1 Data collection procedure

LCI is developed based on both foreground and background data. Foreground data refers to specific data required to build a downstream process or product model (e.g., yarn production, fabric production, finishing etc.) and are collected from both (1) primary sources i.e., site specific data (e.g., 3D weaving and finishing) and (2) secondary sources i.e., published literature/ reports/datasets, etc. Background data required to model the upstream processes including energy (e.g., electricity and steam production), resources, transport (e.g., truck), and waste management (e.g., recycling), are taken from the ecoinvent 3.8 and GaBi professional extension database 10.6.1 (GaBi Solutions, 2022). The foreground and background data collected and used in this study are described below.

Foreground data:

Primary sources - To collect data related to supply chains and product information, a set of questionnaires was prepared and provided by Green Story to Unspun.

Supply chain and product Information provided by Unspun:

- Location of 3D weaving, finishing and modes of transportation
- Product details like product type, fiber type and product weight
- Electricity used for 3D weaving and finishing of the 100% cotton and 100% polyester 3D woven pants; weights of the accessories used in pants, and packaging details.
- Electricity consumption of the unweaving device per pair of pants.

Table 7 lists the primary foreground data collected from Unspun. Data related assumptions made can be found in section 3.10 above.

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TABLE 7: LIFE CYCLE INVENTORY (LCI) OF 3D WEAVING, FINISHING AND UNWEAVING PROCESSES, FOR 'ONE PAIR OF UNSPUN'S 3D WOVEN PANTS'

S. no.	Input/Output Flow	100% Cotton/100% Polyester pants	Transport distance (km)	Dataset used
3D WEAVING				
Inputs				
1	Yarn (kg)	0.8088	4000	
2	Electricity (kwh)	3.8	---	US: market group for electricity, medium voltage ecoinvent 3.8
3	Pallet, plastic (kg)*	0.0068	30	RoW: polyethylene production, high density, granulate ecoinvent 3.8
4	Cones, corrugated boxes (kg)*	0.115	---	RoW: corrugated board box production ecoinvent 3.8
Inputs				
5	Woven fabric (kg)	0.8	---	US: market group for electricity, medium voltage ecoinvent 3.8
6	Yarn waste (kg)*	0.0008	---	Mechanical recycling of cotton (GS confidential data), recovered fiber is looped back.
7	Fabric waste (kg)*	0.008	---	
8	Plastic waste (kg)	0.0068	70	US: polyethylene production, high density, granulate, recycled ecoinvent 3.8 (used for recycling of plastic waste) RoW: polyethylene production, high density, granulate ecoinvent 3.8 (used to give credits for avoided production of similar virgin material)
9	Cone waste (kg)	0.115	70	CA-QC: corrugated board box production ecoinvent 3.8 (used for recycling of cones) CA-QC: corrugated board box production ecoinvent 3.8 (used to give credits for avoided production of virgin material)

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TABLE 7: LIFE CYCLE INVENTORY (LCI) OF 3D WEAVING, FINISHING AND UNWEAVING PROCESSES, FOR 'ONE PAIR OF UNSPUN'S 3D WOVEN PANTS'

S. no.	Input/Output Flow	100% Cotton/100% Polyester pants	Transport distance (km)	Dataset used
FINISHING				
Inputs				
1	3D woven fabric (kg)	0.8	---	
2	Woven fusible interfacing (grams)	20	4657	US: Conventional cotton (ICAC) - Far West, ICAC Cotton ring spinning, GS confidential data Air-jet weaving, GS confidential data
3	Lining (grams)	30	4525	US: Conventional cotton (ICAC) - Far West, ICAC Cotton ring spinning, GS confidential Air-jet weaving, GS confidential data
4	Adhesive (grams)	0.5	---	RoW: market for polyester resin, unsaturated, ecoinvent 3.8
5	Brass zipper (grams)	9	29	RoW: market for brass, ecoinvent 3.8 GLO: market for casting, brass, ecoinvent 3.8
6	Rivets (grams)	3.6	30	RoW: market for brass, ecoinvent 3.8 GLO: market for casting, brass, ecoinvent 3.8
7	Brass button (grams)	0.25	29	RoW: market for brass, ecoinvent 3.8 GLO: market for casting, brass, ecoinvent 3.8
8	Sewing threads (grams)	0.732	8895	RER: polyethylene terephthalate production, granulate, amorphous, ecoinvent 3.8 Yarn production (Synthetic), Van der velden, 2014 RoW: bleaching and dyeing, yarn, ecoinvent 3.8

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TABLE 7: LIFE CYCLE INVENTORY (LCI) OF 3D WEAVING, FINISHING AND UNWEAVING PROCESSES, FOR 'ONE PAIR OF UNSPUN'S 3D WOVEN PANTS'

S. no.	Input/Output Flow	100% Cotton/100% Polyester pants	Transport distance (km)	Dataset used
FINISHING				
Outputs				
9	Finished pants (kg)	0.8	---	
10	Packaging (100% recycled kraft paper) (kg)	0.1	---	RoW: graphic paper production, 100% recycled, ecoinvent 3.8
UN-WEAVING				
Inputs				
1	Waste/used pants (kg)	0.8	---	The weight depends on Return Rate (RR). Here 100% RR is considered
2	Electricity (kWh)	0.0639	---	US: market group for electricity, medium voltage ecoinvent 3.8
Outputs				
1	Yarn (kg)	0.6744	---	
2	Waste (kg)s*	0.1 (Assumed)	---	RoW: treatment of waste yarn and waste textile, unsanitary landfill, ecoinvent 3.8.

*- 100% RECYCLING AT THE END OF ITS LIFE (EOL) IS CONSIDERED, SYSTEM EXPANSION IS APPLIED, CREDITS GIVEN FOR THE PRODUCTION THAT IS AVOIDED BY THE RESPECTIVE BY-PRODUCTS.

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Secondary sources – Literature/ecoinvent/Sphera datasets:

- Datasets along with their sources used for modelling manufacturing stages like cotton cultivation, fiber production (both cotton and polyester), yarn production, yarn dyeing and 3D weaving are listed in Table 8 and Annexure A1.
- The inventory of the air-jet weaving process was taken from Green Story industry sources and not presented here for confidential reasons.

Background data:

Gabi 10.6.1 (GaBi Solutions, 2022) and ecoinvent 3.8 databases were used to model all the upstream processes like fuel production, electricity generation, chemical production, extraction, production of raw materials and transportation.

Data were collected in different reference quantities (e.g., electricity in kWh or MJ) and to ensure consistency, appropriate conversions were made to a common unit (MJ). The process flow of the inventory analysis is described below.

1. First the input/output data for each life cycle stage and the unit processes were collected from primary/secondary sources and checked for relevance (e.g., Electricity, MJ/per kg of fabric produced).

2. Second the collected data were converted according to the functional unit defined. Finally, each inventory data is characterised according to the three selected environmental indicators/impact categories.

The details of the ecoinvent and Sphera datasets used to model the processes are listed in Annexures A1 and A2.

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4.2 Overview of the 3D woven pants production process, datasets used and their sources

This section provides an overview of the life cycle stages and the datasets along with their sources used to model the production of 'one pair of Unspun's 3D woven pants' from 100% cotton (SC 1) and 100% polyester (SC 2).

4.2.1 3D woven pants manufacturing processes

TABLE 8: DATASETS AND THEIR SOURCES, USED FOR MODELLING 'ONE PAIR OF UNSPUN'S 3D WOVEN PANTS

Finished pants	Production processes (life cycle stages)	Dataset/flow used	Source
100% Cotton 3D woven pants (SC 1)	Cultivation and fiber production	US: Conventional cotton- Far West	ICAC, 2021
	Yarn production	Yarn production (cotton, ring spinning)	GS confidential
	Yarn dyeing	Yarn dyeing light shade (100% Cotton)	GS confidential
	Fabric production (3D weaving)	Primary data (Table 7)	unspun
	Finishing (attachment of accessories)	Primary data (Table 7)	unspun
100% Polyester woven 3D woven pants (SC 2)	Granulate production	RoW: polyethylene terephthalate production, granulate, amorphous	ecoinvent 3.8
	Yarn production	Yarn production (Synthetic)	Van der Velden, 2014
	Yarn dyeing	RoW: bleaching and dyeing, yarn	ecoinvent 3.8
	Fabric production (3D weaving)	Primary data (Table 7)	unspun
	Finishing (attachment of accessories)	Primary data (Table 7)	unspun

4.2.2 Transport provisions

The ship distances are calculated using sea rates (Searates, 2021), and for truck distances google maps (Google maps, 2023) are used. The supply chain locations used in the calculation of transportation distances are provided in Annexure A4 and the datasets used to model are listed in Table 9 below.

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For production processes happening in the same city but in different facilities, when the exact address of the production facility is not available, a standard inner-city transportation distance of 30 km is assumed. Transportation within facilities i.e., forklift distances are not considered.

TABLE 9: DATASETS USED TO MODEL TRANSPORTATION ACROSS THE VARIOUS LIFE CYCLE STAGES OF 3D WOVEN PANTS PRODUCTION

Mode of transportation	Dataset used	Source
Truck	GLO: Truck, Euro 6, 7.5 t - 12t gross weight / 5t payload capacity	Sphera, 2021
Ship	GLO: Bulk commodity carrier, average, ocean going	Sphera, 2021

4.2.3 Energy datasets

Table 10 presents the ecoinvent and Sphera datasets used for modelling the energy requirements across the various life cycle stages of 3D woven pants production. The geographies of the datasets are chosen based on the production location details provided by Unspun and some assumptions made by Green Story (GS) that are listed above in section 3.10.

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TABLE 10: DATASETS USED FOR MODELLING THE ENERGY REQUIREMENTS
(GEOGRAPHIES CHOSEN BASED ON UNSPUN'S SUPPLIER LOCATIONS)

Electricity consumption	**US: market group for electricity, medium voltage ecoinvent 3.8**
Thermal energy consumption (a thermal energy mix was created based on (International Energy Agency, 2023)	**US: Thermal energy from hard coal Sphera** **US: Thermal energy from heavy fuel oil (HFO) Sphera** **US: Thermal energy from biomass (solid) Sphera** **US: Thermal energy from natural gas Sphera**
Diesel consumption	**RoW: market for diesel ecoinvent 3.8**

Note: GLO: stands for Global, RoW for Rest of World, US for United States of America. Break down of the thermal energy mix by renewable and non-renewable sources along with their %s can be found in Annexure A3.

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5. Life Cycle Impact Assessment (LCIA) and interpretation

This section presents the LCIA results for the selected Unspun's 3D woven pants using three impacts categories of interest for Unspun: (1) Global Warming Potential (GWP), (2) Primary Energy Demand (PED), and (3) Blue Water Consumption (BWC). The results are displayed per FU i.e., 'one pair of Unspun's 3D woven pants' from cradle to gate. The results presented here should be considered as potential environmental impacts i.e., approximations and not actual impacts, as these will occur only if similar foreground/background data, datasets and assumptions are made.

The LCIA results include: (1) baselined results i.e. impacts or benefits of Unspun's 3D woven pants achieved by replacing the air-jet weaving process with 3D weaving, (2) stagewise GWP, PED and BWC impacts of 100% cotton 3D woven pants, (3) stagewise GWP, PED and BWC impacts of 100% polyester 3D woven pants, (4) environmental impacts associated with the production of 3D woven pants with 90% circularity and 100% return rate, (5) environmental impacts of both cotton and polyester 3D woven pants with 90% circularity, estimated for five different return rates: 20%, 40%, 60%, 80% and 100%, (6) environmental impacts of switching the final distribution, from direct shipping to customers, to transporting the pants to a warehouse/retail outlet from factory and then to a customer.

5.1 Baselined LCIA results of 100% cotton 3D woven pants (SC 1)

LCIA results of Unspun's 100% cotton (SC 1) 3D woven pants baselined with air-jet woven pants are presented in Table 11

TABLE 11: BASELINED LCIA RESULTS: PERCENTAGE SAVINGS OF 100% COTTON 3D WOVEN PANTS OVER 100% COTTON AIR-JET WOVEN PANTS (PER PAIR OF PANTS)

Supply chain and fibre/material	Global Warming Potential	Primary Energy Demand	Blue Water Consumption
100% cotton 3D woven pants (SC 1)	**-23.93%**	**-25.00%**	**-1.41%**

* + SIGN INDICATES HIGHER IMPACT AND - SIGN INDICATES IMPACT SAVINGS RELATIVE TO THE BASELINED APPAREL

Baselining shows savings for GWP, PED and BWC impact categories for 100% cotton 3D woven pants (See Table 11). This is because the electricity requirement of 3D weaving is significantly lesser than air jet weaving. Also, the fabric waste generated at cut & sew are eliminated as the pants are directly woven from yarn in tubes and sent to the sewing area for attaching pockets/buttons/trims. Fabric loss at cut and sew determines the amount of fiber needed in the cultivation stage and the process energy/materials needed in the yarn/fabric/apparel production processes. So higher fabric waste means lower process efficiency, more fiber and process energy/materials are needed to produce the required output, resulting in higher environmental impacts across the life cycle of the pants.

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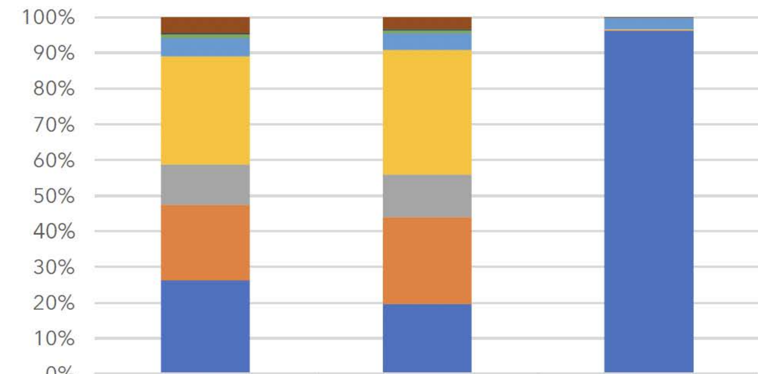
5.2 Stagewise LCIA results of 100% cotton 3D woven pants (SC 1)

100% cotton pants production is broken into the following life cycle stages: cotton cultivation & fiber production, yarn production, yarn dyeing, 3D weaving, finishing (attachment of accessories) and final distribution (direct shipping to customers from the supplier). Figure 5 shows the contribution of each of these life cycle stages to the GWP/PED/BWC impacts of pants production.



	GWP (kg CO2 eq.)	PED (MJ)	BWC (Litres)
Packaging	0.28	3.84	2.18
Distribution	0.02	0.37	0.04
Inner Transport	0.06	0.83	0.01
Finishing	0.32	5.38	156.00
3D weaving	1.89	39.90	11.60
Yarn dyeing	0.70	13.70	12.00
Yarn production	1.32	27.80	8.05
Cultivation and Fiber production	1.64	22.40	4720.00

FIGURE 5: CONTRIBUTION OF EACH LIFE CYCLE STAGE OF 100% COTTON 3D WOVEN PANTS PRODUCTION TO GWP/PED/BWC IMPACTS

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3D weaving process is the highest contributor to the overall GWP (30%) and PED (35%) impacts of cotton 3D woven pants, followed by cotton cultivation & fiber production (ginning) and yarn production. Impacts from 3D weaving process are primarily driven by the energy (electricity) used. It should be noted that 3D weaving happens in USA, where there is a heavy reliance on fossil sources like natural gas (37.31%) and coal (22.51%) to generate electricity, resulting in higher GWP and PED impacts (IEA, 2020). Yarn production and ginning require mostly electricity that again mainly rely on fossil fuels in the US, resulting in significant GWP and PED impacts.

Cultivation and fiber production stages are found to be the highest contributor (95%) to overall BWC impacts, followed by finishing (3%) and yarn dyeing (0.24%). Cotton cultivation employs traditional practices to irrigate the fields, thus requiring enormous water (ICAC 2020). Impacts mainly come from the withdrawal of water from the ecosystem for irrigation.
The production of accessories like lining fabric fusible interfacing made from 100% cotton that are attached to the pants in the finishing process drive the impacts of finishing process. As already mentioned, cotton is a thirsty fiber, its cultivation demands sizeable quantities of irrigation water.

Note that, 3D weaving also contributes to BWC impacts. Although 3D weaving itself does not require water, since water is used in the combustion of fossil fuels to produce electricity, it contributes to the BWC impacts.

5.3 Baselined LCIA results of 100% polyester 3D woven pants (SC 2)

LCIA results of 100% polyester 3D woven pants (SC 2) baselined with air-jet woven pants are presented in Table 12. 3D woven polyester pants also show savings compared to their conventional counterparts, for similar reasons already mention section 5.1.

TABLE 12: BASELINED LCIA RESULTS: PERCENTAGE SAVINGS OF 100% POLYESTER 3D WOVEN PANTS OVER 100% POLYESTER AIR-JET WOVEN PANTS (PER PAIR OF PANTS)

Supply chain and fibre/material	Global Warming Potential	Primary Energy Demand	Blue Water Consumption
100% polyester 3D woven pants (SC 2)	**-19.02%**	**-17.84%**	**2.58%**

* + SIGN INDICATES HIGHER IMPACT AND - SIGN INDICATES IMPACT SAVINGS RELATIVE TO THE BASELINED APPAREL

Note that the overall water savings of 3D woven pants (3%) is lower than savings in energy (18%) and carbon (19%) because, 3D weaving and air jet weaving are both power driven, so more savings are realised in the PED and GWP categories (Table 12).

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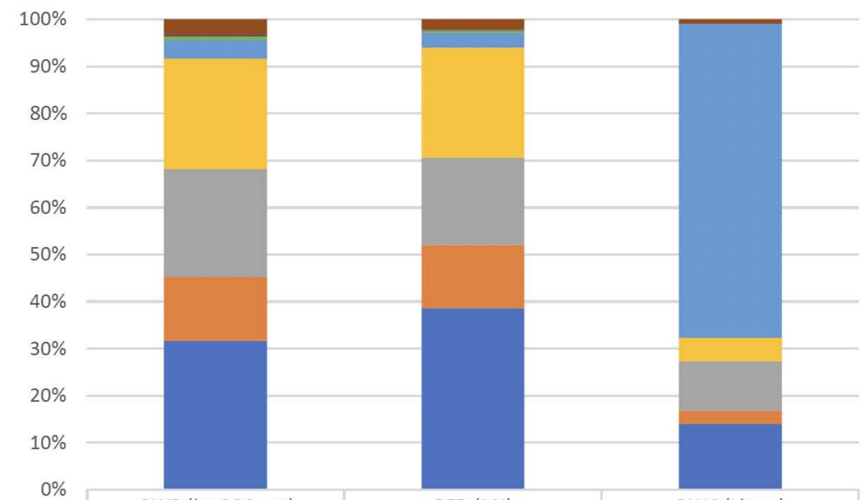
5.4 Stagewise LCIA results of 100% polyester 3D woven pants (SC 2)

100% polyester 3D woven pants production is broken into the following life cycle stages: raw material extraction, granulate production, melt extrusion, yarn production, yarn dyeing, 3D weaving, finishing (attachment of accessories) and final distribution (direct shipping to customers from the supplier). Figure 6 shows contribution of these life cycle stages to the GWP/PED/BWC impacts of pants production.



	GWP (kg CO2 eq.)	PED (MJ)	BWC (Litres)
Packaging	0.2703	3.68	2.128
Distribution	0.0237	0.365	0.0406
Inner Transport	0.0578	0.827	0.0216
Finishing	0.324	5.38	156
3D weaving	1.89	39.9	11.6
Yarn dyeing	1.86	31.6	24.6
Yarn production	1.09	22.9	6.63
Granulate production	2.56	65.9	32.7

FIGURE 6: CONTRIBUTION OF EACH LIFE CYCLE STAGE OF 100% POLYESTER 3D WOVEN PANTS PRODUCTION TO GWP/PED/BWC IMPACTS

Granulate production appears to be the highest contributor to GWP (32%) and PED (39%) impacts of 100% polyester 3D woven pants. Impacts mainly come from the production of monomers like, ethylene glycol and terephthalic acid used as key raw-materials in PET fiber production (Wernet et al. 2016).

3D weaving process is the second highest contributor to GWP (23%) and PED (23%) impacts. Most of these impacts are linked to the electricity used in this process in the corresponding

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processing locations. Electricity used in granulate production and 3D weaving processes are modelled using US electricity mix, which is dominated by fossil fuels (IEA, 2021) like natural gas (37%) and hard coal (22%), which reflects in higher GWP and PED impacts.

Yarn production and yarn dyeing are also key contributors, though to a lesser extent. Yarn production requires mostly electricity. Yarn dyeing also has a higher energy demand in the form of thermal energy because of the wet processes used, that require heating sizeable quantities of water. Thermal energy related impacts are a result of the processing locations' reliance on natural gas (81%) mainly to generate heat.

Finishing stage (67%) is clearly a dominant contributor to BWC impact followed by granulate production stage (14%). Finishing process refers to the attachment of accessories like lining fabric and fusible interfacing made from cotton. The impact of these accessories is significant despite their small share in the fiber content of pants due to the water-intensive cotton cultivation process used in their production. In contrast, production of polyester, the dominant fiber in the pants (almost 100%), hardly has any BWC impact.

It should be noted that all the impacts reported here, except for 3D weaving and finishing process, are estimated mainly based on secondary data i.e., published literature, ecoinvent/Sphera datasets and GS confidential industrial sources. Also split between electricity demands for 3D weaving and finishing could not be calculated, since 3D weaving requires most electricity, all the electricity numbers provided were assumed to be for 3D weaving. So, the results could possibly be slightly over estimated here. To validate the findings reported here, Green Story recommends conducting a on-site validation of the process-level primary data.

5.5 LCIA results of 100% cotton (SC 1) and 100% polyester (SC 2) 3D woven pants production with 90% circularity.

Table 13 below presents impacts of the two types of 3D woven pants produced (1) from 100% virgin resources, and (2) from used 3D pants returned by customers, assuming 90% circularity and 100% return rate. Impact reduction is observed across all the three categories for cotton and polyester 3D woven pants remade from similar pants returned by customers at the end of their life. It is obvious since 90% of the fabric in the returned pants is converted back into yarn in the unweaving process, meaning fresh yarn and related fiber production needed for a new 3D woven pants is avoided.

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Note that one key assumption made here is that only 3D pants are returned, unwoven into yarn and then woven again into new 3D pants, other garments are not considered. So, it should be noted that the impacts of 3D woven pants produced from used pants could possibly be underestimated here.

TABLE 13: IMPACT RESULTS OF 3D WOVEN PANTS (1) MADE FROM 100% VIRGIN RESOURCES AND (2) REMADE FROM USED 3D PANTS CONSIDERING 90% CIRCULARITY AND 100% RETURN RATE

Impact Category	90% circularity (100% return rate)	No circularity (100% virgin resources)
100% CONVENTIONAL COTTON PANTS		
Global warming potential (kg CO2 eq.)	4.01	6.23
Primary energy demand (MJ)	76.20	114.00
Blue water consumption (Liters)	764.00	4910.00
100% CONVENTIONAL COTTON PANTS		
Global warming potential (kg CO2 eq.)	5.22	8.26
Primary energy demand (MJ)	97.40	175.00
Blue water consumption (Liters)	342.00	378.00

5.6. Scenario analysis

5.6.1. Return rates

A 100% return rate, that Unspun aims for, is an ideal case and may not feasible. So, scenarios were built to understand the influence of five different return rates 20%, 40%, 60%, 80% and 100%, on the GWP impacts of pants remade from used pants with 90% circularity.

Similar trends can be observed for PED and BWC impacts. Environmental impacts are found to be inversely correlated with 3D woven pants return rates, meaning that as return rates rise, the impacts reduce. This is because, a greater return rate causes more waste/returned pants to be turned into yarns, which lessens the demand for virgin yarn production and related fiber production, as a result has reduced environmental impacts.

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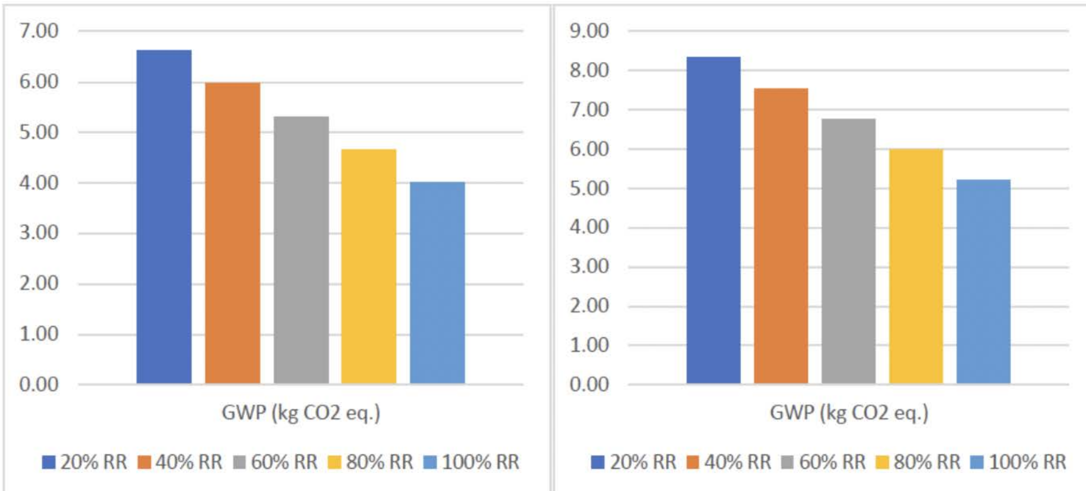

RR-Return Rate

FIGURE 7: IMPACT RESULTS OF ONE PAIR OF 100% COTTON 3D WOVEN PANTS (LEFT) AND ONE PAIR OF 100% POLYESTER 3D WOVEN PANTS (RIGHT) FOR FIVE RETURN RATES, WITH 90% CIRCULARITY

5.6.2. Distribution

In this scenario, the final distribution of both cotton and polyester 3D woven pants, was switched from 'direct shipping to customers, to 'transporting the pants to a warehouse/retail outlet from supplier and then to a customer'. In case of direct shipping, i.e., baseline, the customer is in a radius of 100 miles from supplier location in the US. While, transporting the pants from the supplier in the US to the warehouse/outlet in China via ship and then to the customers by truck covers around 7000 miles.

Distribution represents a relatively very small portion of the overall footprint of the 3D woven pants, so switching from direct shipping to customers to a distribution that includes warehouse/retail outlet, results only in a slight increase (1%) in the overall energy/carbon footprint of the 3D woven pants (Table 14). Nevertheless, it should be noted that direct shipment to customers as a whole has far less of an impact than a typical distribution via warehouse/outlets and then to customers, 76% lesser in the case of GWP, 73% in the case of PED, and 66% in the case of BWC. (Table 15).

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TABLE 14: IMPACT RESULTS OF 100% COTTON 3D WOVEN PANTS FOR TWO DISTRIBUTION SCENARIOS, PER PAIR OF PANTS

Impact Categories	100% cotton 3D woven pants (Direct shipping to customers, 100 miles away, via truck)	100% cotton 3D woven pants (Distribution via warehouse/retail stores and then to customers, 7000 miles away, via ship and truck)	% Difference
Global warming potential (kg CO2 eq.)	6.43	6.51	-1.23%
Primary energy demand (MJ)	119.00	120.00	-0.83%
Blue water consumption (Liters)	5060.00	5060.00	0.00%

Note: * + sign indicates higher impact and – sign indicates impact savings relative to the baselined apparel

TABLE 15: COMPARATIVE IMPACT RESULTS FOR DIRECT SHIPPING TO CUSTOMERS VS DISTRIBUTION VIA WAREHOUSE/OUTLETS TO CUSTOMERS, PER PAIR OF PANTS

Impact Categories	Direct shipping to customers (100 miles away, by truck) per FU (one pair of pants)	Distribution via outlets/retail stores and then to customers (7000 miles away, via ship and truck) per FU (one pair of pants)	% Difference
Global warming potential (kg CO2 eq.)	0.0237	0.1	-76.30%
Primary energy demand (MJ)	0.365	1.39	-73.74%
Blue water consumption (Liters)	0.0406	0.119	-65.88%

Note: * + sign indicates higher impact and – sign indicates impact savings relative to the baselined apparel

6. CONCLUSIONS AND RECOMMENDATIONS

Key insights from the study:

- Baselining 3D woven pants with air jet woven pants made from similar fibers resulted in savings for 3D woven pants in all the three impact categories: GWP, PED, and BWC.
- Savings from using 3D weaving process is similar for both cotton and polyester pants. However, the GWP and PED impacts from the other life cycle stages like fiber production and yarn production are lower for cotton, resulting in higher energy and emission savings for 3D cotton pants. In contrast, BWC impacts of cotton fiber production is significantly higher than polyester fiber production, resulting in lower water savings for cotton pants.

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- Overall water savings of 3D pants (3%) are lower than savings in energy (18%) and carbon (19%) because, 3D weaving and air jet weaving are both power driven, so more savings are realized in the PED and GWP categories.
- Considering by-stage impacts, 3D weaving process is the highest contributor to the GWP and PED impacts of 100% cotton 3D woven pants.

- PET granulate production followed by 3D weaving process are the key contributors to GWP and PED impacts of 100% polyester pants.

- Finishing process that refers to the attachment of accessories like lining fabric and fusible interfacing made from cotton, is found to be a clear dominant contributor to BWC impacts. Due to the water-intensive cotton cultivation process required in the production of these accessories, even though their share in the fiber composition of pants is negligible, their impacts are significant. In contrast, production of polyester, the dominant fiber in the pants (almost 100%), hardly has any BWC impact.

- 3D woven pants remade from returned 3D woven pants were found to have lesser environmental impacts compared to 3D woven pants made from 100% virgin raw materials, while assuming 90% circularity and 100% return rate. The higher the return rates, lesser the environmental impacts of the 3D woven pants remade from returned pants.

- Shifting the final distribution, from direct shipping to customers, to transporting the pants to a warehouse/retail outlet from factory and then to a customer, would cause an increase in energy and emissions.

Focus areas for Unspun:

The environmental impacts of cotton and polyester 3D woven pants are mainly driven by 3D weaving and fiber production life cycle stages. Mitigating impacts related to fiber production is not within the direct control of Unspun, however, their aim to circularize the resources and close the loop, offers them the potential to reduce impacts by avoiding the production of those fibers. Unpsun has already opted for 3D weaving technology which is found to be less impactful compared to air-jet weaving. Opting for renewable energy plans will allow them to further reduce the impacts from 3D weaving. Changing to less impactful fibers for accessories, focusing on distribution related impacts while decision making, and finally promoting energy efficiency across supply chains are few other areas to focus on. Each of the above-mentioned action item is described below in more detail.

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Shifting to renewable energy:

Unspun informed that they are using a 100% renewable energy plan, however due to lack of enough certificate proofs, fossil fuel-based grid mix had to be used for modelling and estimating impacts. So, this switching from fossil-based energy to renewable energy like solar, wind or hydro to power when considered, can considerably reduce the related GWP and PED impacts.

Energy efficiency across supply chains, distribution of products, and change to synthetic fibers:

3D weaving and finishing are primarily driven by electricity, though less than air-jet weaving, is still the highest contributor to the overall GWP and PED impacts. Focusing on energy productivity of these processes can improve energy efficiency and subsequently may reduce related GWP, PED and BWC impacts. Fibers like organic cotton and recycled polyester, use less water than cotton fibers do, so accessories made from cotton can be replaced with these fibers without compromising on the functionality.

Locally sourcing yarns and accessories can further reduce distribution related impacts. Distribution via outlets/warehouse to customers is more impactful compared to direct shipping to customers, increases carbon emissions by 76%, energy demand by 73%, and increases the overall GWP/PED impact of 3D woven pants by 1%. Impacts from transport via outlets/warehouse can be reduced by optimizing fleets and fuel choices (low impact fuels). Impacts from direct shipping to customers can be further reduced by opting for a cleaner last mile delivery like bicycles, electric scooters, that improve air quality.

Note that, the final distribution option of 'direct shipping to customers' has its own advantages and disadvantages that have to be clearly understood before decision making. Factors that increase the overall product footprint by opting for direct shipping to customers: increased impulse buying, energy -intensive online purchasing options (data centres and devices), additional packaging for safe delivery, half-filled trucks and frequent deliveries to meet customer requirements. Factors that possibly decrease the footprint: fewer visits by customers to the stores, sustainable packaging options, optimized fuel choices for truck transport, cleaner last mile, optimized stock and reduced excess inventory. LCA study has to be conducted to track the impacts, and understand the impact creation/reduction potential of the above-mentioned factors.

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Implementing circular economy measures:
Results clearly indicate the reduction in overall impacts of the 100% cotton 3D woven pants by opting for circularity, 36% in case of GWP impacts, 35% in case of PED and 84% in case of BWC impacts. A 90% circularity was applied, meaning 90% process efficiency was assumed for the new unweaving technology/equipment, 10% waste was assumed to be landfilled with energy recovery. It was also assumed that all the customers return their used pants i.e., 100% return rate. 100% circularity, meaning an ideal unweaving process with no wastage could allow additional impact reduction. Reduction in return rates will increase the impacts relatively. Circularity offers the best potential for impact reduction, because it eliminates/lessens the need for the production of virgin fibers, which is found to be a key contributor to overall impacts of the pants. So, Unspun should focus on increasing the return rates and process efficiency of the unweaving equipment.
Currently, waste from the 3D weaving process is stored by Unspun and would be eventually sent to recycling for fiber recovery. In this study, it is assumed, 100% of the waste gets recycled and 100% of the recovered fibers are re-looped into the system, avoiding the production of polyester and cotton fibers. Unspun should focus on implementing this strategy since avoiding the manufacturing of fibers like cotton and polyester is essential for minimizing the effects of fiber and granulate production, which are found to be main factors that drive the overall impacts of 3D-woven pants. Although the amount of waste produced by 3D weaving is considerably less than the amount of fiber required to make the pants, the impact reduction potential of this focus area is lower than other areas, but even these modest savings will help the product's overall impacts be reduced.

7. GENERAL LIMITATIONS & FUTURE OUTLOOK

- According to the results of this study, 3D weaving process and the circular economy approach i.e., closing the loop, were found to have the best impact reduction potential for Unspun. With more data on renewable energy usage, energy productivity/efficiency of 3D weaving and finishing process, waste recycling technology used, fate of recovered fibers, factors affecting the final distribution options, the other focus areas can be analysed, highest impact reduction potential can be clearly identified, and tailored recommendations can be given.

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- In this study, the system boundary considered for Unspun's 3D woven pants is from 'cradle to gate,' i.e., from raw material extraction to warehouse gate. Consumer use and end of life related impacts are not estimated here. With the growing interests to understand the emissions from these life cycle stages, and Unspun's intention to collect post-consumer waste and convert them into new garments, it would be useful to understand Unspun customers' behaviour towards their purchase. Estimating return rates based in surveys, will yield results that are more representative of Unspun's operations and will aid them to make decisions.

- A key limitation of the study is usage of secondary data, which is representative of average operations of many industries. A completely validated primary data based LCA study results could be more representative, with robust interpretation.

- This LCA study only focuses on three environmental indicators i.e., GWP, PED, and BWC, however there are other relevant indicators (e.g., Acidification Potential (AP), Eutrophication Potential (EP), Ozone Depletion Potential (ODP), Abiotic Depletion Potential (ADP), Freshwater Aquatic Ecotoxicity Potential (FAETP), etc.) that will help in making holistic interpretation of environmental performance of studied products.

- Textile production stages like yarn dyeing require thermal energy/ steam as input for operation. Country specific data is used to create the mixers based on the supplier location, however the information on exact source for heat and steam generation could be more representative of Unspun's operations.

RECOMMENDATION TO ENHANCE REPRESENTATIVENESS OF THE RESULTS OBTAINED IN THE STUDY

Green Story recommends conducting onsite data validation and a complete process-level primary data-based LCA study to better understand the impacts associated with Unspun's supply chains and related life cycle stages. This can help Unspun's management to identify the inefficiencies in the existing supply chains from an environmental sustainability perspective.

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8. REFERENCES

1. Aliyu, M., Hassan, G., Said, S. A., Siddiqui, M. U., Alawami, A. T., & Elamin, I. M. (2018). A review of solar-powered water pumping systems. Renewable and Sustainable Energy Reviews, 87, 61-76.

2. Beton, Adrien, Debora Dias, Laura Farrant, Thomas Gibon, Yannick Le Guern, Marie Desaxce, and Anne Perwueltz. (2014). Environmental improvement potential of textiles (IMPRO-textiles).

3. Bhakar, P., & Singh, A. P. (2018). Life cycle assessment of groundwater supply system in a hyper-arid region of India. Procedia CIRP, 69, 603-608.

4. European Commission, Joint Research Centre, Institute for Prospective Technological Studies. doi:10.2791/52624. Assessed January 4th, 2023.

5. Buxel, H., Esenduran, G., & Griffin, S. (2015). Strategic sustainability: Creating business value with life cycle analysis. Business Horizons, 58(1), 109-122.

6. Distance Calculator for Sea Shipping. Retrieved from https://www.searates.com. Accessed January 4th, 2023.

7. Ecoinvent. (2021). Database ecoinvent version v3.8. The Swiss Centre for Life Cycle Inventories. Accessed January 4th, 2023.

8. IEA 2020 USA. https://www.iea.org/countries/united-states, for thermal energy upstream input data and electricity generation by source data. Accessed January 4th, 2023.

9. International Cotton Advisory Committee. (2021). ICAC Cotton Data Book- A report.

10. IPCC. (2013). Climate Change 2013: The Physical Science Basis. Geneva, Switzerland: IPCC. IPCC. (2013). Climate Change 2013: The Physical Science Basis. Genf, Schweiz: IPCC.

11. ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and Framework. (2006). https://www.iso.org/standard/37456.html. Accessed January 4th, 2023.

12. ISO 14044:2006 - Environmental management - Life cycle assessment - Requirements and Guidelines. (2006). https://www.iso.org/standard/38498.html. Accessed January 4th, 2023.

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8. REFERENCES

13. McNeill, L., & Moore, R. (2015). Sustainable fashion consumption and the fast fashion conundrum: fashionable consumers and attitudes to sustainability in clothing choice. International Journal of Consumer Studies, 39(3), 212-222.

14. Pelton, R. E., & Smith, T. M. (2015). Hotspot scenario analysis: Comparative streamlined LCA approaches for green supply chain and procurement decision making. Journal of Industrial Ecology, 19(3), 427-440.

15. Quantis. (2018). "MEASURING FASHION". Environmental Impact of the Global Textile product and Footwear Industries Study Full report and methodological considerations. https://refashion.fr/eco-design/sites/default/files/fichiers/Measuring%20Fashion%20Environmental%20Impact%20of%20the%20Global%20Textileproduct%20and%20Footwear%20Industries%20Study.pdf. Accessed on January 4th, 2023.

16. Sphera. (2022). GaBi 10.2.1, Leinfelden-Echterdingen GaBi Software-System and Databases for Life Cycle Engineering.

17. Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, [online] 21(9), pp.1218–1230. Available at: http://link.springer.com/10.1007/s11367-016-1087-8

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ANNEXURE

A1: Datasets, Literature used and assumptions made for 100% cotton (SC 1) 3D woven pants

CONVENTIONAL COTTON FIBER PRODUCTION			
CONVENTIONAL COTTON FIBER PRODUCTION- MODELLED BASED ON DATA FROM ICAC 2021.			
Inputs	Dataset/Flows used in Gabi	Data sources	Assumptions made
Cotton Seed	GLO: market for cottonseed, for sowing	ecoinvent 3.8	
Electricity, medium voltage	US: market group for electricity, medium voltage	ecoinvent 3.8	Country specific dataset to be selected
Diesel, burned in agricultural machinery	GLO: diesel, burned in agricultural machinery	ecoinvent 3.8	
Manure, solid, cattle	GLO: manure, solid, cattle, Recycled Content cut-off	ecoinvent 3.8	
Urea, as N	US: market for inorganic nitrogen fertiliser, as N	ecoinvent 3.8	Country specific dataset to be selected
Irrigation	US: market for irrigation	ecoinvent 3.8	Country specific dataset to be selected
Inorganic phosphorus fertiliser, as P2O5	US: market for inorganic phosphorus fertiliser, as P2O5	ecoinvent 3.8	Country specific dataset to be selected
Insecticides, unspecified	RoW: pesticide production, unspecified	ecoinvent 3.8	
Potash magnesia (agriculture)	US: market for inorganic potassium fertiliser, as K2O	ecoinvent 3.8	Country specific dataset to be selected
Output			
IN: Cotton Fiber Bales	To yarn production	ICAC 2021	
IN: Cottons seed from Gin		ICAC 2021	

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YARN PRODUCTION, COTTON, RING SPINNING			
RING SPINNING MODELLED FROM ECOINVENT 3.8 DATASETS "GLO: RING SPINNING COTTON"			
Inputs	Dataset/Flows used in Gabi	Data sources	Assumptions made
Cotton fiber bale (kg)	From fiber production		
Electricity	US: market group for electricity, medium voltage	ecoinvent 3.8	Country specific dataset to be selected
Lubricating oil	RoW: market for lubricating oil	ecoinvent 3.8	
Output			
Yarn, cotton	To yarn dyeing		
Waste yarn and waste textile			

YARN DYEING			
YARN DYEING IS MODELLED BASED ON GS CONFIDENTIAL INDUSTRY DATA, HENCE LCI IS NOT DISCLOSED			
Inputs	Dataset/Flows used in Gabi	Data sources	Assumptions made
Yarn, cotton	From yarn production production		
Output			
Dyed yarn	To weaving		

3D WEAVING			
WEAVING IS MODELLED BASED ON PRIMARY DATA COLLECTED FROM UNSPUN			
Inputs	Dataset/Flows used in Gabi	Data sources	Assumptions made
Dyed yarn	From yarn dyeing		
Electricity	US: market group for electricity, medium voltage	ecoinvent 3.8	Country specific dataset to be selected
Output			
Woven fabric	To finishing		
Waste yarn			
Waste fabric			

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FINISHING (ATTACHMENT OF ACCESSORIES)			
FINISHING IS MODELLED BASED ON PRIMARY DATA COLLECTED FROM UNSPUN			
Inputs	Dataset/Flows used in Gabi	Data sources	Assumptions made
Woven fabric	From 3D weaving		
Woven fusible interfacing and Lining fabric	US: Conventional Cotton (ICAC) - Far West	ICAC, 2019-20	
	Cotton Ring Spinning	GS confidential	
	Air jet weaving	GS confidential	
Brass zipper	RoW: market for brass GLO: market for casting, brass	ecoinvent 3.8	
Rivets			
Brass buttons			
Sewing threads	RER: polyethylene terephthalate production, granulate, amorphous,	ecoinvent 3.8	
	Yarn production (Synthetic)	Van der velden, 2014	
	RoW: bleaching and dyeing, yarn	ecoinvent 3.8	
Output			
Finished 3D woven pant			

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A2: Datasets, Literature used and assumptions made for 100% polyester (SC 2) 3D woven pants

POLYESTER GRANULATE PRODUCTION			
RER- VIRGIN PET PRODUCTION- MODELLED FROM THE ECOINVENT DATASET "RER: POLYETHYLENE TEREPHTHALATE PRODUCTION, GRANULATE, AMORPHOUS ECOINVENT 3.8 <U-SO>.			
Inputs	**Dataset/Flows used in Gabi**	**Data sources**	**Assumptions made**
Ethylene glycol	GLO: market for ethylene glycol	ecoinvent 3.8	
Purified terephthalic acid	GLO: market for purified terephthalic acid	ecoinvent 3.8	
Electricity, medium voltage	US: market for electricity, medium voltage	ecoinvent 3.8	
Heat, district or industrial, natural gas	GLO: market group for heat, district or industrial, natural gas	ecoinvent 3.8	
Heat, district or industrial, other than natural gas	GLO: market group for heat, district or industrial, other than natural gas	ecoinvent 3.8	
Nitrogen, liquid	DE: Nitrogen (liquid)	Sphera	
Steam, in chemical industry	RER: market for steam, in chemical industry	ecoinvent 3.8	
Waste plastic, mixture	RoW: market for waste plastic, mixture	ecoinvent 3.8	
Municipal solid waste	RER: market for municipal solid waste	ecoinvent 3.8	
Output			
Polyethylene terephthalate, granulate, amorphous	To yarn production		

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YARN PRODUCTION, MELT SPINNING (SYNTHETIC FIBERS)			
YARN PRODUCTION FOR SYNTHETIC FIBERS IS MODELLED FROM VAN DER VELDEN, 2014 DATA			
Inputs	**Dataset/Flows used in Gabi**	**Data sources**	**Assumptions made**
Plastic granulates	From fiber production		
Electricity	US: market group for electricity, medium voltage	ecoinvent 3.8	Country specific dataset to be selected
Lubricating oil	RoW: market for lubricating oil	ecoinvent 3.8	
Output			
Yarn	To yarn production		

YARN DYEING			
YARN DYEING MODELLED FROM ECOINVENT DATASET “ROW: BLEACHING AND DYEING, YARN ECOINVENT 3.8, AGG”			
Inputs	**Dataset/Flows used in Gabi**	**Data sources**	**Assumptions made**
Yarn	From yarn production		
Output			
Dyed yarn	To 3D weaving		

3D WEAVING			
WEAVING IS MODELLED BASED ON PRIMARY DATA COLLECTED FROM UNSPUN			
Inputs	**Dataset/Flows used in Gabi**	**Data sources**	**Assumptions made**
Dyed yarn	From yarn dyeing		
Electricity	US: market group for electricity, medium voltage	ecoinvent 3.8	
Output			
Woven fabric	To finishing		
Waste yarn			
Waste fabric			

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FINISHING (ATTACHMENT OF ACCESSORIES)			
FINISHING IS MODELLED BASED ON PRIMARY DATA COLLECTED FROM UNSPUN			
Inputs	**Dataset/Flows used in Gabi**	**Data sources**	**Assumptions made**
Woven fabric	**From 3D weaving**		
Woven fusible interfacing and Lining fabric	**US: Conventional Cotton (ICAC) - Far West**	**ICAC, 2019-20**	
	Cotton Ring Spinning	**GS confidential**	
	Air jet weaving	**GS confidential**	
Brass zipper	**RoW: market for brass GLO: market for casting, brass**	**ecoinvent 3.8**	
Rivets			
Brass buttons			
Sewing threads	**RER: polyethylene terephthalate production, granulate, amorphous,**	**ecoinvent 3.8**	
	Yarn production (Synthetic)	**Van der velden, 2014**	
	RoW: bleaching and dyeing, yarn	**ecoinvent 3.8**	
Output			
Finished 3D woven pant			

Note: GLO- Global, US- United States of America, RoW- Rest of the World and DE: Germany.

A3: Energy Mixers

Thermal energy mix, United States of America (USA)
Thermal energy Mix is based on IEA statistics for USA (IEA, 2020). All upstream processes are taken from Sphera.

TABLE 16: THERMAL ENERGY MIX DISTRIBUTION

Inputs	**Dataset used**	**Share of thermal energy mix (%)**
Thermal energy from natural gas	**US: Thermal energy from natural gas**	**81%**
Thermal energy from biomass	**US: Thermal energy from biomass (solid)**	**8.5%**
Thermal energy from oil	**US: Thermal energy from heavy fuel oil**	**7%**
Thermal energy from hard coal	**US: Thermal energy from hard coal**	**3.5%**

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A4: Transport Distance Calculation

The transport distances were calculated based on the locations provided by Unspun and some assumptions taken by GS. They were calculated between each of the manufacturing processes using the below mentioned distance calculators:

- All ship distances were calculated using searates.com.
- All road distances were calculated using google maps.
- All distance assumptions containing unknown locations were used in accordance with (Quantis, 2018).

Supply Chain 1: Cotton

- Cultivation: Assumed as United States of America-Far west by GS.
- Cultivation to Fiber production: Vertically integrated (United States of America)
- Fiber production to Yarn production: Vertically integrated within United States of America.
- Yarn production to Yarn dyeing: Vertically integrated within United States of America.
- Yarn dyeing to 3D weaving facility: Transport by truck to Emeryville, CA, USA (4000 kms)
- 3D weaving to Finishing facility: Vertically integrated within Emeryville, CA, USA
- Finishing to Warehouse/Costumers: Transport by truck for 161km.

Supply Chain 2: Polyester

- Cultivation: NA
- Fiber production: Assumed as United States of America-Far west by GS.
- Fiber Production to Yarn Production: Vertically integrated within United States of America.
- Yarn production to Yarn dyeing: Vertically integrated within United States of America.
- Yarn dyeing to 3D weaving facility: Transport by truck to Emeryville, CA, USA (4000 kms)
- 3D weaving to Finishing (attachment of accessories) facility: Vertically integrated within Emeryville, CA, USA.
- Finishing to Warehouse/Costumers: Transport by truck for 161km.

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ABOUT GREEN STORY

Green Story is a sustainability platform that enables brands to accurately measure and communicate the positive impact of their products and make them carbon neutral.

By combining Life Cycle Assessment methodology with interactive data and impact visuals and a carbon offsetting platform, we enrich the customer experience with your green story throughout the customer lifecycle. Enhancing transparency, increasing engagement and loyalty, and driving revenue.

Partnering with hundreds of sustainable fashion players like ThredUP, Rent the Runway, Threads 4 Thought, Pact, and Hanesbrands, Green Story has a global team of experts working to empower 1 billion people to know their impact and make choices that are better for the planet and the generations to come.

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