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# Environmental aspects of wool industry

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**Abstract**
Since global warming and climate change are global issues, the international community has started addressing them, through research and development. Life Cycle Assessment (LCA) is a scientific approach to comparative analysis and assessment of the environmental impact of product systems. Textile and fashion industries have a huge impact on the environment. The present textile industry is one of the largest emitters of greenhouse gases on earth, by its size. The wool industry is much smaller than that of cotton and man-made fiber-based industry. It is bridging the gap between the rural economy and manufacturing industries. LCA studies show the various impacts of the wool industry on the environment such as water pollution, air emission, land pollution, etc. This article will elucidate informative data on various LCA studies in the wool sector.

**Keywords:** Characteristics of LCA, environmental assessment of wool, LCA in textile sector, life cycle assessment

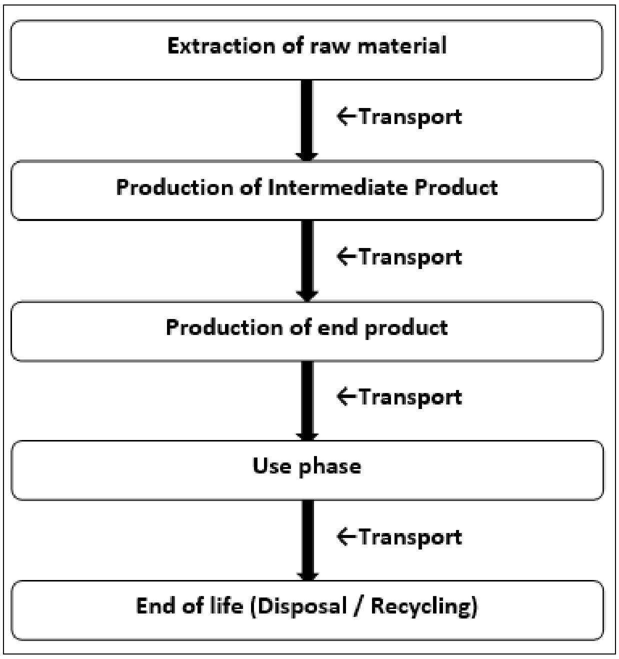
## Introduction
The present generation is facing many challenges because of increasing environmental concerns [1]. Life Cycle Assessment (LCA) is a scientific approach for comparative analysis and assessment of environmental impacts of product systems [2]. International standard ISO 14040 serving as a framework, has defined LCA as follows:
'LCA studies the environmental aspects and potential impacts throughout a product's life cycle from raw material acquisition through production, use, and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences [3].'
LCA has been broadly utilized in different sectors of the economy as a means to generate accurate appraisals of the environmental significance attached to products and services. It has been accepted by the scientific community as an impact appraisal tool characterized by a high level of accuracy and reliability [4].
Since the 1960's life-cycle-oriented approaches for environmental profiling of products have experienced strong development, both in methodology and applications [5]. Later on, several studies were carried out based on Resource and Environmental Profile Analysis (REPA) [6].

## Characteristics of LCA:
LCA plays a key role in assessing the environmental friendliness of a product or service, because of the following characteristics:
- It takes a life cycle perspective.
- It covers a broad range of environmental issues.
- It is quantitative.
- It is based on science [7].

## Life Cycle of a Product
As depicted in Figure 1, the life cycle of a product starts from the acquisition of the raw material going through the production process and end-use, taking into account, the transport and energy consumption during these processes. The life cycle of a product terminates at the disposal or recycling phase. The interconnected processes in the life cycle of a tangible product are known as product systems [8].

### Impact of Textile and Fashion Industry

The textile and fashion industries have a huge impact on the environment [9]. It is one of the largest emitters of greenhouse gases on Earth [10]. It significantly grew during the industrial revolution, which offered society the opportunity to produce more textiles, faster and with less human effort [12]. The textile industry represents one of the most varied and complicated productive processes of the entire manufacturing system [15], in recent years, textile production and consumption have risen drastically due to global population growth and improvements in living standards [13]. Manufacturing of all types of textiles impacts the environment by releasing effluents or emissions, which can cause the degradation of natural resources [18]. The textile manufacturing processes involve large consumption of water, energy, and various chemicals which will generate waste at the end or as a by-product.




**Source:** Klopffer W. and Grahl B[A]

**Fig 1:** Simplified life cycle of a tangible product

The major problem concerning water usage is the untreated effluents that are discharged directly into nearby water bodies [14]. Besides using water resources, the textile industry also uses large quantities of both electricity and fuels. The dry processing unit is one of the major electricity-consuming sectors in the textile industry. The electrical energy is used for driving machinery, cooling, temperature control, lighting, and office equipment. Among the various processes of textile industries, the spinning industry takes the major share of electricity [16] in its various stages (mixing, opening, preparation, the spinning operation itself, winding, and doubling) [17].

The manufacturing process of synthetic fabrics is an energy-intensive process requiring large amounts of crude oil and releasing emissions including volatile organic compounds, particulate matter, and acid gases such as hydrogen chloride, all of which can cause or aggravate respiratory disease.[19] On the other hand, natural fibres have a smaller carbon footprint, since they can be degraded by microorganisms and thereby improves soil structure, and releases the $CO_2$ fixed in the fibre, thus closing the cycle [20].

### Need of LCA in Textile Industry

The textile Industry in India is one of the vital components of the Indian economy and contributes around 14% of total industrial production, about 4% of India's Gross Domestic Product (GDP), about 17% of the gross export earnings, and employing about 35 million people being the second largest provider of employment after agriculture [21]. Although textile industry is contributing to economic growth and eradicating unemployment, it is also a major source of environmental pollution.

Since global warming and climate change are global issues, the international community has started addressing them through research and development initiatives. Buyers are demanding low-carbon products. In this scenario, the Indian industry must also prepare itself for the upcoming challenge of a carbon-compliant system for Global business. People working in textile industries must be sensitized towards the environmental concerns [22].

### Wool Industry

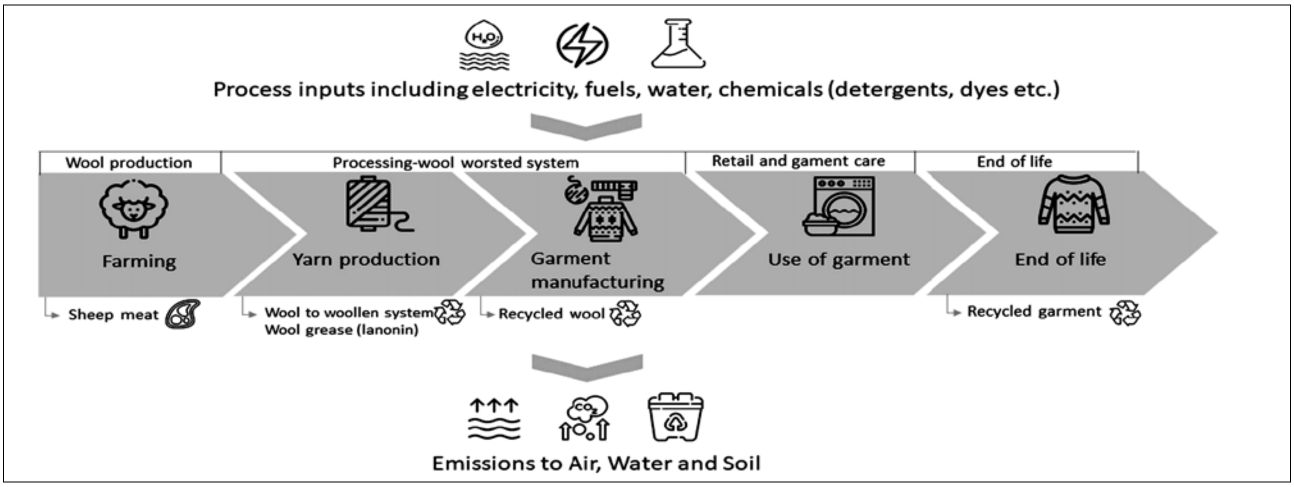
The wool industry is much smaller than that of cotton and man-made fiber-based industry. In 2014-2015, 65.06 million sheep were produced in India and yielded 48 million Kg of raw wool, making India 3rd largest sheep-populated country in the world. From the total raw wool, 85% was graded as carpet wool, 5% was graded as apparel wool, and the remaining 10% coarser grade wool for making rough *kambals*, etc [23]. The industry employed 2.7 million people in 2010-11. The main states producing woolen products in India are Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana, Rajasthan, Uttar Pradesh, Uttarakhand, Gujarat, Maharashtra, Andhra Pradesh, and Karnataka [24].

Sheep play a vital role in the agricultural economy, as they have multifunctional use in producing meat, milk, wool, and other products [25]. Sheep rearing is practiced in dry and mountainous areas because of the non-economical and unfavorable climate conditions for agricultural activities and dairy farming. In India, sheep are mostly reared for wool and meat. Wool and sheepskin have been used as raw materials in many rural-based industries. Moreover, the manure of sheep enhances soil fertility [26].

### Wool -Life Cycle Stages & Point of Consideration for LCA of Wool

There are several stages in the life span of wool products as given in figure 2. These stages have different environmental concerns. Details about these stages and their respective environmental concerns are given below:

- On Farm
- Processing and Manufacturing
- Use Phase
- End of Life




**Source:** Wiedmann S.G., *et al.*; 2020[B]

**Fig 2:** Life cycle stages of wool products/garments

**On Farm:** A complete LCA for wool includes on-farm data about Greenhouse gas emission (GHG), fossil energy use, water stress level from farms, freshwater consumption, land occupation, and potentially a wide range of other impacts.

The grasslands which are generally less suitable for other agricultural activities are used for grazing sheep. Grazing sheep might imbalance the ecosystem and can cause soil erosion. The sheep feed on grassland and require separate health maintenance. Generally, a sheep gives about 1-2 kilograms of fleece per annum. Sheep releases important greenhouse gases, like methane, and nitrous oxide, therefore they have a considerable role in climate change [48]. The production of gasses is because of its metabolic activity enteric fermentation and manure left in the pasture. The process of collecting fleece from the sheep is known as shearing. The quality and quantity of wool produced depend on the sheep husbandry practices adapted by the shepherds. [27] The fleece is kept in one piece and contains its natural fat content [29], which needs to be removed by further processing.

**Processing and Manufacturing:** The important impact categories while processing and manufacturing wool are water, GHG, energy, and chemicals used during scouring and combing, spinning, dyeing, weaving, finishing, cutting, and sewing.

The very first step in processing of wool is grading. In grading the fleece is judged for overall fibre fineness, length, fibre type, and quality [30]. The graded/raw wool contains 30-70 percent impurities [28]. To remove the impurities wool is scoured in an energy-intensive process requiring large amounts of hot water loaded with non-ionic detergents (namely alcohol ethoxylates and alkyl phenol ethoxylates) and builders (inorganic salts) to emulsify the wool grease [31].

Then comes carbonization and scouring, in which wool grease and vegetable matter are removed from the wool. A series of heavy metal fluted rollers are used to crush the decomposed carbonic matter into dust. A mechanical rotary shaker or dedusting unit dust off all the dust from the wool. The use of sulphuric acid leads to the acidic nature of wool, which is neutralized by sodium carbonate treatment [32].

After scouring and carbonizing, the wool is processed in the carding and combing machine. The carding machine splits up the intertwined bunch of fibers into a web of individual fibers by putting it into a series of closely spaced moving surfaces that are covered with pointed wire, pins, or teeth (the card clothing) [33].

After carding and combing, drawing and drafting of wool is carried out. It results in a long continuous fiber strand with lower linear density [36]. Drafting rolls draw out the roving to its final size. Traveler glides freely around a ring and inserts the twist as the spindle rotates the bobbin on which the yarn is wound [37]. As this can be observed carding and drawing uses heavy metal machines and hence the major impact factor in these stages is electricity consumption.

Following the production of yarn, the fabric is manufactured by using knitting or weaving techniques [45]. As per the specification of the final product, finishing processes might comprise different processes [40]. To remove the excess sizing agents which were applied by the weaving units to strengthen the fabric, desizing is carried out. This process uses enzymes and other auxiliaries; therefore, it has a high wastewater production [44].

After the production of woolen fabric, it is processed for dyeing and printing. The process of making fabric brighter or whiter is referred to as bleaching. Hydrogen peroxide and reagents like sodium hypochlorite, sodium chlorite/chlorate, and sulfur dioxide gas are the most commonly used bleaching reagents [43]. Bleaching is a mandatory operation for dyeing and printing fabric in pastel colors. On the contrary, dyeing in dark colors can be done without requiring bleaching.[41] Printing is considered as localized dyeing [42] where large amounts of chemicals and dyeing/printing auxiliaries are used in this process.

Succeeding the fabric manufacturing process, the final stage of textile making is the sewing process, which includes fabric cutting and garment assembly. It can be achieved by using different types of cutting and sewing machines. Similar to combing and drafting, electricity consumption is the major impact factor in the fabric construction process.

**Use Phase**

In the use phase, the environmental impacts of using, wearing, and maintaining the wool product are measured. Impacts taken into account are the amount of water used for washing, washing temperatures, drying methods, number of wears before washing, Lifetime of a garment, including when that garment is used by a second or subsequent owner (reused).

**End of life**

The end-of-life phase looks at impacts related to the timespan in which textile has been rejected for further use. This includes the number of times a product is recycled and end of life such as landfill and biodegradation [46].

### Environmental Impacts due to Production of Wool

The textile industry causes harm to the environment in many aspects. Water, air, and land pollution are the major concerns of the harmful impacts of textile industry. Following are the various pollutants and their respective emission stages:

### Water consumption

Water-related impacts originate in the dyeing and chemical finishing processes of textile manufacturing [49,50]. Motivation to use non-toxic dyes and less harmful chemicals and recycle/reuse water within the supply chain is required. This wastewater effluent is specifically alkaline and has high Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). It might escalate the temperature of effluent. These emissions typically consist of pollutants from dyeing processes such as heavy metals, suspended solids, halogenated organics, mineral oil, phenols, and surfactants. [51,52] Along with this, wool processing may include microbiological pollutants, pesticide residue, and wax (grease and suints) in water waste [53, 54, 55]. Generally, in the textile industry, water pollution is one of the most important environmental problems [56]. Figure 3 depicts the life cycle stage and pollutants released by it.

**Table 1:** Specific water pollutants

| Life cycle stage | Compounds |
|---|---|
| Desizing | Sizes as enzymes and starch, waxes, ammonia |
| Scouring | NaOH, surfactants, soaps, fats, waxes, pectin, oils, sizes, anti-static agents, spent solvents, enzymes, insecticides, and pesticides. |
| Bleaching | $H_2O_2$, AOX, sodium silicate or organic stabilizer, high pH |
| Mercerizing | High pH, NaOH |
| Dyeing | Colour, metals, salts, surfactants, organic processing assistants, sulphide, acidity/alkalinity, Formaldehyde |
| Printing | Urea, solvents, colour, metals |
| Finishing | Resins, waxes, chlorinated compounds, acetate, stearate, spent, solvents, softeners |

**Source:** Wang, Z., *et al.*.; 2011[E]

### Energy consumption

Fossil fuels have been used for electricity production to operate industrial machinery, heating processes, transportation, and agricultural machinery. It largely accounts for resource depletion and climate change. Water and energy usage are interrelated, as energy is mainly used for heating the process bath and drying up wet products.[58] When the life cycle stage of "garments use" is accounted for, washing processes contribute about 65% of electricity consumption [59] In Figure: 4, the table indicates that fabric finishing (both knitting and weaving) requires a major amount of electricity, heat, and water supply.

**Table 2:** Benchmark value for electricity, heat, and water consumption [F]

| Life cycle stage | Electricity, kWh/kg | Heat, MJ/kg | Water, L/kg |
|---|---|---|---|
| Wool scouring | 0.3 | 3.5 | 2-6 |
| Fibre dyeing | 0.1-0.4 | 4-14 | 4-20 |
| Spinning | 1-3 | 1.1 -4.7 | - |
| Yarn finishing | - | - | 70-120 |
| Yarn dyeing | 0.8-1.1 | 13-16 | 15-50 |
| Knitted fabric finishing | 1-6 | 10-60 | 70-120 |
| Woven fabric finishing | 0.5-1.5 | 30-70 | 50-100 |
| Dyed woven fabric finishing | - | - | <200 |

**Source:** Commission, E., 2003

### Air Emissions

All energy-consuming activities, agricultural practices, and grazing sheep are the chief components of air emissions. Several air emissions are not produced on the farm but in the electricity-generating power plants [60]. Enteric fermentation of livestock production results in $CH_4$ emission and livestock manure management causes both methane and nitrous oxide emissions [61].

Wool processing has a significant amount of direct air emission in various stages such as cleaning, drying, printing, dyeing, and finishing [62]. A list of the major pollutants is given below:

**Table 3:** Sources of air emission in the textile industry.

| Life cycle stage | Pollutant | Origin |
|---|---|---|
| Sheep Farming | $CH_4$, $N_20$, $NO_2$ and $NH_3$ | Livestock emissions and fertilizers application |
| Spinning | Dust | Natural fiber processing as bale breaker and automatic feeders |
| Dyeing<br>Printing<br>Finishing | HVOCs: ammonia, formaldehyde, alcohols, esters, aliphatic hydrocarbons Odours | Use of oils, solvent, formaldehyde, sulphur compounds, and ammonia |
| Boilers and electricity generation | $C0_2$, CO, $NO_x$, $SO_2$ | Exhaust gases |

**Source:** Group, W.B., 2007[G]

**Solid Waste Generation:** The production of solid waste in the supply chain has diverse chemical composition and origins, residual materials are majorly non-hazardous, e.g., Fabric scarps or yarn and packaging material [63,64].

**Table 4:** Solid waste generated in the Textile Industry.

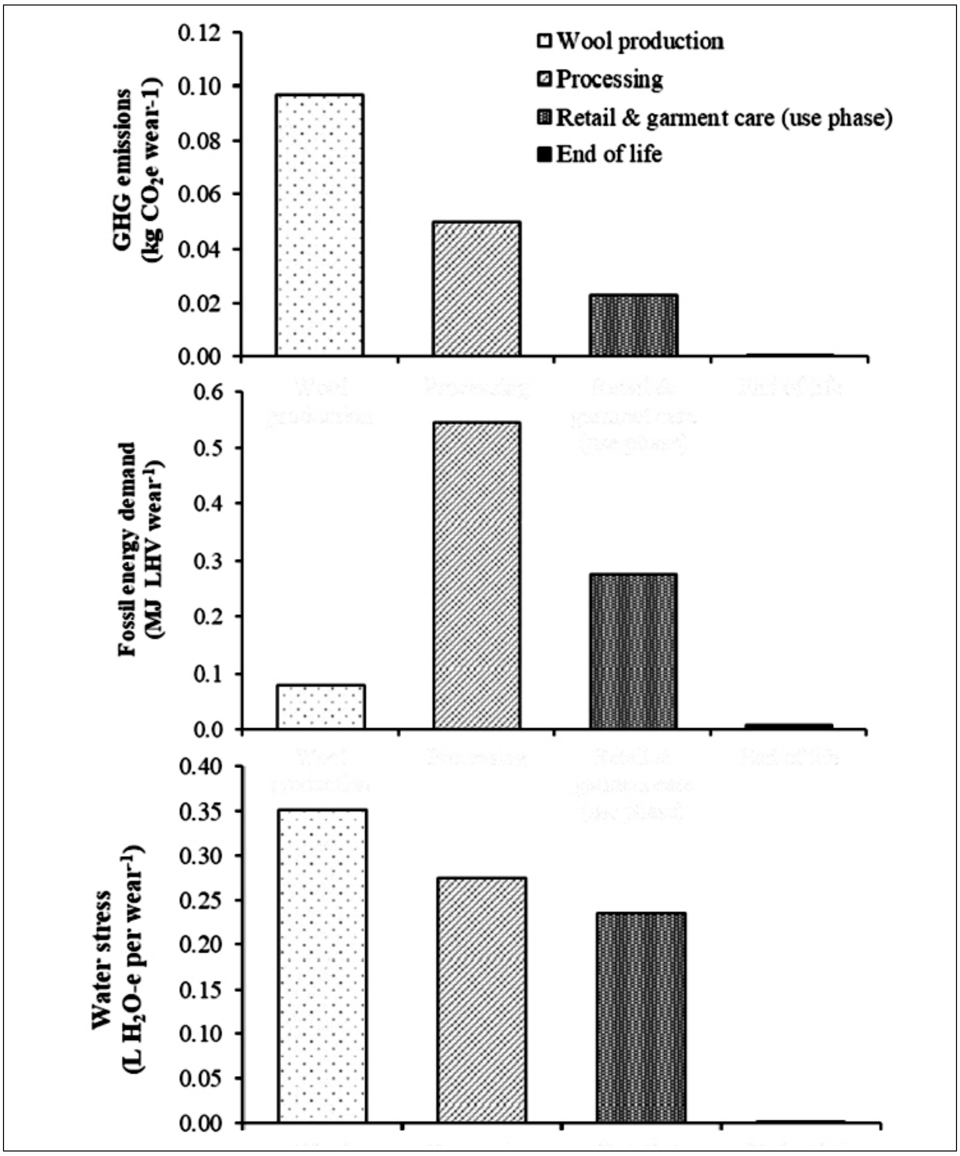
| Life cycle stage | Solid Waste |
|---|---|
| Fiber preparation | Fiber waste; packaging waste; and hard waste. |
| Yarn spinning | Packaging waste; sized yarn; fiber waste; cleaning and processing waste. |
| Scouring | Little or no residual waste is generated. |
| Bleaching | Little or no residual waste is generated. |
| Dyeing | Little or no residual waste is generated. |

**Source:** Babu, B.R., *et al.*., 2007[H]

### Studies on LCA of wool

The considerable amount of air emissions, odours production, and solid waste from processing fibres cannot be neglected. [47] New production techniques must be applied to minimize the use of natural resources, water, hazardous chemicals, and land throughout the supply chain. The textile manufacturers are concentrated on the production of sustainable products, also various LCA studies have been done on wool. The outcomes of a few of them are mentioned below:

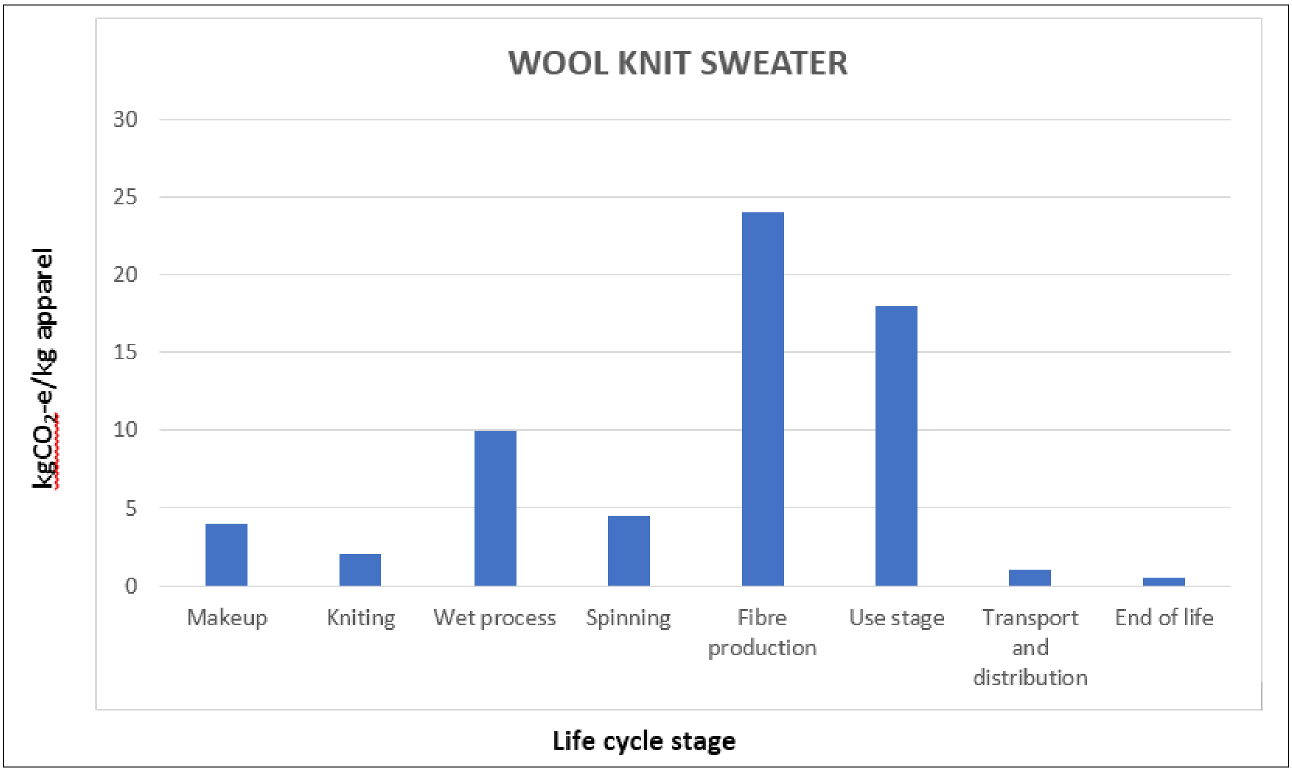
In Figure 7 Greenhouse gas emission in kilogram carbon dioxide equivalent per wear (Kg $CO_2$ e wear$^{-1}$), fossil energy demand in megajoule lower heating value per wear (MJ LHV wear$^{-1}$), and water stress had been calculated in various life-cycle stages of wool garments such as wool production, processing, use phase, and end phase. According to the given bar graph, the wool production stage emits the highest level of greenhouse gas and has the highest water stress as compared to other life cycle stages of a woolen garment, whereas, the processing stage has the highest fossil fuel demand. It indicates the fact that the end phase has the lowest values in all the parameters.




**Source:** Wiedmann S.G., *et al.*; 2020 [C]

**Fig 3:** Environmental impact of various life cycle stages of wool.

In Figure 8, In another LCA study carbon dioxide emission is calculated in various life cycle stages of a wool knitted sweater. The given bar graph indicates that the fiber production stage emits the highest level of $CO_2$ during the various sub-processes.




**Source:** Moazzem S., *et al.*; 2018 [D]

**Fig 4:** Breakdown of Impact climate changes per Kg apparel

## Limitations of LCA Studies of Wool

The farm stage and early stages of wool processing are the major interest areas of LCA studies on wool [65, 66, 67]. Sustainable Apparel Coalition's Material Sustainability Index is an assessment tool [68] that studies the life cycle approach of wool fabric production and reports its environmental impact, but to evaluate approximate impacts of spinning, dyeing, knitting/weaving, and finishing proxy inventory data is used. [69] Valuable information can be obtained by partial LCA of an individual phase of a product life cycle. However, to improve the environmental efficiency of a product, a full life cycle approach is required. This will decrease the chances of burden shifting (a condition in which sustainable development of one resource will increase the usage of another resource). Moreover, the total lifespan of a product is determined by the consumer and plays a vital role in evaluating the environmental efficiency of the product. There is a huge knowledge gap in this area as it has not been assessed for woolen garments.

## Conclusion

LCA plays a very important role in dealing with the environmental problems faced by our ecosystem. LCA gives quantitively comparable units to determine the eco-friendliness of a product or system. In the textile sector, a lot of research has been conducted to assess the various perspectives of textile manufacturing taking the Life Cycle approach. However, very few studies have been done in the field of Life Cycle Assessment of woolen textiles. A cradle-to-grave approach for woolen textiles is a requirement because woolen textiles play a very crucial role in northern India. To decrease the associated environmental impact of a woolen textile product, new production techniques must be implemented so that the usage of water, chemicals, non-renewable resources, and fertilizers can be minimized.

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