Comparative Life Cycle Assessment (LCA) of second-hand vs new clothing

Prepared for ThredUP

GreenStory

Title of the Study:
Comparative Life Cycle Assessment (LCA) of second-hand clothing vs new clothing

Prepared for:

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1 Introduction

The Unites States is the world's largest apparel consumer market as of 2018, and the apparel industry ranks as having one of the most impact on the environment, both in terms of carbon footprint and water footprint. The shift to a circular economy is crucial to reduce the impact of the apparel industry. As the world's largest online second-hand clothing store, ThredUP is a company that's helping change consumer attitudes towards the second-hand, and consequently could reduce the apparel industry's environmental impact. By using Life Cycle Analysis (LCA) methodologies, it's possible to objectively estimate what the impact of this could be.

LCA methodology is a widely used tool to quantify the environmental burden of a product during every phase of its lifecycle. It allows objective and scientific evaluation of the resource requirements of a product and its potential impact on the environment.

Green Story carried out a comprehensive LCA study for ThredUP following the ISO 14040 (1) and ISO 14044 (2) guidelines to quantify the environmental savings when consumers switch from buying newly manufactured clothes to buying second-hand clothes from ThredUP.

2 Goal and Scope

2.1 Objectives and Goals of the Study

The study was undertaken with the following objectives:

1. To estimate the environmental savings from buying second-hand clothing sold by ThredUP instead of buying brand new clothes. The environmental savings are estimated across three impact categories: Global Warming Potential (GWP), Primary Energy Demand (PED) and Blue Water consumption (Water)
2. Provide a comprehensive Life cycle inventory (LCI) of ThredUP's operations in the US

2.2 Reasons for carrying out study, Intended application and Audience

This study is meant to provide ThredUP, its investors and consumers with a holistic picture of the environmental impacts and savings of their operations. The findings of the study are intended to be used as a basis for communication and marketing by ThredUP. ThredUP will also use the findings to further improve its operations from an environmental perspective. This study intends to support comparative assertions intended for public disclosure, with primary audiences being ThredUP, its investors, and customers.

2.3 Scope of the study

2.3.1 System description

The goal of any system which encourages product reuse is to extend the life of the current product (apparel item) and reduce the environmental burden both from manufacturing a new product and from the disposal of the old product.

ThredUP operates on the same principle. See figure 2-1 When consumers no longer want to wear an item of apparel, they can sell it to ThredUP instead of disposing of it in the garbage. Sellers typically order a "Clean Out Kit" bag from ThredUP to ship all the good quality, unwanted clothing to ThredUP. The bag can be mailed to ThredUP or can be dropped off at one of their stores or warehouses. Once clothes are received by ThredUP, the company sorts the clothes based on their quality. All clothes which pass the quality threshold are listed online for sale, and remaining items are either returned to buyers or donated to charities. Consumers can then visit ThredUP's online store and buy used clothing at a fraction of the price they would have paid for new clothes. The clothes are then mailed to the buyers.

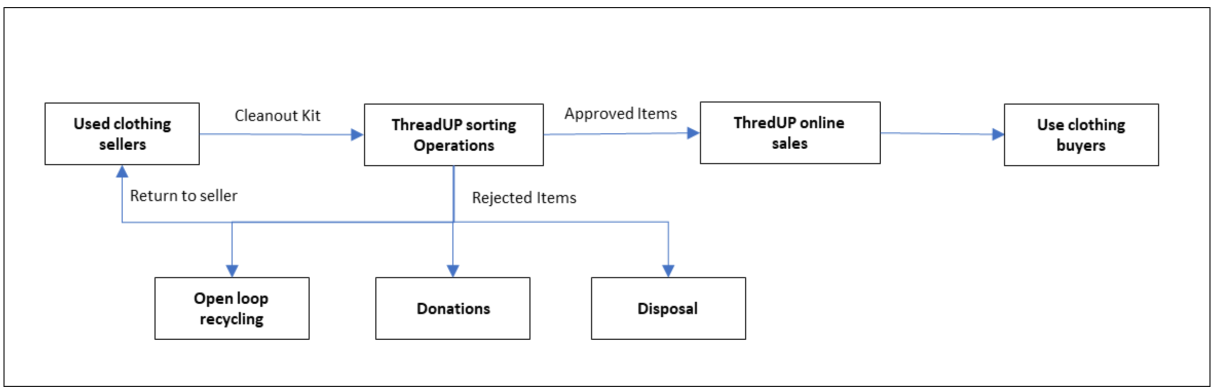

Figure 2-1 ThredUP Overall Operations Model

2.3.2 Function and Functional unit:

The function of the product (apparel item) is to be worn by a consumer for its useful lifetime. **The functional unit is an average second-hand item of apparel sold online by ThredUP in the USA which replaces a similar new item of apparel bought by consumers in the USA.** The average item of apparel is calculated based on the weighted average of garment type and fabric composition in ThredUP's inventory. See section 2.4 Methodology & Assumptions for more details.

Note: *Useful life has been defined as apparel life span after which the apparel starts losing its quality and becomes worn, torn, faded or bleached out etc.*

2.3.3 System Boundary

The system under consideration is a cradle-to-grave Life Cycle Inventory including all life cycle stages of new and second-hand apparel, except for consumer use. For new clothing, it includes raw material acquisition, fiber and fabric manufacture, transport and end-of-life. For second-hand clothing, it includes collection and management of used clothing, online sales, and end-of-life. Impacts for all upstream inputs such as fuel production, fertilizer production, electricity generation etc. are included across all considered lifecycle stages.

Figure 2-2 shows the overall system for reused apparel. The blue and red enclosed boxes depict the life cycle stages taken into consideration for this study for new apparel manufacturing and second-hand apparel sales respectively. Figure 2-3 shows the system boundary in greater detail. In both figures, stages outlined in dotted lines are not considered.

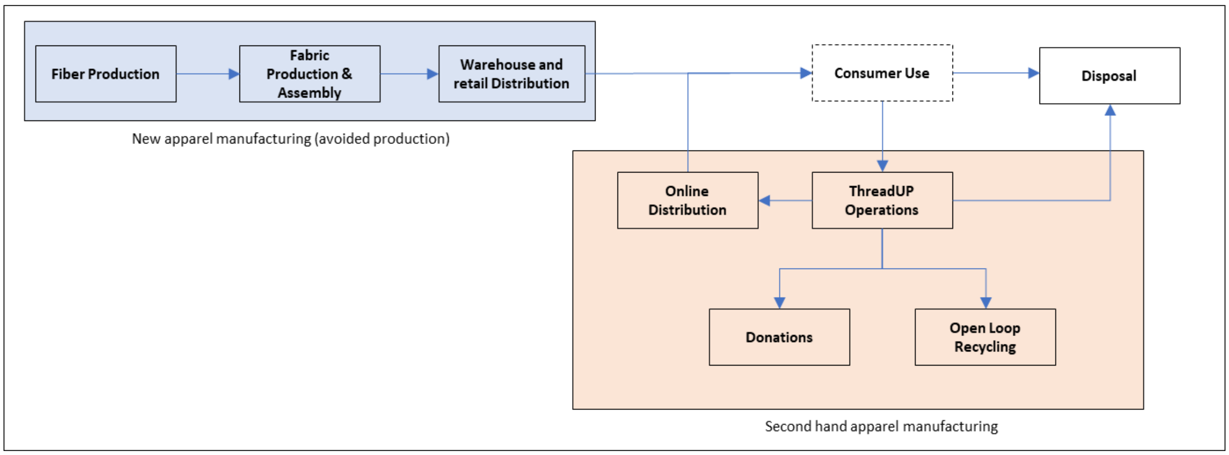

Figure 2-2 Apparel Reuse System

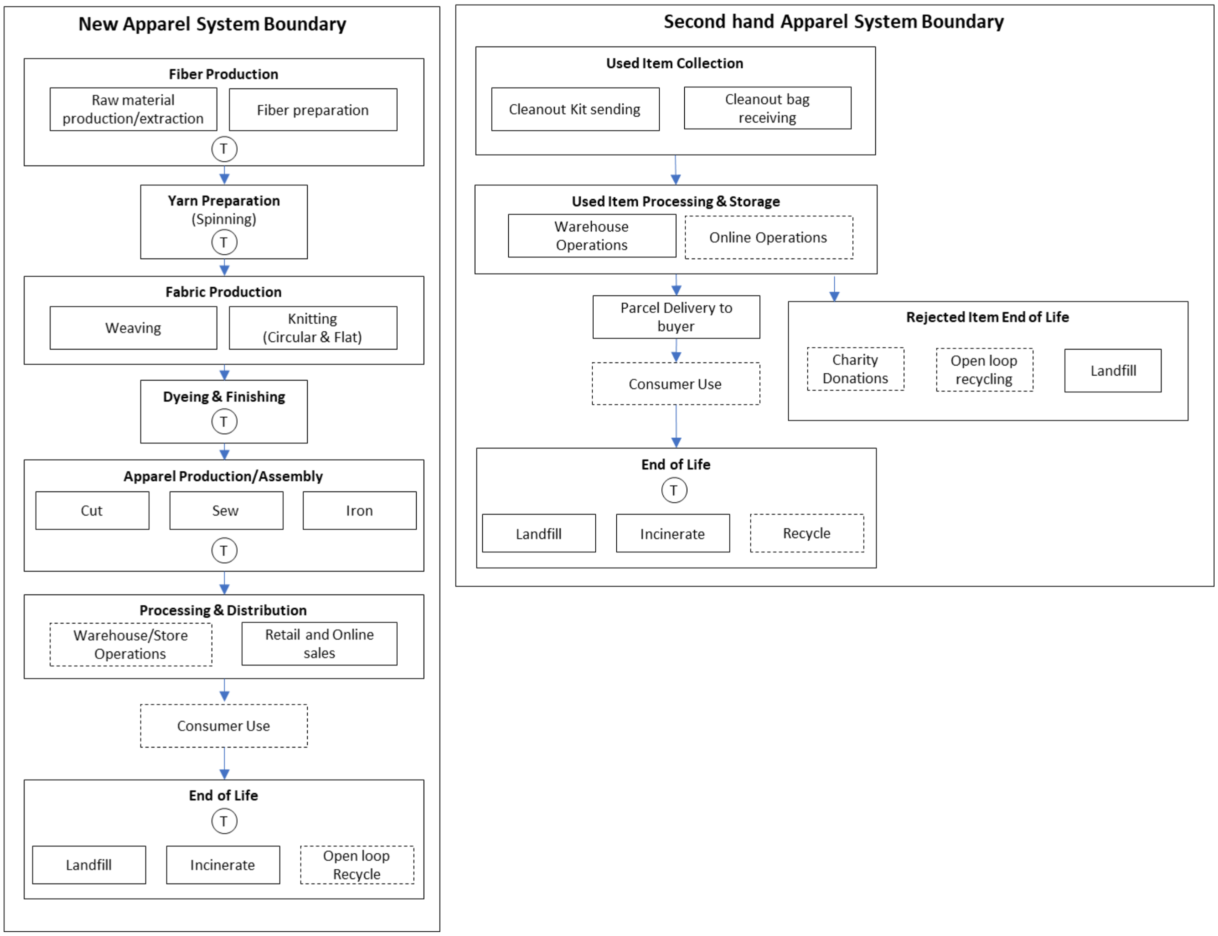

Figure 2-3: System boundaries considered in this study

2.3.3.1 New Apparel Life Cycle Stages

Fiber Production: This process covers the extraction and processing of fibers. It includes all sub-processes such as the cultivation of crops, scutching, degumming, ginning etc. depending on the type of fiber. It includes transportation from raw material extraction location or farm to fiber processing stage.

Yarn Manufacture: This includes the spinning of yarn of either filament or staple fibers. It includes all related processes such as carding, combing, roving and spinning for natural/cellulosic fibers and wet spinning (Partially oriented yarn and Draw textured yarn) processes for synthetic fibers. It includes the transportation from the fiber factory gate to the yarn preparation stage.

Fabric Manufacture: This process covers the knitting and weaving of yarn into fabric and considers all subprocesses of sizing and warping, sanforizing, and compacting. Two different knitting techniques (circular and flat) are taken into consideration. Transportation from the yarn gate to fabric preparation stage is also included in here.

Dyeing and Finishing: This includes the scouring, bleaching, dyeing, and fabric finishing processes and subprocesses such as water softening processing and wastewater treatments.

Assembly: Covers the cutting and sewing of fabric into apparel products. It includes steam and ironing of clothes before packaging.

Distribution: This process considers the transportation from the assembly location to warehouse/store and from warehouse/store to end-users. Only packaging for online sales is included as the amount of packaging in retail sales is highly dependent on the customer.

End of life: Involves the collection and management of apparel products at the end of their useful life (reuse, recycling, incineration and landfilling).

2.3.3.2 Second Hand Apparel Life Cycle Stages

Second-Hand apparel collection: Encompasses the collection of used clothing from consumers. It also includes all the packaging required for the collection process.

Distribution: This process considers the warehouse operations to sort good quality clothes, make them available for sale online and transport them from the warehouse to end-users. It includes all the packaging required for collection.

Rejected item Processing: Includes sending rejected clothes back to sellers and disposing of remaining items by donating to charities, open-loop recycling and landfilling.

End of life: Involves the collection and management of apparel products at the end of their useful life (recycling, incineration and landfilling).

2.3.4 Fibers Covered

This study covers 26 fibers, which comprise 99% of ThredUP's inventory. The following fabrics and materials were considered. See section 3.3 for LCI modeling details of each fiber.

Furs and exotic leathers such as snakeskin were not included in the study as they make up a negligible quantity (<1%) of the overall fiber mix coupled.

Table 2-1: Fibers considered in the study

Natural Fibers	Cellulosic Fibers	Synthetic Fibers
1. Cotton	1. Viscose	1. Nylon 6
2. Pima Cotton	2. Rayon	2. Nylon 6.6
3. Recycled Cotton	3. Tencel	3. Acrylic
4. Organic Cotton	4. Modal	4. Polyester (PET)
5. Canvas	5. Bamboo	5. Recycled Polyester (RPET
6. Hemp	6. Lyocell	6. Polyurethane (Spandex)

7. Linen 8. Wool 9. Recycled Wool 10. Merino Wool 11. Ultra-Fine Merino Wool 12. Silk 13. Ramie 14. Leather		7. PVC 8. Polypropylene (PP)

2.3.5 Product Categories Covered

The following apparel categories were considered. The environmental savings were calculated for each of these categories separately as well as a weighted average of all these categories as per ThredUP's inventory weighting.

Table 2-2: Apparel product categories

1. Active Dress 2. Active Pants 3. Active Skirts 4. Active Tops 5. Blazers 6. Coats & Jackets 7. Dresses 8. Headwear	9. Jeans 10. Leggings 11. Overalls 12. Pants 13. Shorts 14. Active Shorts 15. Skirts & Shorts	16. Sweaters 17. Sweatshirts & Fleece 18. Swimwear 19. Tees & Tanks 20. Tights & Hosiery 21. Tops & Blouses & Shirts 22. Vests

Table 2-3: Non-apparel and clothing accessories product categories

1. Boots 2. Shoes 3. Handbags 4. Wallets 5. Winter Accessories 6. Scarves & Wraps

For products made of leather (boots, handbags, shoes, and wallets) only the leather portion was considered and weighted accordingly. Other parts such as shoe inners and soles, linings, etc. were excluded from the model as the material details used for these parts were not available.

Some products are not considered within the scope of this study as they do not constitute clothing or clothing accessories. These include jewellery, bags, luggage and watches.

2.3.6 Exclusions and cut-off criteria

A few processes considered negligible were excluded for the study at hand, notably, flows contributing less than 1% by mass or energy. The following materials and/or stages were omitted from the study supported by specific reasons for their exclusion:

Packaging (Assembly to Warehouse): This packaging varies significantly from retailer to retailer and on the type and value of clothing. It is expected to have a negligible impact on the overall footprint of an apparel item.

Support materials: Items such as buttons, threads, laces, zippers and other accessories were not included in the study. As the weight of these materials is negligible to the total weight of an apparel item, they are considered to have a negligible impact on apparel's overall footprint.

Use phase: Use phase impact is highly dependent on consumer behavior. This impact can be considered to be identical for both new and second-hand clothing. If included, it would introduce significant uncertainty in the LCA and would not change the overall comparative results of study.

Distribution: Warehouse and store operations for new apparels are excluded from the assessment as no reliable public data is available from the apparel industry and varies significantly from retailer to retailer.

Others Excluded Processes

- Human labor
- Animal labor
- Transport of agricultural equipment
- Certification; extension, farm visits
- Construction of capital equipment and infrastructure

The study focuses strictly on the environmental aspect of reused clothing. Social issues in the manufacture of new clothing and its reuse were outside the scope of this study and were excluded.

2.3.7 Geographic boundaries of the study

This study focuses on new and second clothes sold in the United States. As clothing sold in the USA have supply chains which span the entire globe, a geographical allocation spanning the globe was taken for each of the apparel production stages up until warehouse distribution. All other processes post warehouse distribution, including all processes related to apparel reuse, were modeled as being located in the USA.

2.3.8 Temporal boundaries

The fiber and fabric datasets from the latest GaBi 2018 (3) and Ecoinvent 3.4 (4) databases were used for LCA modeling as much as possible. All background process datasets were also from the latest GaBi and Ecoinvent datasets. Geographic weighting for each supply chain stage for apparel manufacturing was based on 2016 data from Fiber Year Consulting (2017) and Quantis International 2018 report (5), (6), (7). For fabrics for which GaBi and Ecoinvent databases were not available, academic studies were referenced which ranged from 2007 to 2017.

2.3.9 Data Collection

Primary data for the fabric types in each type of clothing and their weight in the inventory was provided by ThredUP. All data related to ThredUP operations were also provided by ThredUP. Data related to production and manufacturing for each of the fabrics was obtained directly from GaBi and Ecoinvent databases or through published LCA studies, academic studies or third-party reports. More detailed information for each fabric is given in section 3.3.

2.4 Methodology & Assumptions

2.4.1 Life Cycle Assessment (LCA) methodology

This study followed the general guidelines of the ISO standards 14040 (1)and ISO 14044 (2) for conducting LCA. It uses the consequential LCA modeling approach (8) to calculate the environmental savings across three key metrics: GWP, PED, and Water. The consequence of apparel reuse is the avoided burden of manufacturing new apparel up until the use phase and the reduced burden of disposal via landfill and incineration.

2.4.2 Life cycle impact assessment (LCIA) methodology

The CML 2001-2010 method was used to evaluate the environmental impact and savings. CML 2001 Method for depicting GWP was chosen as it is an internationally accepted method and supported by GaBi 2019 (9) as well as being used in numerous LCA studies such as Cotton Inc. (2012) (10) and Textile Exchange (2014) (11). The metrics used in this analysis are as follows:

- CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]
- Primary energy from renewable and non-renewable resources (net cal. value) [MJ]
- Blue water consumption [kg]

These three impact categories were selected in order to build a holistic perspective of the inputs required and primary impacts on nature. The results were grouped through midpoint categories (9) in order to display the savings on the environment with a greater amount of certainty (12).

Global Warming Potential was chosen as an impact category, since climate change is deemed to be one of the most pressing environmental issues of our time. Only fossil-based CO2 emissions were considered in this study. The category indicator results are kg of CO2 equivalents (kgCO2e) per functional unit. Primary energy was taken for both renewable and non-renewable sources to give an overall indicator of energy use and energy efficiency. The category indicator results are megajoules (MJ) per functional unit. Water scarcity is a growing issue across the globe especially in developing countries where are lot of fiber for textile is produced. The blue water consumption impact category was selected for consumption to provide a clear impact from the water required for the system, without being released back to the environment. The category indicator results are kilograms (kg) of water use per functional unit.

The reason for using CML 2010 instead of the latest CML 2016 was that several of the referenced LCA studies only provided the LCA results for CML 2010. Due to the lack of underlying LCI data available, it was impossible to transform the results to the latest CML 2016. Hence all impact results are displayed in CML 2010 figures as to have consistency in results.

The methodology is described in further detail in section 4.

2.4.3 Software and database

The LCA model is created using the GaBi 8.7 Software system for life cycle engineering, developed by GaBi AG. The GaBi Professional LCI database (2016) and Ecoinvent database (3.4) provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.4.4 Allocation

Most of the fiber and fabric datasets referenced by this study are external datasets from GaBi, Ecoinvent and other third parties. A mix of mass-based and economic allocation is used by these datasets. However, economic allocation was the most common allocation methodology used by most datasets Economic allocation was also used for the top two fibers in the study, cotton and leather which together account for almost 50% of the total ThredUP inventory weight.

2.4.5 Assessment of data quality

Representativeness

Technological: All primary data is modelled to the specific technology mixes under study. The secondary data for each of the fabric supply chains is based on the technological mixes considered by the referenced datasets. As the fabrics in used clothing can be produced by a variety of technologies especially during the knitting and weaving stages, the modelled data might not be always representative of the actual technology used. Technological representativeness with regard to the goal and scope of this study is fair.

Geographical: Identifying the exact supply chain for used clothing was not possible due to the vast reach of ThredUP's apparel accumulation. Geographic allocation for each of the fabric production steps was based on the secondary data from Fabric Year Consulting, (2017) (5) and Quantis International (2018) (7). With regards to ThredUP's own operations, accurate geographical information was available. Geographical representativeness with regard to the goal and scope of this study is considered to be fair.

Temporal: The time reference for primary data is up-to-date (2018), while secondary data for fabrics is dependent on the referenced dataset. Most of the secondary datasets come from GaBi (2018) (3) and Ecoinvent (2018) (4) databases which were valid during the time period of the study. Hence temporal representativeness for the goal and scope of this study is considered to be good.

Completeness

All relevant processing steps are considered and modelled to represent each specific situation. The process chain is considered reasonably complete with regard to the goal and scope of this study. Excluded process steps are described in section 2.3.6.

Reliability

Most data used for this study is retrieved from Ecoinvent (2018) and GaBi (2016) databases. Any additional data from secondary sources for fabrics are retrieved from published LCA studies, and any other secondary data is retrieved from published articles and third-party reports. The reliability in terms of the goal and scope for this study is good.

Consistency

All background data were sourced from Ecoinvent (2018) and where not available from GaBi (2016) databases . For most fabrics, all post fiber production steps were modelled in GaBi using consistent methodology. All other process steps for reuse operations were modelled in GaBi.

2.4.6 Key Model Assumptions

Two key assumptions apply to the overall modeling approach. A sensitivity analysis is performed for these assumptions and results are shown in section 5.

1. **Switching Rate (Rate of reuse among ThredUP customers):** The majority of ThredUP customers in 2018 were first-time buyers of second-hand clothing. All these customers would have bought brand new clothing if ThredUP services were not available on the market. The key assumption of this study is 1: 1 switching from buying brand new apparel to buying second-hand apparel from ThredUP.

2. **Replacement Rate:** A typical apparel has a useful life of about 50 washes (13) before it is significantly worn out. Many consumers use garments for less than half of their useful life before disposing of them. ThredUP further sorts used clothing so that only good quality clothes are available for sale in their online store. The study assumes that second-hand clothing sold by ThredUP has 70% of its useful life still left (13).

All other model assumptions for each process are detailed in their individual process methodology in section 3.

2.5 Review

The study was reviewed by an independent third-party reviewer, Mr. Panos Panagiotakopoulos, Ph.D. The review was conducted for a thorough assessment of the goal and scope of the study, system boundary, inventory analysis, LCA methodology and system modeling. The review was performed in concurrence with the study. Review was performed at following milestones in the study

1. The goal and scope definition;

2. Mid-term review of system boundary, inventory analysis and LCA modelling;
3. Review of the draft final report.

Dr. Panagiotakopoulos is the founder of Close the Loop, a sustainability advisory, coaching and research company. He holds an M. Eng. in Environmental Engineering (Democritus University of Thrace), a Ph.D. in Corporate Sustainability (Heriot-Watt University), and a Postdoc on Ecolabel Strategies. Dr. Panagiotakopoulos is currently teaching at the University of Toronto, OCAD University and Seneca College various sustainability-related topics including Life Cycle Assessment, Sustainability Management, and Business Design. He has also trained numerous professionals on these topics around the world. Dr. Panagiotakopoulos is a member of the Circular Economy Working Group of the City of Toronto and an advisor to Ashoka's Globalizer program, while the Global Reporting Initiative (GRI) has assigned him as a Quality Control Consultant for its Certified Training Programs in Greece.

3 Life cycle inventory (LCI) analysis

3.1 Datasets used for each fiber stage

Datasets for each material fiber came from the Ecoinvent database (3.4), GaBi Professional LCI database (2016), published LCA studies, Cotton Inc (10) and Textile Exchange datasets (11). Below is a summary of the datasets used for each fiber. Post fiber stage all process steps were consistently modeled in GaBi for all fibers (except linen and Ramie) using geographical allocation as described in section 3.2. For Linen, the fabric LCI dataset was used from GaBi and for Ramie, yarn LCA result was used published study.

Table 3-1: LCI dataset source details by fiber type

#	Material	Dataset Type	Geography	Dataset Source
1	Leather Hide	LCI	Canada and India	Published LCA (14) (15) (16)
2	Polyester granulate	LCI	Global	Ecoinvent (4)
3	Nylon 6 granulate	LCI	Global	Ecoinvent (4)
4	Nylon 6.6 granulate	LCI	Germany	GaBi (3)
5	Cotton	LCI	Global	Cotton Inc (10)
6	Pima Cotton	LCI	Global	Cotton dataset used as proxy
7	Viscose	LCI	Global	GaB[i] (3)
8	Silk	LCIA result	India	Published LCA (17)
9	Modal	LCIA result	Austria	Published LCA (18)
10	Linen	LCI	EU-28	GaBi (3)
11	Tencel	LCIA result	Austria	Published LCA (18)
12	Lyocell	LCIA result	Austria	Tencel dataset used as proxy
13	Acrylic granulate	LCI	EU-28	GaBi (3)
14	Ramie	LCIA result	EU-28	Published LCA (19)
15	Wool	LCI	EU-28	GaBi (3)
16	Rayon	LCI	Global	Viscose dataset used as proxy
17	Merino Wool	LCIA result	Australia	Published LCA (20) (21)
18	Merino Extra Fine Wool	LCIA result	Australia	Published LCA (20) (21)
19	Recycled Wool	LCIA result	EU-28	Published LCA (13)
20	Recycled Polyester gran.	LCI	Global	Ecoinvent (4)
21	PVC granulate	LCI	EU-28	Ecoinvent (4)
22	Organic Cotton	LCI	Global	GaBi (3)
23	Bamboo	LCI	Global	GaBi (3)
24	Recycled Cotton	LCIA result	EU-28	Published LCA (21)
25	Hemp	LCI	Global	Published LCA (22)
26	Canvas	LCI	Global	GaBi (3)
27	Polypropylene granulate	LCI	Global	GaBi (3)
28	Polyurethane (Spandex) granulate	LCI	Global	Ecoinvent (4)

See section 3.4 for details on datasets

3.2 Geographic allocation

All apparel manufacturing process steps were geographically allocated based on the below distribution as per Quantis International (2018) (7).

Table 3-2: Apparel manufacturing geographic distribution by process stage

	Fiber Production	Yarn Production	Fabric Production	Dyeing & Finishing	Assembly
Bangladesh	0%	3%	3%	28%	7%
Brazil	1%	0%	1%	0%	0%
China	57%	64%	60%	44%	35%
EU	7%	1%	0%	11%	11%
India	13%	9%	12%	0%	7%
Indonesia	2%	0%	0%	0%	0%
Pakistan	0%	4%	2%	0%	0%
Russia	0.7%	0%	0%	0%	0%
Turkey	0%	0%	5%	17%	0%
USA	4%	0%	0%	0%	0%
Vietnam	0%	0%	0%	0%	6%
ROW	15%	19%	17%	0%	34%
Total	100%	100%	100%	100%	100%

All secondary datasets such as electricity grids and other fuels (diesel, coal, light and heavy fuel oil etc.) were adjusted as per the geographical distribution of each of the process steps. The total percentage from the countries mentioned from the Quantis International 2018 (7) study did not always amount to 100% and was then allocated to Rest of the World (ROW).

Secondary fuel datasets for steam, thermal energy, diesel, and light fuel oil were used for each specific country when possible. Not all datasets for these fuels were available in GaBi or Ecoinvent 3.4 databases for each country. India datasets was used for Bangladesh, China, Indonesia, Pakistan and Vietnam. EU-28 datasets were used for Turkey and Russia. Steam and thermal energy mixes were either assumed to be generated from hard coal or natural gas depending on the country of origin and are categorised in the table 3-3:

Table 3-3: Steam and thermal energy source by geography

Country	Steam and thermal energy source
India, China, Pakistan, Bangladesh, Vietnam, Indonesia	Hard Coal
Turkey, USA, Brazil, EU, Russia	Natural Gas

3.3 Fabric Preparation

3.3.1 Cotton and Organic Cotton

Conventional cotton, referred to as cotton in the study, is one of the top fabrics used across the world. It also has the largest share of all fabrics in the current study (34%). Organic cotton is a growing sustainable variant of cotton. Cotton and organic cotton fabric have almost identical manufacturing process except at the fiber stage where organic cotton is cultivated without the use of chemical fertilizers and pesticides and mostly irrigated with rain-fed water.

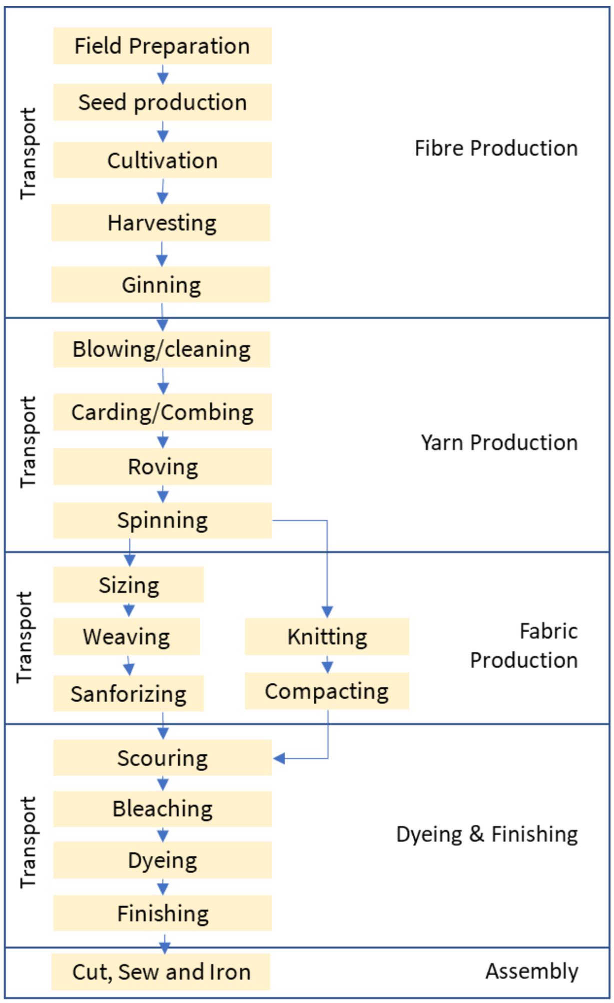

Figure 3-1: Main life cycle steps in the production of cotton and organic cotton clothing

Cotton fiber LCI dataset from Cotton Inc (10) was used to model cotton fiber. Pima cotton which constitutes 0.2% of total fabric weight was modeled using a global cotton fibre dataset. Organic cotton fiber LCI dataset from Textile Exchange (11) was used to model organic cotton fiber. Both datasets were based on a weighted average production of cotton and organic cotton fibers across the globe. The following key processes are included in each dataset: field preparation, cultivation, harvesting, ginning, and transportation.

All other processes of yarn making, fabric production, dyeing, and assembly for cotton and organic cotton are similar to other natural fibers and described in detail in sections 3.4 to 3.7.

3.3.2 Canvas

Canvas fabric is usually made from cotton, linen or PVC fibers. For this study it was assumed that canvas fabric was exclusively made of cotton fiber. The global cotton fiber dataset from Cotton Inc (10) was used to model canvas fiber. As canvas fabric is exclusively weaved, electricity for yarn (weaving) was used in the yarn production process and 100% weaving was assumed for the canvas fabric making process. All other processes were the same as conventional cotton as described in section 3.3.1.

3.3.3 Recycled Cotton

Recycled cotton is produced from the shredding of post consumer and post-industrial cotton fabric. It avoids all the environmental impacts related to the cotton cultivation and dyeing of yarns. This means avoiding the use of blue water, fertilizers and pesticides during cultivation and the use of water, dyes, wetting agents, softener, and other related products during dyeing. It requires the additional steps of collection, cutting, shredding and color mixing.

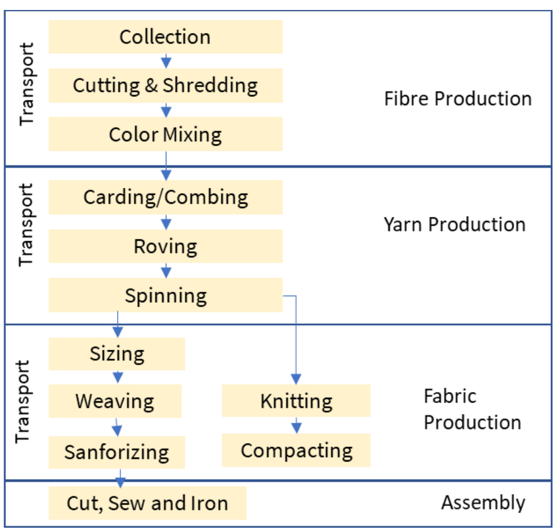

Figure 3-2: Main life cycle steps in the production of recycled cotton clothing

The specific steps of cutting, shredding and color mixing of recycled cotton were modeled on a Spanish dataset (21). All other apparel manufacturing's steps are similar to cotton and described in detail in sections 3.4 to 3.7.

3.3.4 Hemp and Flax (Linen)

Hemp and Flax fibers are one of the oldest plants used for producing textiles. Textile manufacturing from these bast fibers follow the same general steps as described in figure 3-3. The Gabi (2018) (3) dataset for flax fabrics is used to model Linen fabric in this study. It is based on the European average flax fabric production.

China is the largest producer of Hemp fabric in the world. Hemp fiber is modeled on a Chinese dataset (22) which has been adjusted for average global hemp production. All other processes of yarn making, fabric production, dyeing and assembly for hemp and linen are similar to other natural fibers and described in detail in sections 3.4 to 3.7.

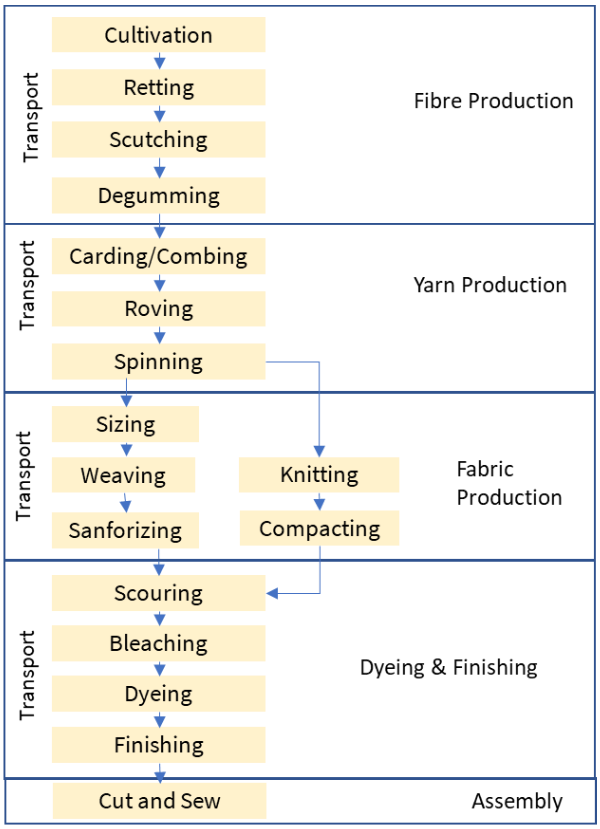

Figure 3-3: Main life cycle steps in the production of hemp and linen clothing

3.3.5 Silk

Over 90% of commercially produced silk is extrusion spun by the domesticated silkworm Bombyx mori, a monophagous insect whose diet is restricted to the leaves of the mulberry tree. Only mulberry silk is modeled in the study.

The raw silk dataset modeled on Indian mulberry silk production (17) is used to model the silk yarn. The dataset includes mulberry leaves production, silkworm rearing, cocoon cooking, drying, reeling and re-reeling. No process data is available for silk throwing process (degumming and doubling of the yarn). So only sericin losses of 25% are accounted in that process prior to blending it with other yarns. (24)

All other processes for fabric production, dyeing and assembly for silk cotton are like other natural fibers and described in detail in sections 3.4 to 3.7.

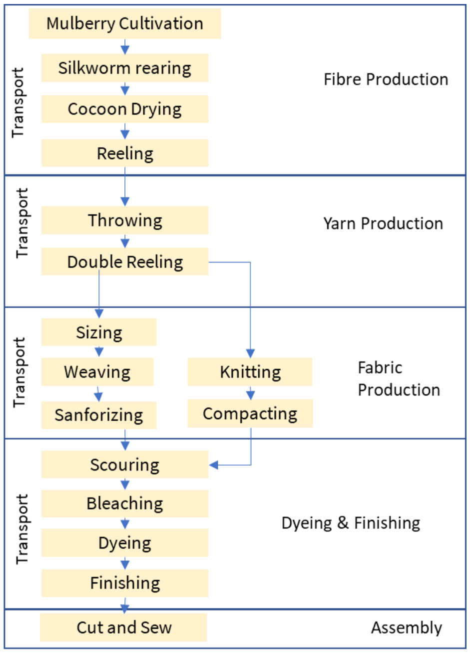

Figure 3-4: Main life cycle steps in the production of silk clothing

3.3.6 Ramie

The LCIA results of ramie yarns were taken from Dong et al. (2018) (19) and include all impacts from ramie cultivation, harvesting, peeling, transportation, degumming, carding and spinning. The LCIA results were adjusted from one tonne of yarns to 1 kg of yarns. After yarn production, ramie apparel follows the apparel making process for any other natural fiber as detailed in section 3.4 to 3.7.

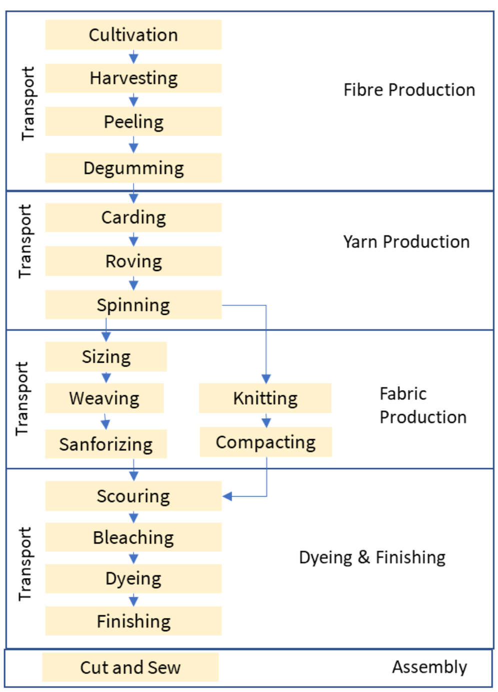

Figure 3-5: Main life cycle steps in the production of Ramie clothing

3.3.7 Wool and Recycled Wool

The production of raw wool yarn and all prior steps are modeled using GaBi 's DE: Sheep wool yarn dataset and used as a global average dataset. It includes sheep farming, scouring, top making and carbonization. After raw wool yarn production, wool follows the same apparel making process for other natural fiber as detailed in sections 3.4 to 3.7. Wool fabric is dyed using acid dyes as stated by Hassan and Shao (2016) (25). Figure 3-6 describes all the process steps for wool apparel:

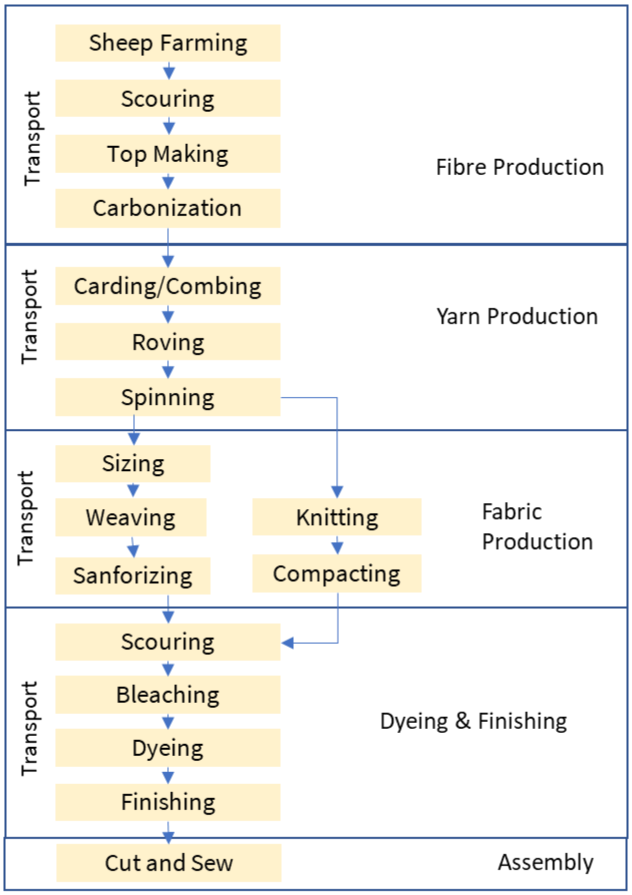

Figure 3-6: Main life cycle steps in the production of wool clothing

Recycled wool is produced from the shredding of post consumer and post-industrial wool fabric. It avoids all the environmental impacts related to the sheep farming, scouring, top making, carbonization and dyeing of yarns. It requires the additional steps of collection, cutting, shredding and color mixing (25). Figure 3-7 describes all the process steps for recycled wool apparel:

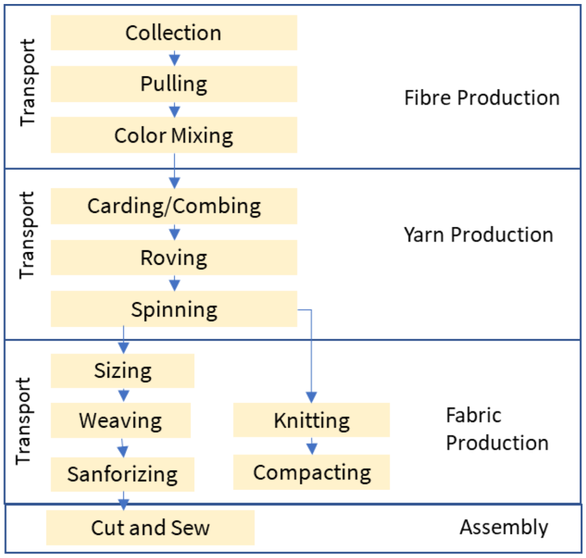

Figure 3-7: Main life cycle steps in the production of recycled wool clothing

3.3.8 Merino Wool (Medium and Ultra-fine)

The production process of medium and ultra-fine Merino wool is identical to conventional wool production and can be seen in Figure 3-8 below:

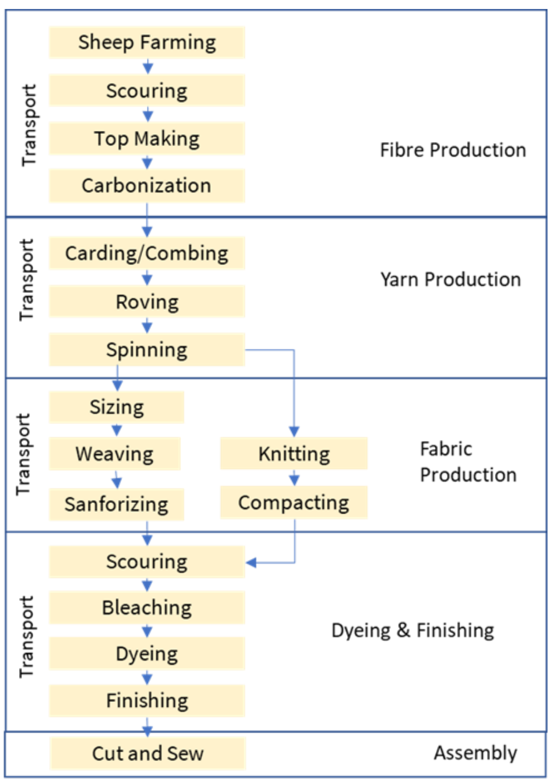

Figure 3-8: Main life cycle steps in production of merino wool (medium and ultra-fine) clothing

The high rainfall zone located in New South Wales, Australia (NSW HRZ) produces extra-fine Merino wool. The impact results from this region were used as an average for extra-fine merino wool fiber production. The southern pastoral zone (SA SPZ) of central Australia produces medium Merino wool. The impact results from this region were used as an average for medium merino wool fiber production. (21) (20).

Off-farm impacts from transportation of livestock and sheep feed production were included within the LCIA results. Energy inputs and waste produced for the wool scouring process was taken from another study (20).

After raw wool yarn production, merino wool follows the same apparel making process as other natural fiber as detailed in sections 3.5 – 3.7. As in conventional wool, Merino wool fabric is dyed using acid dyes (25).

3.3.9 PVC

Vinyl in the fashion industry is primarily used for coating a fabric to make it shiny or water resistant. The PVC dataset published by Plastics Europe (26) and available in Ecoinvent is used to model the PVC granulate. PVC granulate is then extruded to make the plastic film and heat pressed on a fabric to make the PVC coating. The production process is illustrated in Figure 3-9 below.

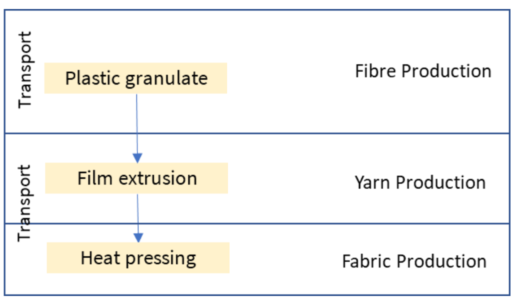

Figure 3-9: Main life cycle steps in production of PVC coating on clothing

3.3.10 Polyester, Nylon6, Nylon 6.6 Acrylic, Polypropylene and Polyurethane (Spandex)

For synthetic fibers, only the process to produce the raw plastic granulates was assumed to be different. All other production steps were assumed to be same for all synthetic fibers and described in detail in section 3.4 to 3.7.

The LCI datasets for synthetic fabrics were taken from Ecoinvent and GaBi datasets. Below is the list of datasets for synthetic materials used for this study. Regional datasets from GaBi and Ecoinvent were adjusted to global average production as per the geographic allocation described in section 3.2.

GaBi

- Acrylic: EU-28 Polyacrylonitrile Fibers (PAN)
- Nylon 6.6: DE Polyamide 6.6 Granulate (PA 6.6) Mix

Ecoinvent

- Nylon 6 - RoW: nylon 6 production
- Polyester - RER: polyethylene terephthalate production, granulate, amorphous <u-so>

- GLO: market for polypropylene, granulate
- RER: Polyvinyl chloride film (PVC) Plastics Europe
- Spandex: GLO: market for polyurethane, flexible foam

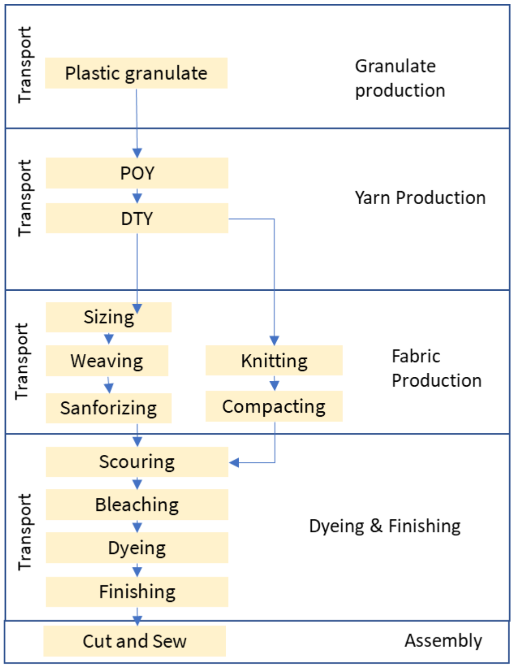

Figure 3-10: Main life cycle steps in production of 3 Polyester, Nylon, Acrylic, Polypropylene and Polyurethane fabric clothing

3.3.11 Recycled Polyester

Recycled polyester was assumed to be created by open loop recycling of single use plastic bottles. The collection and sorting of plastic bottles and turning them into plastic granulates was modeled based on Ecoinvent datasets. Regional datasets were adjusted to global average production as per the geographic allocation described in section 3.2. All other production steps were assumed to be same as for other synthetic fibers and described in detail in section 3.4 to 3.7. The production processes for this material is displayed in Figure 3-11 and datasets used are given below.

Ecoinvent datasets

- CH: polyethylene terephthalate production, granulate, bottle grade, recycled <u-so>
- CH: treatment of waste polyethylene terephthalate, for recycling, unsorted, sorting <u-so>

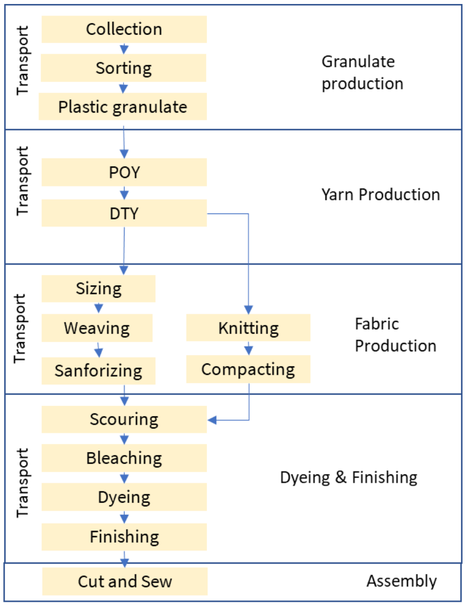

Figure 3-11: Main life cycle steps in the production of recycled polyester clothing

3.3.12 Viscose, Rayon, Bamboo and Modal

Conventional viscose fiber, bamboo viscose fiber and modal fibers are all manufactured using the same viscose cellulose regeneration method. The main difference between the three is that conventional viscose is made from Eucalyptus, bamboo viscose uses Bamboo and Modal is made from European Beech. Modal is the brand name fabric of Lenzing Tencel and is manufactured in an integrated production facility in Austria. Modal fiber is manufactured by a modified viscose process with a higher degree of polymerisation and modified precipitating baths (18). The production process of these materials is illustrated in Figure 3-12.

Modal staple fiber dataset is based on Shen and Patel (2010) (18). Conventional viscose and bamboo viscose are modeled using Ecoinvent and GaBi datasets and provided below. As Thailand and China are one of the largest producers for Eucalyptus pulp and Bamboo pulp respectively no global allocation was done. Viscose production was globally allocated as per section 3.2. All other production steps were assumed to be same as for other natural fibers and described in detail in section 3.4 to 3.7.

Ecoinvent

- TH: sulfate pulp production, from eucalyptus ssp. from sustainable forest management, unbleached <u-so>
- GLO: viscose production <u-so>

GaBi

- Natural bamboo fibers

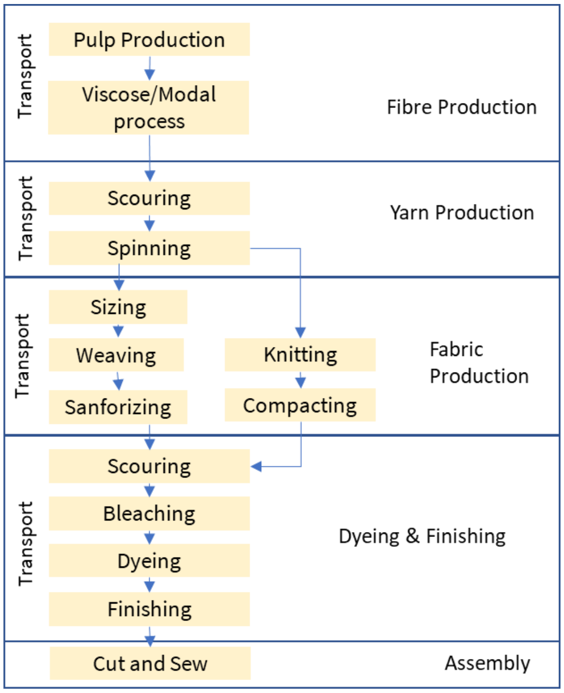

Figure 3-12: Main life cycle steps in the production of viscose, bamboo and Modal clothing

3.3.13 Tencel and Lyocell

Tencel and Lyocell fabrics are based on the Lyocell method of cellulosic regeneration. The lyocell process uses NMMO (N-methylmorpholine-N-oxide) to dissolve pulp and regenerate cellulose. The process has an almost completely closed solvent cycle. This not only avoids the use of the highly toxic solvent CS2, but also reduces a number of the process steps and total chemical use. Tencel fabric is a brand name of Lenzing Tencel and is manufactured exclusively in its integrated Austrian plant using 100% recovered energy from MSWI (18). Figure 3-13 illustrates the Tencel and lyocell production process in detail.

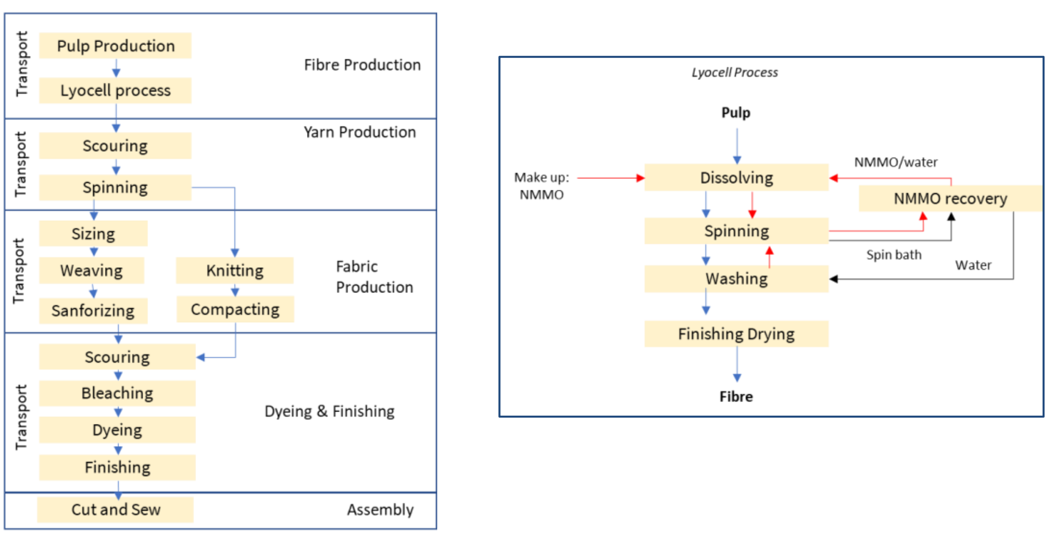

Figure 3-13: Main life cycle steps in the production of Lyocell and Tencel clothing

Tencel staple fiber dataset is based on Shen and Patel (2010) (18). As no other Lyocell staple fiber LCI dataset was available, the Tencel dataset was used as proxy for all other Lyocell fibers. All other production steps were assumed to be same as for other natural fibers and described in detail in section 3.4 to 3.7.

3.3.14 Leather

Only bovine leather was modeled in this study as it constitutes the majority of leather in the world market (27). Figure 3-14 shows the key process steps in the manufacture of leather. The dataset for cattle raising, slaughtering and hide production was based on a Canadian study by Desjardins (2012) (16). Economic allocation was used to allocate environmental burden to cattle hide. Since India is one of the largest leather producers in the world, the dataset for leather manufacture from the hide was based on an Indian study by Joseph and Nithya (2009) (14). The electricity for product assembly was not considered due to lack of data for non-apparels such as boots, shoes, wallets, handbags and belts, while. Losses during assembly were taken into consideration (28).

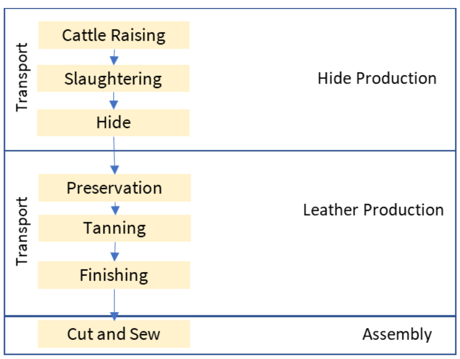

Figure 3-14: Main life cycle steps in the production of leather

3.4 Yarn production

It was assumed that all natural and cellulosic fibers have a similar yarn production process and all synthetic fibers have a similar yarn production process. The two exceptions are hemp and silk yarn which require degumming prior to spinning. Leather was modelled separately as it follows a completely different process.

Approximation used by fiber:

- Synthetic fiber yarn approximated with polyester fiber yarn process
- Cellulosic fiber yarn approximated with viscose fiber yarn process
- Natural fibers yarn approximated with cotton fibers yarn process

The energy use for natural/cellulosic yarn making in the model is based on the study from Hasanbeigi and Price (2012) (29) and Koc (30)' (31) and for synthetic yarn is based on Velden et al. (32) and the EDIPTEX database (33).

Table 3-4: Electricity data for yarn making (per kg)

Yarn Type	Electricity (MJ)
Natural/ cellulosic yarn for knitting	11.02
Natural/ cellulosic yarn for weaving	13.10
Synthetic yarn (for knitting/weaving)	9.72

There is negligible blue water consumption in the yarn making process except in case of wet spinning of semi synthetic and synthetic fibers and is not included in the model.

3.4.1 Natural and semi-synthetic (cellulosic) fibers

Yarn production for natural and semi-synthetic fibers includes the spinning of fibers into yarn and all subprocesses; blowing, cleaning, combing, carding, groving, and winding. The electricity input for yarn production varies depending on whether yarn produced is to be knitted or weaved. Based on Quantis International (2018) (7) and The Fiber Year 2017 report (6), the model assumed 64% of yarn is knitted and 36% is weaved on average. A weighted average of electricity inputs for the spinning was used based on this distribution. The energy inputs for yarn production provided in Table 3-4.

3.4.2 Synthetic fibers

The yarn production of synthetic materials covers the spinning of granulate material to partially-orientated yarn (POY) and the drawing and texturing of POY into draw textured yarn (DTY). It was assumed that there is no significant difference in electricity consumption to create synthetic yarn for knitting or weaving purposes. The inputs needed for these processes were taken from van der Velden et al. (2014) (32) and are provided in detail in the Appendix.

3.5 Fabric Production

Fabric production includes the processes of knitting or weaving, dyeing and finishing. The ratio of yarn being knit vs weaved is assumed at 64% and 36% respectively, following the Quantis International (2018) (7) and Fiber Year Consulting (2017) (5)' (6).

3.5.1 Weaving

The weaving process includes warping and sizing, weaving and sanforizing. The warping and sizing process for all fabrics was modeled based on a hemp production study due to lack of data (22). The electricity required solely for the weaving process was taken from Koc and Cincik (2010) (30) as an average input from 5 weaving machines to ensure proper representation of global weaving equipment.

The sanforizing process assumes a material of 170 grams per meter square (gsm) as per a medium weight jersey (34). The inputs needed for all weaving processes are given in table 3-5.

3.5.2 Knitting

The knitting process includes knitting and compacting. Two different knitting techniques (circular and flat) were taken into consideration and were set to 60% circular and 40% flat as per Quantis International (2018). Flat knitting electricity is taken from van der Velden et al. (2014) (31) as flat knitting with large panels as done in European Commission JRC, 2014 for baseline scenario. Energy consumption for knitting and weaving are derived from multiple literature sources and are displayed in Table 3-5.

Table 3-5 Electricity, steam and thermal energy data fabric production (per kg)

Fabric Type	Electricity (MJ)	Thermal Energy (MJ)	Steam (MJ)
Weft Knitting	0.76 (10) (32)	0.19 (32)	4.59 (10)
Warp Knitting	4.25 (10) (32)	0.19 (32)	4.59 (10)
Weaving	11.10 (10) (32) (30)	0	14.68 (10) (32)

The following datasets used were used in these processes:

GaBi:

- GLO: Steam conversion (mp)

Ecoinvent 3.4:

- GLO: market group for tap water

3.6 Dyeing

Batch dying of greige fabric is considered for all materials in this study. It is assumed that fabric making, and batch dyeing is a vertically integrated process and takes place at the same facility. The dyeing processes have been modeled based on GaBi datasets for each of type of dyeing. The dyes used for each material are outlined in the following table:

Table 3-6: Type of dye used by fabric type

Fabric Type	Fabric Name	Type of Dye
Natural	Cotton, organ cotton and Pima cotton	Light Reactive dyes
	Linen	Light Reactive dyes
	Ramie	Light Reactive dyes
	Hemp	Light Reactive dyes
	Canvas	Light Reactive dyes
	Wool and Recycled wool	Acid dyes
	Merino wool and Ultra-fine merino wool	Acid dyes
	Leather	Chrome dyes
	Silk	Acid dyes
Semi-synthetic	Bamboo	Light Reactive dyes
	Modal	Light Reactive dyes
	Viscose/Rayon	Light Reactive dyes
	Lyocell	Light Reactive dyes
	Tencel	Light Reactive dyes
Synthetic	Polyester and Recycled Polyester	Disperse Dyes
	Acrylic	Disperse Dyes
	Nylon 6 and Nylon 6.6	Disperse Dyes
	Polyurethane (Spandex)	Disperse Dyes
	PVC	Disperse Dyes
	Polypropylene	Disperse Dyes

The following GaBi plans were used for the dyeing processes. These plans include additional subprocesses which were not displayed in this report:

GaBi:

- Silk fabric dyed with light acid dyes in jigger
- Flax fabric dyed with light reactive dyes with antistatic finishing
- Viscose or cupro fabric dyed with light reactive dyes with antistatic finishing
- Polyester fabric dyed with light disperse dyes in beam

3.7 Apparel Assembly

The apparel assembly production step includes the cutting, sewing and ironing of fabric into garments. The average electricity and steam requirements for assembling each type of apparel was calculated based on the European Commission JRC (2014) (35) and Sustainable Energy Saving for the European Clothing Industry (2013) (36).

3.7.1 Weight modeling of each fabric for impact calculation

In order to get the percent weight contribution for each fabric, the inventory data was firstly gathered from ThredUP. The inventory data provided the distribution of apparels by category and fabric blend. Only the top 5 fabrics for each unique fabric blend in each apparel category were considered as they represented >99% of the total weight of each apparel category. Their weight was then scaled up to 100% of the apparel category weight. Each apparel category was then assigned an average weight as per Parcl (37). The average weight for each apparel was then multiplied by the percentage of fabric blend in order to get the weight of each fabric in that apparel category. Then, the weight of each fabric was aggregated across the entire inventory to get the total weight of each fabric in the inventory. Based on this the percent weight contribution was then calculated. Lastly, the fabric weight ratio was scaled to the annual sales data to calculate total weight of each fabric for 1 year of ThredUP sales. See figure 3-15.

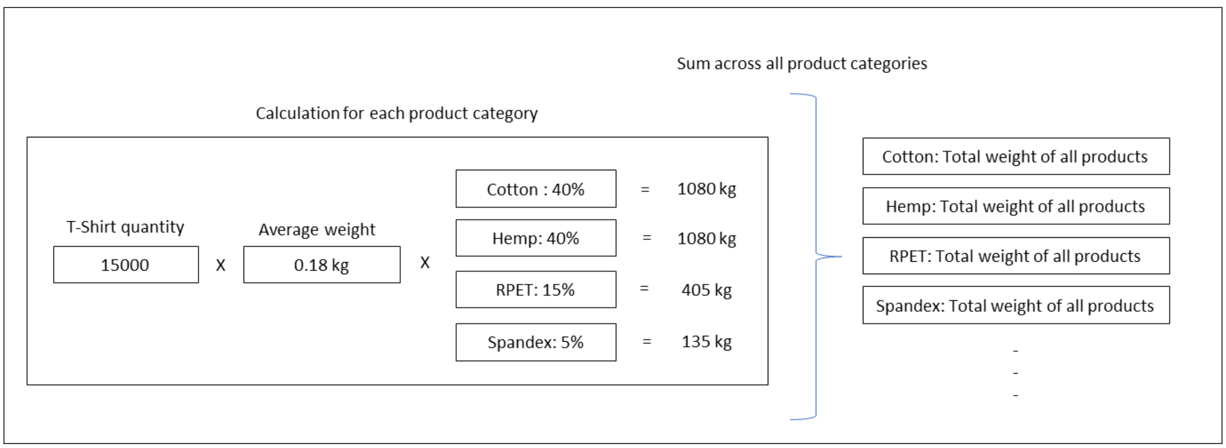

Figure 3-15: Weight modeling of each fabric for impact calculation

3.7.2 Electricity and steam usage modeling

The electricity and steam used for assembly is directly dependent on the apparel category. As the LCA model was created at a fabric level and not for each apparel type, the average electricity and steam use per kg of fabric in the assembly stage needed to be calculated. In order to do so, the following methodology was used:

1. Electricity use, steam use and average weight for each apparel category was identified
2. Apparel items were aggregated by their major fabric type and apparel category (major fabric is defined as fabric with >50% share in the blend)

3. Weighted average calculation was performed on electricity and steam use per item and the average weight per item for each fabric.

A categorisation of the weight, electricity, steam and losses at the apparel assembly stage are displayed in the table below. The electricity and steam for belts, shoes, cover ups, handbags and one piece were not considered due to lack of data.

Table 3-7: Average product weight, energy use and losses during assembly by category

Product Type	Average weight (kg)	Electricity per garment (kWh)	Steam per garment (MJ)	Cutting Losses per garment (%)
Active Dress	0.25	0.31	0.063	13
Active Pants	0.60	0.44	0.55	14
Active Skirts / Skorts	0.30	0.44	0.55	14
Active Tops	0.10	0.16	0	13
Belts	0.15	0	0	20
Blazers	0.70	2.01	7.84	16
Boots	0.84	0	0	25
Coats & Jackets	1.10	2.01	7.84	16
Cover up	0.17	0	0	16
Dresses	0.25	0.44	0.55	18
Handbags	0.60	0	0	20
Headwear	0.09	0.16	0	18
Jeans	0.72	0.44	0.55	14
Leggings	0.28	0.44	0.55	14
One Piece	0.80	0	0	0
Overalls	0.80	0.44	0.55	18
Pants	0.60	0.44	0.55	14
Scarves & Wraps	0.17	0.16	0	4
Shoes	0.34	0	0	25
Shorts	0.20	0.16	0	15
Shorts - Active	0.20	0.16	0	15
Skirts & Skorts	0.25	0.44	0.55	14
Sweaters	0.40	0.25	0.78	10
Sweatshirts & Fleece	0.40	0.25	0.78	10
Swim	0.14	0.072	0	18
Tees & Tanks	0.18	0.16	0	13
Tights & Hosiery	0.06	0.072	0	0
Tops & Blouses & Shirts	0.17	0.31	0.063	13
Vest	0.25	0.25	0.78	10
Wallet	0.13	0	0	20
Winter Accessories	0.13	0.44	0	18

3.8 ThreadUP Operations

ThredUP operations for clothing reuse includes second-hand apparel collection from sellers, warehouse operations to select clothes which can be sold back, the processing of rejected clothes and their disposal. All data related to ThredUP operations is listed in the Appendix from Table 8.1 – 8.4. Details for each process in developing the LCI dataset are shown below.

3.8.1 Used clothing collection

This process includes all steps required in the collection of used clothing from sellers by ThredUP and any packaging associated with it. Sellers can send used clothing to ThredUP either via post or drop it off at one of their warehouse/stores. The transportation modeling and assumptions for this step is covered in detail in section 3.9.3.

It is assumed that all sellers who mail their used clothing order a cleanout kit from ThredUP. Cleanout kit details are listed in Table 3-8. Low-density polyethylene (LDPE) granulate for the cleanout kit bag was modeled on the Europe dataset (as US dataset was not available).

Table 3-8: ThredUP cleanout kit packaging details

Cleanout Kit Components	Material	Weight
Total cleanout kit	-	100 g
Outer envelope + insert	Super calendared paper	27 g
Inner bag	LDPE bag	73 g

Below are additional assumptions in the modeling of the cleanout kit:

- All cleanout bags are sent to recycling by ThredUP. The impact of packaging recycling is out of scope for this study
- The cleanout kit is entirely manufactured and printed in the USA
- Offset printing is used for both envelope and cleanout bag printing. The process is identical for both paper and LDPE film printing including amount of ink, energy and other resources consumed
- A total transportation distance of 500 km was considered for paper and LDPE film from factory to offset printer and from offset printer to ThredUP warehouses

3.8.2 Warehouse and store operations

This process includes all warehouse operations at ThredUP: sorting used clothes as per quality assurance standards, scanning clothes for fabric information, listing online and any ironing, cleaning or repair required. The total electricity and heating energy used at the warehouse and store (listed in Table 8-3 in the Appendix) were considered in creating the LCI dataset for this process. This includes the overhead energy required for office and administrative tasks as it was not possible to distinguish it from the production energy. The electricity grid assigned to the warehouse was based on the warehouse location and the US Emissions & Generation Resource Integrated Database (eGRID) subregion applicable to that location (38). Per the ThredUP provided data, 10% of clothes sold are steam ironed. Water consumption of 50 ml per garment was assumed for steam ironing was also accounted for.

3.8.3 Rejected clothes processing

This process includes sending rejected clothes back to sellers (for those who opted) and disposal of remaining items by donating to charities, open-loop recycling and landfilling. Table 3-9 provides the distribution pathways for rejected clothes.

Table 3-9: ThredUP rejected items pathway

Rejected items pathway	Percentage
Items resold in aftermarket (%)	90%
Items for industrial use (%)	3%
Items for recycling (%)	2%
Items for landfill/incineration (%)	5%

Only the impacts from transportation and packaging of clothes sent back to sellers, clothes disposed to landfill, and incineration were considered as part of this study. Landfill and incineration were modeled as per the US Environmental Protection Agency (EPA) WARM model (39) and are described in detail in section 3.9.4. All burdens associated with donating clothes to charity and for open-loop recycling were considered as part of those lifecycles and not of the ThredUP lifecycle.

3.9 Transport Modeling

Transportation between each process step was modeled based on the geographic data of each process step. All diesel input required for truck transport was taken as a geographic mix for that step as described previously in the geographic allocation subsection. The distance between countries and ports was calculated using an external web tool (40).

3.9.1 Apparel manufacturing processes

In order to achieve a representative global transportation distance, the transportation distances were calculated for each country in a production step to each of the countries in next production step. The total transport distance from a country was then weighted by the percentage contribution of the country for the current step. The weighted transported distance for each country in this step was then added to get the weighted average transportation between current production step to the next. This was done for each production stage based on Quantis International (2018) (7) distributions.

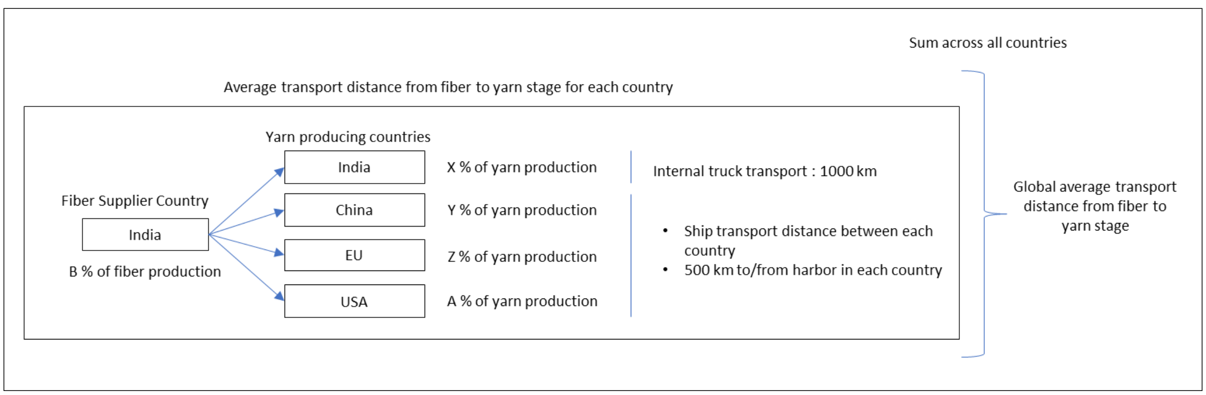

Figure 3-16: Global average distance calculation between two processes

Additional assumptions used based on the above-mentioned report:

- Internal transport within a country is assumed to be 1000 km by truck
- For transport by ship an additional truck transport of 1000 km is assumed for taking the goods from factory to the port
- For transport by air an additional truck transport of 100 km is assumed for taking the goods from factory to the airport

Table 3-10: Average distance between production steps (km) per kg of material transported

	Fiber Production	Yarn Production	Fabric Production	Dyeing & Finishing	Assembly	Distribution
Ship	NA	5,629	10,110	0	6,942	20,308
Truck	NA	1,000	1,000	1,000	1,000	1,317
Air	NA	NA	NA	NA	NA	11,657

3.9.2 Apparel distribution

The distribution of new apparels is modeled in two parts – Transport from assembly to warehouse/store to the centre of USA, and transport from warehouse/store in USA to customer's home.

The following assumptions were considered for the two distributions:

Assembly to warehouse/store transport

- A weighted average warehouse distance between the assembly countries to central US is considered
- A 92%/8% ocean-air transport distribution is taken as per Quantis International (2018) (7)

Warehouse/store to customer transport

- It was assumed 20% customers order online and 80% customers go to a store (41)
- For an online order an average environmental burden for parcel delivery as per USPS (42) was applied
- For store shopping, a car travel distance of 15 km was assumed. Only a 3rd of the car travel environmental burden was allocated to shopping as it is assumed that consumers complete multiple errands when out on a shopping trip.

3.9.3 ThredUP processes

95% of used clothing sellers opt to send clothes to ThredUP via mail. An average environmental burden for parcel delivery as per USPS was applied to this method. The remainder 5% of sellers opt to drop clothes at a ThredUP warehouse or store. A car distance of 15 km was assumed. Only a third of the car travel environmental burden was allocated to shopping as it was assumed that consumers complete multiple errands when out on a shopping trip. All used apparel bought on the ThredUP website are sent via mail to customers. An average environmental burden for parcel delivery as per USPS was applied.

3.9.4 ThredUP Disposal

There are two types of clothing disposals considered in this study. Direct disposal of unwanted clothes by consumers and disposal of rejected items by ThredUP. The majority of unwanted clothes by consumers end up in the garbage where they are either landfilled or incinerated by the municipality. A distance of 39 km by truck is assumed for the transportation to landfill/incineration site. 95% of clothes rejected by ThredUP as part of their quality control process are donated to charities or recycled. The transportation burden in this case is assigned to the following lifecycle. The remaining 5% of clothes are sent to landfill/incineration. A distance of 39 km by truck is assumed for the transportation to landfill/incineration site.

3.10 Disposal

After the customer use phase, the disposal lifecycle stage was considered for this study and the associated ecological impacts were taken into account. For clothes sent to ThredUP this burden was avoided as the majority of these clothes are either reused or donated to charity. The typical textile disposal pathways are either to recycling, incineration or landfill. The distribution for the amount of clothing going to each was taken from US EPA (2015) (43). The distribution of clothing per pathway is displayed in Table 3-11. The ecological impact of landfill and incineration was modeled as per the WARM methodology (39). Incineration energy for each fabric was taken from GaBi datasets and US EPA (39). When data was not available average textile incineration energy was used from World Bank's Municipal Solid Waste Incineration report. (44)

Table 3-11: Average textile disposal pathway in the US in 2014 as per EPA

Option	Percentage
Recycle	15%
Incineration	9%
Landfill	76%

4 Life cycle impact assessment (LCIA)

The impact categories describe potential effects of the product system on the environment. Environmental impact categories are calculated from "elementary" material and energy flows. Elementary flows describe both the origin of resources from the environment as basis for the manufacturing of the pre-products and generating energy, and emissions into the environment, which are caused by a product system.

The GaBi software used for this LCA study allows the comprehensive calculation of all elementary flows required for the components part of the system boundary and all emissions returned to the environment. The impacts upon the environment are calculated by GaBi in various environmental impact categories. This study has chosen to focus on three impact categories, namely

- CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]
- Primary energy from renewable and non-renewable resources (net cal. value) [MJ]
- Blue water consumption [kg]

More detailed information as to why these were chosen can be found in section 2.4.2.

4.1 Manufacturing (Upstream)

Table 4-1 depicts the ecological impacts for manufacturing and distribution of 1 kg of an average ThredUP clothing. Figure 4-1 provides the relative distribution of the impact by each stage of the apparel manufacturing process. The method by which this average was reached is given in detail in section 3.

Table 4-1: LCA of apparel manufacturing per kg clothing (average ThredUP fabric composition)

Indicator	Unit	Impact
Global Warming Potential (GWP)	[kg CO2e]	39.4
Primary energy Demand	[MJ]	574.3
Blue water consumption	[Litres]	1221.4

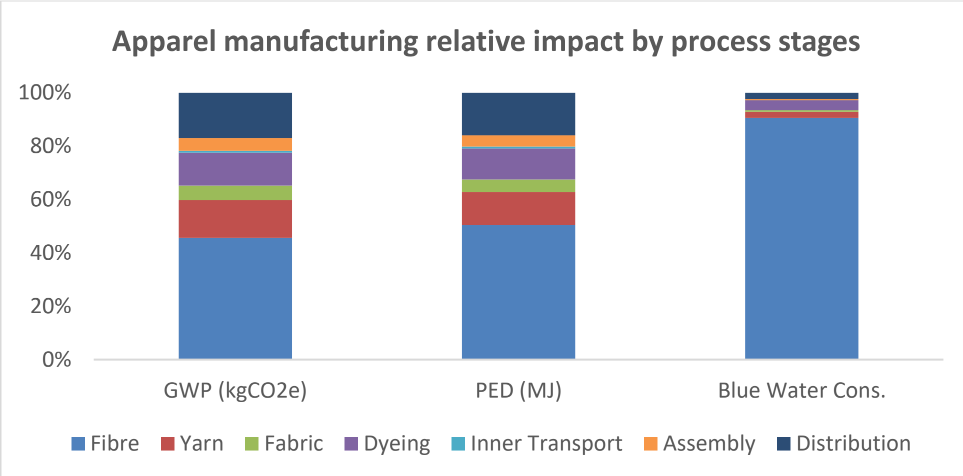

Figure 4-1: Apparel manufacturing relative impact by process stage

4.2 ThredUP Operations (Core)

Table 4-2 illustrates the overall impacts of ThredUP core operations upon the environment which consist of all processes described for the system boundary of second-hand clothing manufacturing in Figure 2-2 and 2-3. The impacts are displayed as an overall value per the processing of 1 kg of second-hand clothing, as well as the percentage of these impacts for each subprocess. The sorting and processing of reused clothing contributes to the majority of the impacts for all three impact categories which is driven primarily by the energy used in the warehouse and stores.

Table 4-2: LCA of ThredUP reuse operations per kg of clothing (annual average)

Indicator	Unit	Total	Reuse processing	Packaging	Transport	Disposal
Global Warming Potential (GWP)	[kg CO2e]	**4.9**	78%	15%	9%	-2%
Primary energy Demand (PED)	[MJ]	**49.5**	56%	40%	3%	1%
Blue water consumption	[Litres]	**12.8**	52%	43%	4%	1%

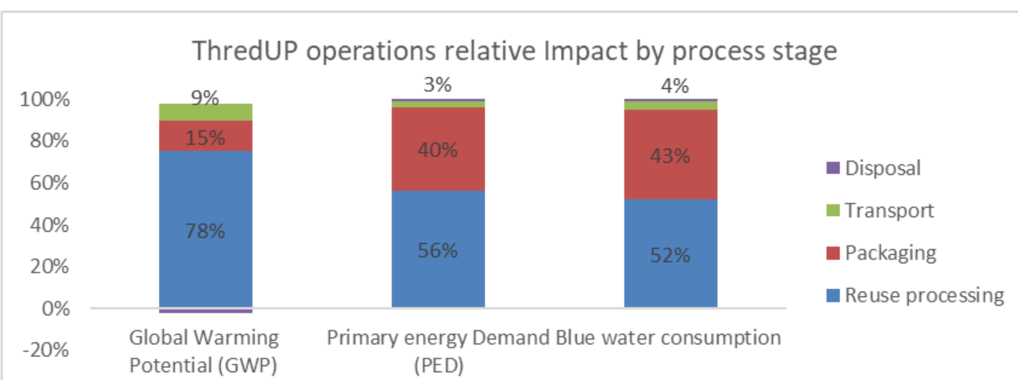

Figure 4-2: ThredUP operations relative Impact by process stage

4.3 Impact Avoidance from Apparel Reuse

ThredUP's core operations are to collect clothing which would be otherwise discarded, and to resell them for a second life to customers. When customers purchase a garment from ThredUP instead of buying a new garment, the manufacturing of that new garment is avoided, which reduces the impact to the environment. The net environmental savings by purchasing 1 kg of reused clothing or 1 item of second-hand clothing from ThredUP is given in Table 4-3.

Table 4-3: Impact avoidance from clothing reuse

Indicator	Unit	Per kg of clothing	Per item of clothing
Global Warming Potential (GWP)	[kg CO2e.]	22.8	7.9
Primary energy Demand	[MJ]	352.5	122.5
Blue water consumption	[Litres]	842.7	292.9

Table 4-4 shows ThredUP's annual savings based on the total products sold by ThredUP in 2018. This takes into consideration both product systems of fabric manufacturing and ThredUP processing operations. Due to ThredUP's services, almost 100 million kgs of CO2 eq. were avoided from being released into the environment, over 3 million liters were saved and over 1 billion MJs energy was conserved.

Table 4-4: ThredUP annual impact avoidance from sale of used items

Indicator	Unit	Impact Savings
Global Warming Potential (GWP)	[kg CO2e]	83,800,482
Primary energy Demand	[MJ]	1,297,789,342
Blue water consumption	[m3]	3,102,355

As described in section 3.7.1, ThredUP's inventory for 2018 apparels was categorized by apparel type. Table 4-5 shows the savings per category for 1 kg of clothing and per item. Green cells represent highest savings while dark red shows the least savings. As can be seen, product categories primarily made of leather, such as belts, boots, handbags, shoes and wallets have substantially higher emissions savings compared to other products due to leather's intensive manufacturing and higher losses during assembly.

Table 4-5: Impact avoidance by product category

Category	Per kg of clothing			Per item of clothing		
	Emissions (kg CO2e)	Energy (MJ)	Water (Litres)	Emissions (kg CO2e)	Energy (MJ)	Water (Litres)
Active Dress	15.2	245	367.2	8.4	61.3	91.9
Active Pants	15.8	251.4	476.1	20.9	151	286
Active Skirts	16.5	260.1	213	10.9	78.1	63.9
Active Tops	16.3	257.8	261.3	3.6	25.8	26.2
Belts	93.4	1,205.20	692.5	30.8	180.4	103.7

Blazers	16.7	289.7	516.4	25.8	202.6	361.2
Boots	96.8	1,230.30	735.3	179.3	1033.4	617.6
Coats & Jackets	18.2	287	678.4	44	315.1	744.9
Cover up	15.1	246	499.7	5.6	41.8	85
Dresses	17.6	312.3	508	9.7	78.1	127
Handbags	91.5	1,166.50	746.4	121.1	699.9	447.8
Headwear	15.3	254.7	745.6	3	22.9	67.1
Jeans	10.6	193.1	1,666.00	16.9	139.9	1207.4
Leggings	13.6	226.8	881.6	8.4	63.5	246.8
One Piece	12.7	224.2	1,067.50	22.4	179.3	853.9
Overalls	10.2	189.1	1,789.30	18.1	151.2	1431.2
Pants	13.8	237.8	895.1	18.3	142.7	537.1
Scarves & Wraps	24.9	470.4	283.4	9.3	79.8	48.1
Shoes	94.3	1,200.50	768.1	70.1	405.2	259.2
Shorts	11.2	202.3	1,547.40	4.9	40.5	309.4
Shorts - Active	16.3	260.3	164	7.2	52.1	32.8
Skirts & Skorts	17.4	306.8	703.8	9.6	76.6	175.7
Sweaters	16	266.3	777.7	14.1	106.2	310
Sweatshirts & Fleece	12.9	221.1	989.3	11.4	88.4	395.5
Swim	20.6	292.9	133.9	6.4	41.1	18.8
Tees & Tanks	11.3	200.6	1,279.10	4.5	36.1	230.2
Tights & Hosiery	19	275.9	429.2	2.5	16.5	25.6
Tops, Blouses & Shirts	17.9	325.3	589.2	6.9	56.9	103.1
Vest	16.3	264.1	437.6	9	66	109.4
Wallet	92.5	1,178.50	779	25.5	147.3	97.4
Winter Accessories	34.6	487.6	317	9.7	62.2	40.5

5 Scenarios

In the following, the influence of the two key assumptions of switching rate and replacement rate as described in section 2.4.6 with regard to system boundaries and modelling approaches on the final results are investigated by means of scenario analysis.

The baseline values in the study for switching rate is 100% and replacement rate is 70%. The following scenarios assess to what extent the results of this study will change if the baseline assumption values are lowered for both assumptions (less preferable scenarios). Lowering the replacement rate will decrease the lifespan of second-hand clothing. Lowering the switching rate means more consumers who are already buying second hand clothing today from other vendors will now buy from ThredUP instead and less consumers will be substituting the buying of new clothes with ThredUP's second hand clothing.

Table 5-1: Impact avoidance from different scenarios for replacement rate and switching rate

Green represents the baseline scenario and blue the worst-case scenario.

Replacement Rate		**70%**			**60%**			**50%**			**50%**
Substitution Rate		**100%**	**75%**	**50%**	**100%**	**75%**	**50%**	**100%**	**75%**	**50%**	**25%**
GWP	**kg CO2e**	7.9	5.5	3.1	6.5	4.5	2.4	5.2	3.5	1.7	**0.0**
PED	**MJ**	122.5	87.6	52.7	102.6	72.6	42.7	82.6	57.7	32.7	**7.8**
Blue Water	**m3**	292.9	218.6	144.3	250.4	186.8	123.1	208.0	154.9	101.9	**48.8**

Lowering the replacement rate and substitution rate has considerable change on the impact avoidance numbers for all environmental indicators. In the worst-case scenario (blue shaded column) of 50% replacement rate and 25% substitution rate the savings are almost zero. This is the condition when consumer behaviour has become highly sustainable with consumers using their first-hand clothes much longer and buying more and more reused clothing instead of new clothing. Although reuse of clothes is on the rise, there is clear evidence that shows majority of American consumers still buy new clothes every year and discard their used clothes much earlier than the clothes expected lifespan (45). Due to this, the baseline scenario is the most realistic scenario representing the consumer behavior at present.

6 Conclusion

The study put forth was compiled in order to calculate the ecological savings which ThredUP has on the environment through its operations and services as a second-hand online thrift store. The LCA was carried out using the ISO 14040 (1) and ISO 14044 (2) guidelines and has fulfilled the objectives and goal of the study.

The key findings of this study can be summarized as follows

- Second-hand clothing has a substantial ecological savings over new clothing across all three environmental impact categories considered in the study
- Judging from the results of ThredUP's annual savings, it can be said that ThredUP has a substantial positive impact on the environment.
- Decisions as well as the choice of modelling approaches and assumptions can influence the results significantly (specifically the assumptions of 70% replacement rate and 1:1 forgoing of new clothing in favor of second-hand clothing).

ThredUP's position as the largest second-hand online thrift store could have a two-fold benefit. Firstly, it's continuous operations would reduce the manufacturing need for new apparel creation, and secondly, due to its large market share could influence consumer behaviour towards increased environmental awareness and preservation.

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8 Appendix

8.1 Data for ThredUP operations modeling

Table 8-1: ThredUP Primary data for modeling

Total items sold (after exclusions)	10,592,084
Avg weight per item (kg)	0.348
Total weight (kg)	3,681,317
Avg. items per kg	2.877
Replacement Rate (%)	70%
Rate of switching to reuse (%)	100%
ThredUP reject rate (%)	61%
Average items per cleanout bag	26.7
Cleanout bag return rate (%)	7%

Table 8-2: ThredUP cleanout kit delivery logistics assumption

Item	Delivery Service	Impact
Cleanout kit shipping from ThredUP to sellers	USPS First class mail service	USPS first class mail delivery average impact
Cleanout bag shipping from sellers to ThreadUP	USPS Parcel service	USPS parcel delivery average impact
Cleanout bag personal delivery to ThredUP store	Personal Car	No impact as combined with another primary errand

Table 8-3: ThredUP warehouse and store annual energy consumption

Warehouse and Store Location	Code Name	Egrid Subregion	Electricity use (kWh)	Natural Gas (CCF)
Vernon Hills, IL	DC01	RFC	447,811	-
Mechanicsburg, PA	DC02	RFC	1,652,985	33,069
Phoenix, AZ	DC03	WECC	941,573	47,422
Duluth, GA	DC04	MRO	1,177,920	24,288
Burlingame Ave - Burlingame, CA	ST01	WECC	16,800	-
University Ave - Los Gatos, CA	ST02	WECC	32,400	-
Stoneridge Mall - Pleasanton CA	ST03	WECC	3,000	-
Main Street - Walnut Creek, CA	ST04	WECC	14,400	-

Table 8-4: USPS major mail product CO2 emissions and energy use

Mail Product	**GHG emissions** (42) **(kgCO2e/piece)**	**Energy use** (42) **(MJ/piece)**
First-Class Mail	0.0871	1.647
Standard Mail	0.1624	3.431
Periodicals	0.7445	14.435
Package Services	1.2107	20.207

8.2 Data for apparel manufacturing and distribution modeling

Table 8-5: Percentage composition of ThredUP Inventory by Fabric

S. No.	Fabric	% inventory share by weight
1	Cotton	36.7%
2	Polyester	25.9%
3	Leather	9.0%
4	Rayon	8.5%
5	Nylon 6	3.6%
6	Wool	3.4%
7	Viscose	2.8%
8	Acrylic	2.4%
9	Polyurethane (Spandex)	2.3%
10	Silk	1.8%
11	Linen	1.2%
12	Modal	0.8%
13	Lyocell	0.3%
14	Merino Wool	0.3%
15	Tencel	0.2%
16	Nylon 6.6	0.2%
17	Pima Cotton	0.2%
18	Ramie	0.1%
19	Organic Cotton	0.1%
20	Recycled Polyester	0.1%
21	Ultra-Fine Merino Wool	0.1%
22	PVC	0.1%
23	Canvas	0.027%
24	Recycled Wool	0.016%
25	Bamboo	0.015%
26	Polypropylene	0.011%
27	Hemp	0.007%

28	Recycled Cotton	0.002%

Table 8-6: Average electricity, steam and losses during assembly by fabric type, per kg

Fabric	Electricity (MJ)	Steam (MJ)	Losses (%)
Cotton	3.69	6.15	13.68
Polyester	5.40	9.85	14.57
Leather	0	0	23.75
Rayon	5.03	6.47	14.19
Nylon	4.26	7.45	15.04
Wool	5.44	16.84	13.63
Viscose	4.80	6.98	14.01
Acrylic	3.34	9.43	11.07
Polyurethane (Spandex)	5.95	20.46	15.06
Silk	5.67	6.98	14.09
Linen	4.73	9.71	13.82
Modal	4.95	5.09	13.93
Lyocell	4.46	6.99	14.52
Merino Wool	2.69	7.91	10.6
Tencel	4.81	8.17	14.39
Nylon 6 and Nylon 6.6	4.00	6.86	15.7
Pima Cotton	3.75	3.63	12.95
Ramie	3.02	7.23	12.11
Organic Cotton	4.11	5.85	13.98
Recycled Polyester	3.84	5.43	14.14
Merino Ultra-Fine Wool	2.54	7.37	10.6
PVC	6.48	24.63	15.63
Canvas	6.34	7.92	18.00
Recycled Wool	6.49	23.46	15.23
Bamboo	4.54	4.31	13.76
Polypropylene	5.73	17.97	14.58
Hemp	4.13	6.52	14.06
Recycled Cotton	3.59	5.57	12.77

Table 8-7: Losses at each stage of apparel manufacturing by type of fiber

	Natural	Cellulosic	Synthetic
Degumming - Hemp	30%	-	-
Degumming Silk	25%	-	-
Yarn	12%	9%	9%
Fabric - Knitted	2%	2%	2%
Fabric - Woven	3%	9%	9%
Dyeing (except silk, wool)	3%	3%	3%
Dyeing (silk, wool)	4%	-	-

Table 8-8: Ocean shipping distance between countries *(40)*

	Bangladesh	Brazil	China	EU	India	Indonesia	Pakistan	Russia	Turkey	USA	Vietnam
Bangladesh	0	16,635	9,347	12,870	3,760	4,858	4,593	13,126	10,050	17,135	4,554
Brazil	16,635	0	19,149	8,394	15,519	17,265	15,070	14,598	11,523	13,791	18,025
China	9,347	19,149	0	19,961	10,899	6,342	11,733	20,217	16,372	12,937	4,903
EU	12,870	8,394	19,961	0	9,935	15,456	9,614	7,157	4,527	13,374	15,168
India	3,760	15,519	10,899	9,935	0	6,410	907	10,190	7,115	18,686	6,105
Indonesia	4,858	17,265	6,342	15,456	6,410	0	7,244	15,711	12,636	13,497	2,429
Pakistan	4,593	15,070	11,733	9,614	907	7,244	0	9,869	6,794	19,520	6,939
Russia	13,126	14,598	20,217	7,157	10,190	15,711	9,869	0	3,077	19,991	15,423
Turkey	10,050	11,523	16,372	4,527	7,115	12,636	6,794	3,077	0	16,915	12,348
USA	17,135	13,791	12,937	13,374	18,686	13,497	19,520	19,991	16,915	0	12,747
Vietnam	4,554	18,025	4,903	15,168	6,105	2,429	6,939	15,423	12,348	12,747	0

8.3 Data for end of life modeling

Table 8-9: End of Life - Incineration energy and GHG emissions by textile type *(4), (46), (39)*

	Incineration Energy (MJ/kg)	N2O emissions (kg/kg)	CO2 emissions (kgCO2E/kg)
Acrylic	29.12	-	2.57
Bamboo	15	0.04	-
Canvas	15.5	0.04	-
Cotton	15.5	0.04	-
Hemp	16.5	0.04	-
Leather	14.2	0.04	-
Linen	15.5	0.04	-

Lyocell	15	0.04	-
Merino Ultra-Fine Wool	11.78	0.04	-
Merino Wool	11.78	0.04	-
Modal	15	0.04	-
Nylon 6	32	-	2.57
Organic Cotton	15.5	0.04	-
Pima Cotton	15.5	0.04	-
Nylon 6.6	32	-	2.57
Polyester		-	2.04
Polypropylene		-	2.79
Polyurethane (Spandex)		-	2.33
PVC	16.5	-	1.25
Ramie	15	0.04	-
Recycled Cotton	11.78	0.04	-
Recycled Wool		0.04	-
Recycled Polyester	11.78		2.25
Silk	27	0.04	-
Tencel	15	0.04	-
Viscose	15	0.04	-
Rayon	15	0.04	-
Wool	11.78	0.04	-

Table 8-10: End of Life - Landfill gas emissions and carbon sequestration by textile *(39)*

	Carbon Sequestration (MTCO2E/Short Ton)	Landfill gas (kgCO2E/kg)
Acrylic	0.00	-
Bamboo	0.14	0.3
Canvas	0.14	0.3
Cotton	0.14	0.3
Hemp	0.14	0.3
Leather	0.14	0.3
Linen	0.14	0.3
Lyocell	0.14	0.3
Merino Extra Fine Wool	0.14	0.3
Merino Wool	0.14	0.3
Modal	0.14	0.3
Nylon	-	
Organic Cotton	0.14	0.3
Pima Cotton	0.14	0.3
Polyamide	0	-

Polyester	0	-
Polypropylene	0	-
Spandex	0	-
PVC	0	-
Ramie	0.14	0.3
Rayon	0.14	0.3
Recycled Cotton	0.14	0.3
Recycled Wool	0.14	0.3
Recycled Polyester	0	-
Silk	0.14	0.3
Tencel	0.14	0.3
Viscose	0.14	0.3
Wool	0.14	0.3

8.4 Secondary Datasets

8.4.1 Packaging Datasets

Ecoinvent 3.4

- CA-QC: paper production, woodcontaining, supercalendered, <u-so>
- CH: offset printing, per kg printed paper, <u-so>
- GLO: Plastic Film (PE, PP, PVC), <u-so>
- RER: polyethylene production, low density, granulate

8.4.2 Transport Datasets

GaBi:

- GLO: Truck, Euro 3, up to 7,5t gross weight / 3,3t payload capacity
- GLO: Truck, Euro 5, 12-14t gross weight / 9,3t payload capacity
- Car petrol, Euro 4, engine size 1,4-2l

Ecoinvent 3.4

- GLO: market for transport, freight, aircraft
- RoW: transport, freight, lorry 16-32 metric ton, EURO4
- GLO: transport, freight, sea, transoceanic ship

8.4.3 Electricity Datasets:

Ecoinvent 3.4

- IN: market for electricity, low voltage
- US: market for electricity, low voltage

- US: market group for electricity, high voltage
- WECC, US only: market for electricity, low voltage
- RFC, US only: market for electricity, low voltage
- MRO, US only: market for electricity, low voltage
- BD: market for electricity, low voltage
- BR: market for electricity, low voltage
- CN: market group for electricity, low voltage
- Europe without Switzerland: market group for electricity, low voltage
- TR: market for electricity, low voltage ecoinvent
- RU: market for electricity, low voltage
- RoW: market for electricity, low voltage
- PK: market for electricity, low voltage
- ID: market for electricity, low voltage

8.4.4 Steam Datasets:

GaBi:

- IN: Process steam from hard coal 85%
- EU-28: Process steam from natural gas 85%
- US: Process steam from natural gas 85%
- BR: Process steam from natural gas 85%

8.4.5 Thermal Energy datasets:

GaBi

- IN: Thermal energy from hard coal
- EU-28: Thermal energy from natural gas
- BR: Thermal energy from natural gas
- US: Thermal energy from natural gas

8.4.6 Light fuel oil datasets:

GaBi

- IN: Thermal energy from light fuel oil (LFO)
- BR: Thermal energy from light fuel oil (LFO)
- US: Thermal energy from light fuel oil (LFO)
- EU-28: Thermal energy from light fuel oil (LFO)

8.4.7 Diesel datasets

GaBi

- IN: Diesel mix at refinery
- CN: Diesel mix at filling station

- US: Diesel mix at filling station
- EU-28: Diesel mix at filling station
- BR: Diesel mix at filling station

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- GLO: diesel, burned in agricultural machinery

About Green Story

Green Story's mission is to help companies communicate their environmental and social impact to stakeholders in a clear, credible, and relatable manner. We work with a range of companies from waste management firms to one of North America's largest eco-fashion manufacturers to engage stakeholders and measure and communicate impact.

The Green Story team is led by Akhil Sivanandan and Navodit Babel. Green Story is a Ministry of Environment Agent of Change, Social Capital Markets scholarship recipient, a member of the MaRS Centre for Impact Investing and of Ryerson University's Social Venture Zone.

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