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Life Cycle Inventory of Indian Textile Sector

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Abstract

Fast fashion, technological development, and the expanding economy fuelled the stunning growth of the global textile industry. Parallel to the sector's increasing consumption of energy, water, and land, it saw an alarming rise in associated environmental impacts, including contribution to global warming and toxicity on humans and ecosystems. Conducting life cycle assessments (LCAs) for identifying the hotspots in the textile value chain responsible for these impacts became critical for informed decisions toward making the sector sustainable. Such LCAs require geographically, temporally, and technologically representative life cycle inventory (LCI) data. This study aims to create a consistent national life cycle inventory for the Indian textile sector. This work covered the textile value chain from raw material production, including agriculture and fiber processing, to yarn production, fabric production, and final finishing. The data, broadly classified into agricultural and industrial data, was collected for 2014-2017 with primary data being gathered through site visits and interviews with farmers, scientists, and manufacturers. The LCI data generated for approx. 52 was critically reviewed according to eco-invent data quality guidelines and submitted to the ecoinvent database. The creation of reliable, consistent, and transparent LCIs will be helpful for a wide range of stakeholders, including researchers as well as designers, manufacturers, and consumers; in addressing many sustainability aspects of the textile life cycle by providing a basis for informed decisions in raw material selection, production technology, and purchase. We conclude that the process-level, high-accuracy inventory data for the Indian textile sector will enable India-specific LCA studies of any product and process linked to the textile sector.

Key words: Textile; Life Cycle Inventory; Life Cycle Assessment; fast fashion; sustainability

1 Introduction

The fashion industry is among the largest and oldest industrial sectors globally (Mukherjee, 2015). According to the World Trade Organisation (WTO), developing economies and Least Developed Countries (LDCs) contribute almost 70% of the global exports of textiles and clothing (Yi, 2014). UNIDO (1992) predicted that, by 2150, total textile consumption will probably double, even by following the relatively conservative (1990's) estimates of 8 kg/person per year (Hasanbeigi, 2010). The global textile and apparel trade may reach US$ 1,600 billion in 2025 with a CAGR of 6.3% over the next decade (ITJ, 2021). The growing levels of disposable income, rapid urbanization, and rising population are driving the growth (Data Bridge, 2020).

The domestic textiles and apparel industry was worth $150.5 billion in 2019-20, and India exported $ 41 billion worth of textile in 2021, with a CAGR of 2.7%, a bit higher than the global average. CAGR is expected to reach 12-13% and to surpass $ 30 billion by 2027 (Tyagi, 2022). The textiles and apparel sector contributes 2% of India's GDP, 7% of industrial output in terms of value, and 12% of export earnings (Ministry of Textiles, 2020). The Indian textile industry has a strong holding across the entire value chain, from natural to man-made fiber and from apparel to home furnishings. The Indian textile industry is broadly divided into two groups – the unorganized and organized. The unorganized fraction comprises of handloom, handicrafts, and sericulture, which operate on a small scale through traditional methods and tools. The organized sector apply modern machinery and techniques and it consists of spinning, apparel and garments segment (Indusconsult, 2021). The decentralized power looms/ hosiery and knitting sector form the largest component of the textiles sector (PMKVY, 2022). While yarn is mostly produced in the mills, fabrics are produced in the power loom and handloom sectors as well. Unlike other major textile-producing countries, India's textile industry is comprised mostly of small-scale, non-integrated spinning, weaving, finishing, and apparel-making enterprises (Landes et al., 2005). According to a report of Confederation of Indian Textile industries (2013), Indian textile industry remained predominantly cotton-based, accounting for more than 65% of the raw material consumed, followed by jute, and a wide range of other fibres, such as silk, wool, synthetic/manmade cellulosic fibres such as polyester, viscose, nylon and acrylic, etc. The annual output of cotton fabric was about 12.8 billion meters (Anand, 2014). India also enjoys a unique global position in producing all commercially valuable varieties of silk, being the second largest producer of silk and accounting for nearly 18% of global raw silk production (IBEF, 2022).

The technological development in the industry has led to the environmental transformation, causing a change in the nature of the environmental impacts of industrial activities (Azapagic, 1999). A close look at the textile value chain, from spinning to finishing, reveals the use of large amounts of water, energy and chemicals generating non-biodegradable wastes besides causing chemical pollution causing allergies, affecting fertility and might even exerting carcinogenic and neurological effects (Gardetti & Torres, 2013). In short, growth in textile production and consumption with increasing population and economic growth will exacerbate use of energy, water and emission of carbon dioxide (CO_2) and other environmentally harmful contaminants (Hasanbeigi et al., 2013) while contributing to child labour and unfair trading conditions. Hence, besides yielding range of economic benefits, clothing has negative environmental and social externalities (Sharda & V.K., 2012).

Life-Cycle Assessment (LCA) is used to identify and evaluate the environmental footprint of products and services from the "cradle to the grave" - from the extraction of resource inputs to the eventual disposal of the product or its waste. ISO 14040 standards give guidelines on the principles and conduct of LCA studies that provide an organization with information on how to reduce the overall environmental impact of its products and services (ISO - Central Secretariat, 2009). The LCA process is a systematic, phased approach consisting of four stages: goal definition and scoping, inventory analysis, impact assessment, and interpretation. Life cycle inventories (LCI) include the summation of inputs and emissions, but do not imply impacts (Helling & Russell, 2009). Industrialized countries have made significant efforts in compiling and updating inventories for product and process life-cycle analysis by developing LCA tools like SimaPro (Netherland), GaBi (Germany) and LCI databases like ecoinvent (Switzerland), Gemis, US Input-Output, etc. However, developing countries due to ineffective environmental regulation and monitoring, lack the foundation of LCI (Steinberger et al., 2008). There are no open or proprietary LCI database for conducting country specific LCAs. The uncertainties, temporal and spatial variations pose different challenges during the LCA based sustainability assessment (Velden et al., 2014). It was therefore concluded that original LCI data pertaining to textiles production in India is urgently needed to enable sound and informed choices. A process level inventory can help in identifying the hotspots in the value chain. The overall purpose of this work was to provide representative LCI data for textile sector in India. The processes were chosen to ensure inclusion of all the important steps from production of the fiber until the formation of the fabric. The inventory data created in this work can be used as a reference by various stakeholders including textile and clothing researchers, manufacturers, designers, environmental organizations, consumers and consumer organizations, to make informed choices towards reduction of their products' environmental footprint.

2 DATA AND METHODOLOGY

2.1 Overview of the supply chain structure

The textile manufacturing processes has four broad stages: Fibre production, Yarn production, Fabric production and Dyeing (elaborated in section 3). The LCIs were created to cover various processes and sub processes under these stages of textile production. Fig. 1 presents an overview of the textile supply chain in Ecoinvent. The dotted line represents the system boundaries considered in the Ecoinvent database, purple boxes are service activities and blue ones are normal transformation activities

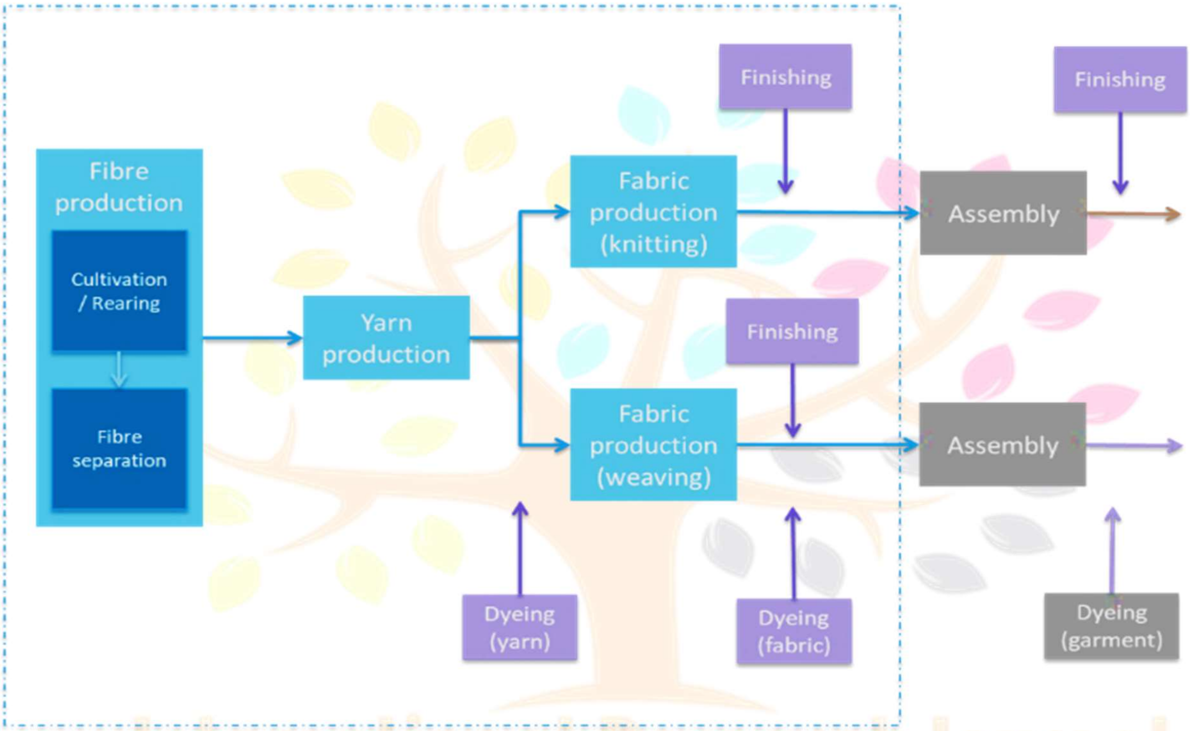

Fig. 1: Overview of the textile supply chain in Ecoinvent (Emmenegger et al., 2018)

2.1 Supply chain structure per fibres

It is important to look at the life cycle impacts of each of the stages to assess the impacts of the entire supply chain. Therefore, the supply chain of each fibre was modelled. The inventory is prepared for 1 kg of the reference product, manufactured in India as of 2017.

a) Bast fibre supply chain: The bast fibre supply chain in India comprises of the following components: cultivation, retting and dressing, spinning, and weaving. Fig. 2. illustrates Bast fibre supply chain.

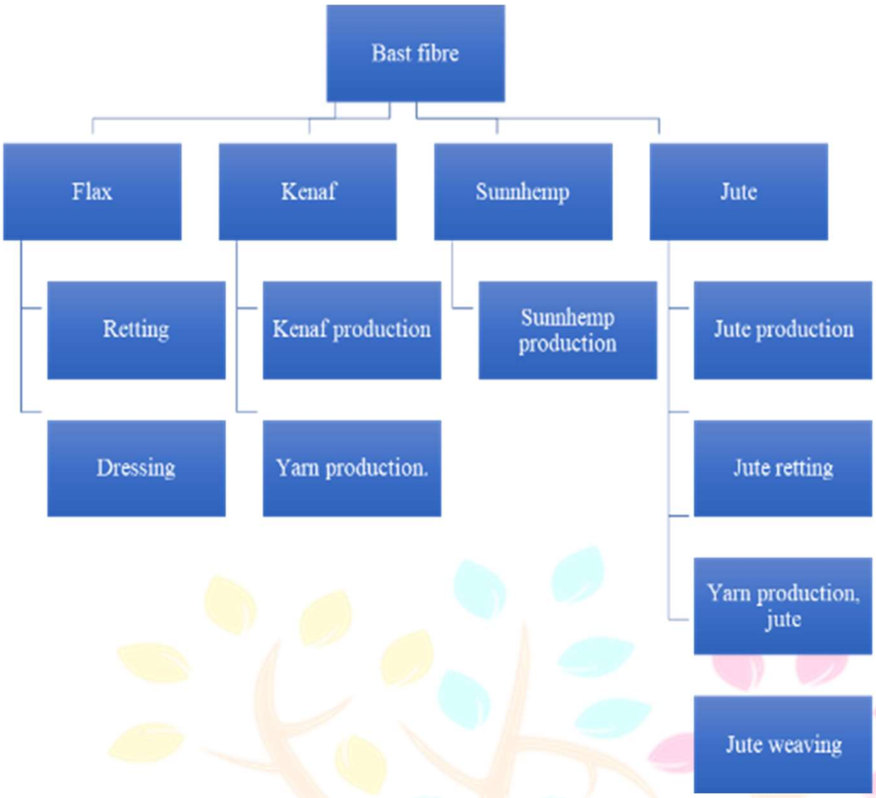

Fig. 2: Bast fibre supply chain

b) Cotton supply chain: The cotton supply chain in India comprises of the following stages: cotton cultivation, spinning, yarn dyeing (bleaching and coloring of the cotton yarn), knitting or weaving, and fabric dyeing. Batch dyeing, bleaching of fabric and yarn dyeing are created as service activities. For yarn and fabric dyeing, bleaching is done prior to dyeing process and the data for both these processes includes bleaching as part of dyeing process.

c) Silk supply chain: The silk supply chain in India has the following phases: mulberry cultivation for leaf production, silkworm rearing, reeling, throwing and weaving. Silk reeling/throwing involves processing of cocoons into raw silk and includes oven drying, cooking, reeling and winding. Reeled silk is then converted to yarn by doubling and winding in a separate process. After this, the yarn undergoes weaving, where weaver interlaces the threads of weft and warp.

d) Nonwoven textile supply chain: The non-woven supply chain consists of the following stages: crude oil production, polymer and granules production, and textile production through spun bonding or needle punching technology. These inventory datasets have been created for textile production only.

2.3 Data collection method

Data collection started off with primary data collection through field visits and interviews. Information was collected from farmers, production sites, government research centers and private manufacturers. Customized questionnaires and templates were used to collect agricultural and industrial process data. The primary data from surveys and secondary data from literature were compared to validate and obtain data of the highest quality. The data for inputs of field activities was then used to calculate field emissions by using the ecoinvent LCI calculation tool for crop production. Data gaps were resolved by expert estimations and from literature surveys. The collected data were then prepared for internal review and validated by Quantis and ecoinvent. After several iterations, inventories were finalized and prepared in Ecospold format using EcoEditor.

3 RESULTS

Despite the many challenges faced during the data collection, this work successfully generated life cycle inventories of 52 textile processes based mostly on primary data. This work covered multiple processes and sub processes related to textile production. The collected and processed data represents resource consumption and environmental impacts of agricultural technologies used for textile fibre production in India and industrial processes for converting raw material into usable textiles as well as some finishing processes. Following section presents an overview of the Life Cycle Inventories:

3.1 Datasets for bast fibres

Names of the bast fibre datasets in India (2017) are as presented in Table 1.

Table 1: Names of the bast fibre datasets in India 2017

Activity name	product name
flax production, irrigated, IN	flax plant, harvested
flax retting, IN	flax fibre
sunnhemp production, irrigated, IN	sunnhemp plant, harvested
kenaf production, irrigated, IN	kenaf plant, harvested
yarn production, kenaf, IN	yarn, kenaf
jute production, irrigated, IN	jute plant, harvested
jute retting, IN	jute fibre
yarn production, jute, IN	yarn, jute
weaving, jute, IN	textile, jute

Source: Sunnhemp Research Station (CRIJAF) Pratapgarh, Uttar Pradesh; National Institute of Research on Jute & Allied Fibre Technology, West Bengal; Composite spinning and weaving mill, Bellur, West Bengal & supplemented with secondary data

a) The dataset *flax production, irrigated, IN* covers the field activity to produce 1 kg of Flax plant in India in 2016-17 through flax cultivation. The transformation of flax from the flax plant (green matter) – the flax retting and dressing process - is covered in a separate dataset. The farming dataset covers soil preparation (fall tillage), inputs of seeds, application of mineral and organic fertilizers, spraying pesticides, irrigation water and ends with the harvesting of flax plant. Usually, Flax crops are grown in both rain-fed and irrigated conditions, but two irrigations at 35 days and 65 days assure higher production and better-quality fibre. The Flax fibre crop matures in around 120-125 days. When 2/3rd of the plants portion turns yellow, and 2/3rd leaves of plants are fallen, plants are harvested and tied in small bundles of 15-20 cm diameter for retting.

b) The dataset *flax retting, IN* includes immersion of the plant bundles of flax, in freshwater tanks in the cultivation field. Plant material to water ratio in the case of a stagnant water body is 1:22. Flax fibre loosen up after 3 days and fibre is extracted from the stalk. In India, since the retting activity is usually accomplished either on the flax growing field or in canals or ponds during the rainy season, the wastewater from the flax retting process gets either diluted by rainwater or washed away. This has minimal environmental impacts and hence, not considered in the inventory.

c) The inventory dataset for_*sunnhemp production, irrigated, IN* covers the field activity to produce 1 kg of Sunnhemp plant (green mater) in India in 2016-17 through Sunnhemp cultivation. The farming dataset covers soil preparation (fall tillage), inputs of seeds, application of mineral and organic fertilizers, spraying pesticides, irrigation and ends with the harvesting of Sunnhemp plants. Sunnhemp is a rotational leguminous crop having potential to meet its requirement of nitrogen and rejuvenate the soil. Usually, Sunnhemp crop can be grown in both rain-fed and irrigated conditions with letter yielding higher production. The Sunnhemp fibre crop matures in around 90 days. Harvesting is done manually at pod formation stage, plants are sorted for equal sizes and tied in bundles of 20-25 cm diameter and left in the field for 2-3 days till they shed leaves or manually removing leaves and plants are sent for retting immediately.

d) The inventory *kenaf production, irrigated, IN* covers field activity for production of 1 kg of kenaf plant. Kenaf (commonly known as Mesta) is an annual or biennial herbaceous plant. The fibres in kenaf are found in the bast (bark) and core (wood). Unlike jute, kenaf requires less care in its cultivation and takes a longer time to mature. The plant is harvested for retting when in full flower stage.

e) The dataset, *yarn production, Kenaf, IN*, refers to the production of 1kg yarn from kenaf fibre. The inventory includes softening, carding, drawing, and spinning of kenaf fibre. The processing chain starts with a softener machine, which softens and splits up raw Kenaf fibres at the initial stage. Then the extraneous matter is removed from the kenaf fibre by the carding machine. Drawing machines blend and equalize sliver of the fibre in three stages, which is then elongated and twisted into yarn. The yarn is wrapped in spools and cops to prepare warp and weft yarns for beaming and weaving operations, respectively. The main inputs are kenaf fibre, castor oil (in the dataset castor oil is approximated with refined vegetable oil), water and energy.

f) The inventory for *jute production, irrigated, IN* covers the field activity to produce 1 kg of Jute plant (green matter) in India in 2016-17, through jute cultivation. The farming dataset covers soil preparation (ridge tillage), inputs of seeds, application of mineral and fertilizers, spraying pesticides, irrigation water and ends with the harvesting of jute plant. Jute is generally sown in February on lowlands and in March-May on uplands. The crop is harvested in about 110 days, but different varieties take different time to mature. Jute cultivation does not involve heavy doses of pesticides, however manuring with farmyard manure and fertilizers is recommended for better yield. Usually, Jute crop can be grown both in rain-fed and irrigated conditions, but irrigation may yield higher production.

g) *Jute retting, IN*, dataset represents production of 1 kg jute fibre from jute plant (fresh green matter). Normally, jute-retting activity involves immersion of the bundles of jute into stagnant water in the jute cultivation field, tanks, ponds, ditches etc., or in slowly flowing clear water in canals, rivulets, rivers etc. The minimum ratio of plant material to water in the case of a stagnant water body is 1:11. After several days for retting the loosened fibre is extracted from the jute stalk, which becomes the by-product of jute retting activity. The wastewater from the jute retting process gets either diluted by rainwater or washed away and the environmental impacts of this wastewater are minimal and hence, it is not considered in this inventory. The activity ends with the extraction of the jute fibres from the retted and dried plants. The fibres are extracted manually by hand with little or no mechanization and then dried in sun.

h) The Dataset-_*yarn production, jute, IN* represents the production of 1 kg of Jute yarn from Jute fibre. The inventory includes batching, softening, damping, carding, drawing, and spinning of jute fibre. The softener machine softens and splits up raw jute at the initial stage. Water and castor oil (approximated with refined oil) is added as emulsion. Then the extraneous matter is removed from the jute fibre by the carding machine. Drawing machines blend and equalize slivers of the fibre. Spinning machines are then used to elongate slivers and fibres and twist them into yarn. After these the winding machine wraps the yarn on spools and cops to prepare them for warping and weaving respectively. The main inputs are jute fibre, castor oil, water and energy.

i) The *weaving Jute, IN* dataset represents the production of 1 kg woven textile from jute yarn in India. The process involves winding, beaming, weaving, damping, calendaring, and lapping. The process starts with beaming where the wrap yarns are coated with sizing-starch paste. Weaving involves interlacement of two sets of threads, called "wrap" and "weft" yarns, to produce the fabric of desired quality, followed by damping (done manually) to provide desired moisture. The damped fabric undergoes calendaring, where it passes through pairs of heavy rollers, which flattens the fabric and improves its quality and appearance. The last step is lapping, in which Hessian fabrics are folded into the required size used in "Bale press" operation. The main inputs are jute yarn, TKP (Tamarind Kernel Powder) sizing solution (equated with maize starch), sodium carbonate, salicylic acid, water, and energy.

3.2 Datasets for cotton

Names of the cotton datasets in India, 2017 are presented in Table 2.

Table 2: Names of the cotton datasets in India, 2017

activity name	product name
seed cotton production, conventional, IN	seed-cotton
seed cotton production, organic, IN	seed-cotton
yarn production, open end spinning, cotton, IN	yarn, cotton
yarn production, ring spinning, cotton, IN	yarn, cotton

activity name	product name
bleaching and dyeing, yarn, IN	dyeing, yarn
textile production, knit cotton, circular knitting IN	textile, knit cotton
weaving, cotton, IN	textile, woven cotton
batch dyeing, fabric, IN	batch dyeing, fabric
bleaching, fabric, IN	Bleaching, fabric
finishing, fabric, IN	finishing, fabric

Source: Spinning – Rudrapur, Uttarakhand; bleaching – Haryana; knitting & weaving - Gurgaon, Haryana; bleaching - Dying & processing units – Sonepat, Haryana

a) The inventory dataset *seed cotton production, conventional IN* exclusively covers the field activity to produce 1kg seed-cotton in India in 2016-17. The production of seed cotton involved inputs of land tillage (ridge tillage), irrigation, seeds, mineral fertilizers (urea, superphosphate), pesticides (in case of conventional cotton) and compost (in case of organic cotton). Cotton requires 6 to 8 months to mature. Its time of sowing and harvesting differs depending upon the climatic conditions. Cotton requires routine fertilization and manuring. The seed cotton activity culminates in manual harvesting or picking of seed cotton and spans over a period of about three months. Cotton plants demand water during the active growth phase and dry weather at maturity. In this dataset, the amount of irrigation needed is included and the irrigation process is covered in a different dataset. The harvested seed cotton, then goes to the ginning process (not part of this dataset) where cotton fibre (lint) and cottonseeds get separated.

b) The *yarn production-ring spinning, cotton, IN* dataset represents the process of spinning of 1 kg of greige yarn, from ginned cotton fibre, by ring spinning process. The activity represents dataset for an average of ring spinning process. Yarn production activity includes opening, mixing, carding, drawing, combing, roving, spinning, and winding. The process also produces waste and by-products such as fibre noil coproduct, fibre waste, dropping, micro dust, hard waste etc., all of these are approximated by waste yarn and waste textile in the dataset. Hence, these are not included as input in the inventory. Therefore, there are only cotton fibre, lubricating oil and energy as the input to the yarn production process.

c) The *yarn production, open end spinning, cotton, IN* inventory represents the process of spinning of 1 kg of greige yarn by open end technology from cotton fibre. The activity represents an average open-end spinning process. Yarn production activity includes opening, mixing, carding, drawing, spinning, and winding. The process also produces wastes and by-products such as fibre noil co-product, fibre waste dropping, micro dust, hard waste etc., all those are approximated by waste yarn and waste textile in the dataset. Therefore, there are only raw cotton fibre, lubricating oil, water, and energy as the input to the yarn production process. The energy data is calculated based on electricity bills and supplemented with available secondary data from literature.

d) The *bleaching and dyeing, yarn, IN* inventory refers to dyeing of 1 kg cotton yarn (medium shade). The yarn dyeing process covers bleaching, hot wash with chemicals after bleaching, neutralization after dyeing, washing, and finishing. Electricity, cotton yarn, dye chemicals, acetic acid, caustic lye, soda ash, and other chemicals are considered as inputs to the activity. Electricity data is calculated using the power specifications of respective motors and machines after multiplying it with number of hours of machine operation.

e) The *textile production, knit cotton, circular knitting, IN* dataset represents the production of 1 kg knit cotton textile by circular knitting technique. The process converts greige/dyed yarn into cloth by knitting which creates stretchable and comfortable fabric. Knitting by machine is done in two different ways: warp and weft. This inventory covers data for circular knitting, which is a form of knitting that creates a seamless tube. This form of knitting is used to create T-shirt Jersey fabric and socks. The main inputs for circular knitting are yarn, electricity, lubricating oil for machinery, diesel used for power backup. The activity also produces yarn dust as waste, which is approximated with waste yarn and waste textile in the dataset.

f) The *weaving cotton, air jet loom, IN* inventory refers to 1 kg of woven cotton textile. The dataset covers warp beaming, sizing, knotting, and drawing, weaving and inspection of woven textile. Weaving is a process of interlacement of two sets of threads, called "warp" and "weft" yarns, to produce the fabric of desired quality. The process starts with warping, where yarns are laid on warp beam, in preparation of weaving. These yarns are sized with maize starch. The weaving is done on Air jet looms. The main inputs for the weaving process are cotton yarn, electricity, lubricating oil for machinery, water, and sizing solution (maize starch, binder, and softener).

g) The *bleaching, fabric, IN* dataset represents the process of bleaching of 1 kg of cotton textile. The process involves immersing fabric in bleach bath and the bath circulates around the fabric. The bath is heated by electricity-generated steam. This is followed by water extraction, drying, and compacting. The fabric is then folded and sent for further processing such as mercerizing, dyeing/printing etc. This activity is modeled as service, so no input of textile is considered. Electricity and chemicals: hydrogen peroxide, sodium hydroxide and other unspecified chemicals (optical whitener, caustic lye, anti-creasing agent, wetting agent). The unspecified chemicals are approximated with chemicals, inorganic in the dataset.

h) The *batch dyeing, fabric, IN* inventory refers to the dyeing of 1 kg fabric. Batch Dyeing Process is the most popular method where textile substrates can be easily dyed at any stage- fiber, yarn, fabric, or garment. The dyeing follows the sequence: bleaching, neutralization, dyeing, neutralization, soaping, hot wash, hydro extraction, drying, conditioning, and utilities. This activity is modeled as a service, so no inputs of fabric are considered. Electricity consumption and chemicals used (wetting and sequencing agent, acetic acid and hydrogen peroxide, sodium hydroxide, dye chemicals, water, greige fabric and electricity) are considered as inputs. The process involves immersing fabric in dye bath and the bath circulates around the fabric. The bath is heated by pet coke generated steam. This is followed by water extraction, drying and conditioning.

i) The *finishing, fabric, IN* inventory dataset refers to finishing of 1 kg cotton fabric through mercerization technique. The material is immersed under tension in a cold sodium hydroxide (caustic soda) solution in warp or skein form or in the piece and is later neutralized in acid. The process causes a permanent swelling of the fiber and thus increases its luster and dye affinity. This activity is modeled as a service, so no inputs of fabric are considered. Inputs considered are electricity, chemicals, sodium hydroxide, dye chemicals, water, and steam (approximated with electricity). Wastewater is generated as output.

3.3 Datasets for Silk

a) The *mulberry production, IN* inventory dataset exclusively covers the field activity to produce 1 kg mulberry leaves in India in 2016-17. The production of mulberry leaves involves inputs of land tillage (zone tillage), irrigation, seeds, mineral fertilizers (Nitrogen, Phosphorus, Potassium), micro-nutrients including calcium, pesticides, fungicides (Mancozeb), insecticides (Dichlorvos) and cattle manure. Mulberry is a perennial crop and once properly raised in the first year, it can come to full yielding capacity during the second year and lasts for over 15 years in the field, without any significant reduction in the yield of leaves. Trimming and pruning are regularly performed to get good leaf yield. Harvesting is done on a regular basis. Normally, the annual expected yield is 30 tons of leaves per hectare.

b) The *rearing, silkworm, IN* inventory dataset represents the production of 1 kg of cocoons from 100 DFLs (disease free layings) equivalent to 40,000 eggs. Farmers collect disinfected eggs from government distribution centers at appropriate times. The rearing hall (mostly close to mulberry garden) is disinfected 15 days prior to silkworm incubation. The egg trays are arranged on incubation frames and covered with polyethene sheet or black paper. Requisite temperature (27-28˚C) and relative humidity (80%) is maintained for incubation. Eggs hatch in 9 days and give rise to Larva, which continues for 22-25 days and consumes mulberry leaves continuously. After this period the larva begins to spin silk around itself and transforms into cocoons. The cocoons are collected and deposited at cocoon banks from where they are sent to reeling centers. The inputs include electricity, water, and unspecified chemicals (bleaching powder, disinfectant chlorophate, lime).

c) The *reeled raw silk hank production, IN* dataset represents the production of 1 kg reeled silk from cocoons. Silk reeling consists of reeling several cocoons baves together from a group of cooked cocoons in a warm water bath and winding the resultant thread onto a fast-moving reel. Raw silk may be reeled directly, on a standard sized reel, or indirectly by reeling on small reels, and then transferring the reeled silk onto standard sized reels on a re-reeling machine. The inputs include cocoons, electricity, water, and firewood for cooking and reeling. Waste silk (short fibres, silk in the dataset) is sold for reuse in carpet industry, pharmaceutical, oil and other industry, which is approximated with bio waste in the dataset. Wastewater from cooking and reeling goes to adjoining mulberry fields, as it is rich in proteins. Electricity is generally solar based and reeling units have their own solar panels.

d) The *yarn production, silk, long fibres, IN* dataset represents the production of 1 kg of Silk yarn from raw reeled silk. The process starts after reeling and re-reeling process is completed. The reeled silk is doubled by combining nine strands together and twisting the doubled yarn which is finally wound into hanks of 70 grams each. The inputs include reeled silk and electricity.

e) The *textile production, silk, IN* inventory dataset refers to production of 1 kg woven silk fabric from silk yarn. The process consists of warping (preparing a sheet of length wise, laid out set of yarns) which is then interlaced with weft yarn to form a fabric. Inputs include silk yarn and electricity. Table 3 shows inventory datasets created for the silk supply chain.

Table 3: Names of the Silk datasets in India in 2017

activity name	product name
mulberry production IN	mulberry leaves
rearing, silkworms, IN	Cocoons
reeled raw silk hank production, IN	fibre, silk
yarn production, silk, long fibres, IN	yarn, silk, from long fibres
textile production, silk, IN	textile, silk

Source: Silkworm Rearing Rearing Centre, Guna, Madhya Pradesh and supplemented with secondary data; spinning - Silk Campus, Hoshangabad, Madhya Pradesh & Weaving unit, Bhagalpur - Bihar

3.4 Datasets for Nonwoven

a) The inventory for *textile production, nonwoven, needle punched polyester, IN,* refers to the production of 1 kg nonwoven needle punched textile from polyester fibres. The process includes opening, mixing, layering, humidification, carding, and needle punching. The fibres are fed through hopper for carding and then cross-lapped in layers, which is then sprinkled with a mixture of water and antistatic agent. The layers undergo a three-step needle punching to form a dense mesh, which is sent for adhesive coating for carpet manufacture. The inputs are polyester fibre, ground water and electricity. Wastewater, fibre, and fabric waste generated is landfilled.

b) The *textile production, non-woven, spun bond polypropylene, IN* dataset refers to the production of 1 kg nonwoven polypropylene sheet for the year 2013-14. The process includes opening/mixing, spinning, bonding by heated rollers, cooling, winding cutting and packaging. PP granules are fed through hopper, and mixed with master batch, granules are melted by heating oil, fibres are thus formed, extruded, and sprayed. The fibre mesh passes under heated rollers and gets pressed into nonwoven sheet, cooled, cut, and wound on paper tubes. The inputs include polypropylene granules, electricity, master batch, tap water, sodium hydroxide and heat from natural gas. The output is wastewater, dissolved NaOH (approximated with NaOH in the dataset), and waste PP granules. Names of the non-woven datasets are presented in Table 4.

Table 4: Names of the Nonwoven textile datasets in India in 2017

activity name	product name
textile production, non-woven, spun bond polypropylene, IN	textile, nonwoven polypropylene
textile production, non-woven, needle punched polyester, IN	textile, non-woven polyester

Source: Anonymous mill in Rudrapur, Uttarakhand

3.5 Impact results

Impacts results were calculated for various impact categories such as climate change, acidification potential, eutrophication potential, land use, ozone depletion potential etc. Impact results can be seen at https://ecoinvent.org/the-ecoinvent-database/.

Conclusion

This work covered multiple processes and sub processes related to textile production in India. The study successfully generated life cycle inventories of around 52 textile activities/products and created a basis for building up further research,

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through which many sustainability aspects of textiles life cycle can be analysed. The inventory data created in this study can be used for LCA studies, environmental product declarations, carbon foot-printing and similar assessments. The creation of reliable, consistent, and transparent LCIs can be useful to researchers, manufacturers and consumers by providing a basis for informed decisions in selection of raw material, production technology and better purchase.

Limitations and Future Studies

This work covered the most commonly produced textiles, i.e. jute and cotton silk and non-wovens. Future studies can be focused on other natural and synthetic textiles. Further life cycle stages of textiles can cover product manufacture, retail, use and end of life.

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Data Availability Statement & Conflict of Interest

The life cycle datasets for the Indian textile sector can be found www.ecoquery.com website and are available to use for licensed users only. The authors declare no conflict of interest and that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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