Assessing Energy Emissions and Water footprint Of integrated textile processing: A Case Study of an Indian Textile Mill

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# Abstract

The objective of this study is to investigate and analyze the effect of varying sources of water, energy inputs and their impact on carbon emissions, water footprint during textile processing .The method involved industrial visits to the textile processing mill and interaction with the manufacturing as well as commercial sourcing teams to gather last three calendar year data. The results and outcome of this analysis indicate that textile wet processing is responsible for a significant carbon emission of about 21.24 kgCO2e/unit of production. Purchase electricity as a source of energy has the highest carbon emission 0.112 kgCO2e/product, while the use of biomass and Diesel (PNG) had significantly lower CO2 emissions. Further, this study evaluated the scope 1 and scope 2 category emissions produced at the textile processing stage which accounted 59580000 kgco2e. Customization in application of dyes and colorants using industry 4.0 techniques like digital printing, digital finishing can further reduce use of resources, water and energy. Designing waterless processes should be the main focus for optimization in energy. Energy consumption is in proportion to the volumes of water required in processing baths. Renewable fuel sources like biomass occupy more space. Processors are somewhat reluctant to adapting to these changes and added production costs. Synchronized efforts from all the stake holder involved in the textile value chain is required to address the sustainability challenges in wet processing of textiles. In this case study addresses five sustainable development goals (SDG) out of seventeen; 6-Clean water and sanitation, 7-Affordable and clean energy; 12-Responsible production and consumption; 13-Climate action; and 15-Life on land.

**Keywords:** CO2 Emission\_1; Greenhouse gases\_2; Renewable energy\_3; Sustainable processing\_4; SDG\_5

# Introduction

Different types of fibres (natural, manmade), forms of substrates (fibre, yarn, fabric, garment) and processing methods (batch, semi-continuous, continuous) make textile processing highly fragmented and complex. Generally, the widely consumed fibres for apparel and home furnishing textiles like polyester and cotton are often studied for their energy and water footprints; the energy impact of other prominent fibre; polyester/cotton blends has received very little attention.

# Wool wet processing

Wool is a naturally occurring protein fiber extracted primarily from the follicles of sheep. Sheared wool contains dead skin, waxes, suints, sand, dirt, and residual animal and vegetable matter as impurities[1]. These impurities are collectively termed as wool grease, for subsequent dyeing and finishing treatments this wool grease is removed in the scouring process by hot water treatments using mild detergents[2]. Wool is dyed majorly using acid dyes, which have a strong affinity for alpha keratin proteins of wool fiber [3]. Generally, processes like carbonizing, chlorination, crabbing, milling, and calendaring are carried out to add commercial and functional value to wool The processing stages like cleaning of wool by removal of impurities (scouring), dyeing and printing (coloration) and finishing are carried out is collectively termed as wet processing of wool[4].

# Environmental Profile of Wool

The wool mark company describes wool as an environmentally positive fibre, having biodegradable, recyclable, and renewable characteristics. Unlike other fibres, wool does not contribute to microplastic pollution in oceans. Wool is associated with the natural carbon cycle. On its decomposition, wool adds to the nutrient value of the soil by acting like a fertilizer and in turn returning carbon into the soil[5]. Wool being a natural fibre, is very often marketed as a sustainable alternative to synthetic fibres, which are known for their energy emissions and environmental impact [6]. Although wool is derived from natural sources, sheep rearing and wool production industry contributes to greenhouse gases (GHG) like methane and nitrous oxide[6-7][.](https://doi.org/10.1016/j.agee.2009.06.007)

# Literature Review

The research published so far has discussed the environmental impact of wool from farm to fleece. Farm-level GHG emissions resulting from sheep transhumance and sheep production in continental rangelands have been reported [9]. Product-based lifecycle assessment (LCA) studies analyzing the energy and water footprints have been carried out for woolen carpets and garments[9-10]. A study investigated the energy, water and land used in Australian wool production. But this study was confined to primary production thus emphasizing only on farm to

gate impact [12]. Another study investigated methane emissions from wool enterprises in Western Australia [13]. All these studies have discussed the emissions generated from grazing ruminants and pastures on farms in major sheep-rearing regions like Australia [14]. The GHG profile of 1kg wool production was assessed for the Yass region, New South Wales [15].

Thus, the studies so far have focused on evaluating environmental impact up till the wool fiber production stage. Also, the reported GHG assessments and LCA studies are from major wool- producing regions like Australia. A review of the environmental performance of sheep farming highlights most of the LCA studies have marked cradle-to-farm gate boundaries for analysis. This detailed review on the sheep sector mentions, “More research is needed on determining impacts of “post-farm” activities such as processing of sheep products before it reaches the consumers and consideration of environmental impacts other than climate change” [16].

There is a lack of information in the published literature about scope-wise CO2 emissions produced during textile processing of wool post its production. Due to the availability of resources, flexible environmental regulations and availability of cheap labour, major textile processing happens in the global south. South Asian countries like China, India and Bangladesh are presently the major hubs for textile processing industries [17]. This study has tried to bridge the gap in the existing literature which lacks information about energy emissions and the sustainability profile of wool at the wet processing stage.

# Methods

All findings reported in this study were made through onsite measurement of quantifiable parameters and field data collected from a wool processing mill located in Huda Panipat, Haryana-India.

The data of fuel sources, energy and water consumption was collected for two consecutive years 2021 and 2022 and compared for analyzing the transition in sustainability measures adopted by the wool processing mill. This mill is engaged in processing of woolen floor coverings, bathmats, door mats, dhurries, flokati rugs, carpets, and a range of upholstery fabrics and home textiles.

The details of instruments and devices used for measuring power, fuel, and water consumption as per standard protocols of regulating bodies are mentioned in the subsequent sections of this chapter. The investigation and site survey of the mill was done as per the protocols mentioned in ISO 14001:2015 management systems protocol[18]

# Energy Consumption

Table 1 indicates the amount of Coal required for generating steam in boiler operations for wool chlorination, coloration, and finishing treatments. This was measured using the Thermax A2Z Flo-S Steam Flow Meter. Energy consumption from other fuel sources like biomass, liquefied petroleum gas (LPG) and pressurized natural gas (PNG) was deduced from supplier invoices and internal monitoring systems.

The emissions produced by any fuel source have an inverse relation with the calorific value of fuels. Calorific value is a primary indicator of fuel performance. Bituminous and Indonesian coal is generally supplied in textile mills. The mill described in this study uses Indonesian coal having a calorific value of 5500 Kcal/kg.

The use of locally available agro residues as Biomass is increasing in India. This includes rice husks, coconut shells, groundnut shells, Coffee husks, Wheat stalks etc. The reported results of biomass consumption in Table 1 are primarily from the usage of Paddy husk having 3568 Kcal/kg calorific value. Diesel (calorific value -10,800 Kcal/kg) is supplied to the mill by a local provider. The supplier details and calorific values of other fuel sources used in the surveyed mill are as follows: LPG: 25350 Kcal/Nm3, Supplier: Neelkamal energies; PNG: 9350 Kcal/Nm3, supplier: Indian oil-Adani gas private limited and Electricity from Purchase power grid supply from Uttar Haryana Bijli Vitaran Nigam Limited.

Up till 2021 the mill was using coal, electricity, diesel and PNG. In 2022, the wool processing mill phased out diesel completely and replaced it by PNG. Also, coal was partially substituted by biomass in 2022. During the survey it was recorded that Coal was in use from 01 January 2022 to 30 August 2022. In an attempt to reduce usage of coal, the use of Biomass was seen from 1st September 2022 to December 2022. Record of individual energy consumption from

independent fuel sources were expressed in single uniform unit-mega joules (MJ) for simplicity in calculations using conversion factors specified by Bureau of Energy Emissions (BEE) [19]

Energy expressed in Mega Joules=Energy consumption in independent unit x Conversion factor

As seen clearly in Table-1, energy consumption (expressed in mJ) column, maximum energy consumption was from usage of coal in 2021. Based on the research study of BEE, Jet dyeing process requires 3.5-6 GJ/MT and stenter operation require 2.5-7.5 GJ/MT of heat energy[20].

Table 1: Annual energy consumption of the wool processing mill

|  |  |
| --- | --- |
| **Annual Energy Consumption** | **Energy consumption expressed****in Mega Joules(mJ)** |
| **Fuel****Source** | **2021** | **2022** | **Unit of****Measurement** | **Conversion****Factor** | **2021** | **2022** |
| **Electricity** | 2909054 | 2990134 | KWH | 3.6 | 104725940 | 107644838 |
| **Diesel** | 2736 | 0 | LTR | 35 | 97948 | 0 |
| **Biomass** | 0 | 4082 | MT | 239 | 0 | 975621 |
| **LPG** | 0 | 37400 | Litre | 25 | 0 | 935000 |
| **Coal** | 1148495 | 23235 | MT | 21887 | 25137445169306 | 508570375 |
| **PNG** | 1097 | 45829 | m3 | 36 | 40589 | 1695327 |

# Emissions produced in wool processing

Figure 1 – Year wise Environmental Impact of Wool Processing

It is well known that climate change is associated with emissions released from anthropogenic activities. For this study the carbon emissions resulting from energy consumption of each fuel source utilized in wet processing of wool was calculated using greenhouse gas equivalencies calculator[21]**.**

Three "scopes" (scope 1, scope 2, and scope 3) are defined for GHG accounting and reporting purposes in order to help distinguish between direct and indirect emission sources, enhance transparency, and offer utility for various types of organizations, as well as various types of climate policies and business goals. As per the greenhouse gas protocol and guidelines of India GHG program, the direct GHG emissions released from sources that are owned or controlled by the company are categorized as scope 1.

Fuel sources like Diesel, Biomass, Coal, LPG used in the wet processing stages of wool were responsible for scope 1 category emissions. The GHG emissions resulting from the production of electricity, steam, dry heat that a company purchases and uses are included in scope 2. Electricity used for processing and non-production activities in the wool processing mill belong to scope 2 category emissions.

Table 2: CO2 emissions in wool processing and category assessment of emissions:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Energy Consumed** | **Unit** | **2021** | **2022** | **Emission factor** | **tCo2-2021** | **tCo2-2022** | **Category- GHG****emission** |
| **Electricity** | KWH | 2909054 | 2990134 | 0.61 | 1767 | 1817 | Scope 2 |
| **Diesel** | LTR | 2736 | 0 | 2.7 | 7 | 0 | Scope 1 |
| **Biomass** | MT | 0 | 4082 | 72.62 | 0 | 296 | Scope 1 |
| **LPG** | Litre | 0 | 37400 | 1.56 | 0 | 58.24 | Scope 1 |
| **Coal** | MT | 1148495 | 23235 | 2403 | 2760798 | 55855 | Scope 1 |
| **PNG** | m3 | 1097 | 45829 | 2 | 2 | 93 | Scope 1 |
| **Total** |  |  |  |  | 2762575 | 58120 |  |

# 2.2 Inlet water consumption and re-use

Figure 2 – Water Mapping in Wool Processing

Table-3 Comparison of annual water consumption in facility

|  |  |  |
| --- | --- | --- |
| **Water Usage** | **2021(Kiloliters)** | **2022(Kiloliters)** |
| Municipal Water source (Inlet water) | 63628 | 53932 |
| Condensate water reused for boileroperations(input) | 0 | 21230 |
| Reverse reject water reused in wet scrubber | 0 | 2796 |
| RO Feed | 9817 | 8741 |
| Boiler (Steam generation) | 7144 | 5944 |
| Fabric Dyeing +soft flow | 24204 | 23393 |
| Digital printing | 2278 | 2290 |
| Sublimation printing | 596 | 556 |
| Yarn dyeing | 10871 | 14720 |
| Domestic | 15170 | 2511 |
| Miscellaneous | 690 | 1718 |

All water consumption measurements and terminologies are reported considering the ISO 14046 water footprint principles[22].The incoming water supplied by municipal bodies is circulated

across the mill for textile wet-processing stages like scouring, dyeing, printing, and finishing. Recirculation and re-use account for this major reduction in water consumption. Processing operations like bleaching full white and dyeing pale shades on wool require optimum bath pH, low water hardness, and total dissolved solids (TDS).

For this reason, the facility is equipped with a softening plant and a reverse osmosis (RO) setup. Wherein the supplied untreated water from municipal bodies is initially passed through a softening machine, followed by RO. The water emerging out of RO has two outlets: permeate and reject. Permeate water is used for pH sensitive processes and chemical treatments where water quality standards are a requisite, as well as for drinking purpose. The rejected water is reused in wet scrubber operations. Industrial boilers are equipped with wet scrubbers to settle the fine ash particles and avoid emission into the air. The boiler condensate water is reused in boiler feeding to generate wet steam.

Wet processing machinery used for calendaring and dyeing using a high-temperature high- pressure (HTHP) machine requires subsequent cooling. Water circulated for such non-contact cooling is stored and reused. As indicated in Table 3, the annual consumption of water in the facility was reduced by around 15%. This transition is evident because of strategies like reuse and recirculation, which were not implemented in 2021. Among all wet processes, fabric dyeing consumes the highest volumes of water compared to yarn dyeing. The material-to-liquid ratio in the soft-slow type machine is higher as compared to the HTHP package dyeing machine used for yarn dyeing.

# 3.4 Waste generated in facility-Hazardous & Non-hazardous

Table 4 -Waste generation and disposal Methods

|  |  |  |  |
| --- | --- | --- | --- |
| **Waste Generated** | **2021** | **2022** | **Final Disposal Method** |
| Fabric (material waste) | 449 | 439 | Recycle |
| Plastic (polybag and plastic scrap) | 1147 | 1312 | Recycle |
| Paper waste | 935 | 976 | Reuse and recycle |
| Food | 951 | 853 | Reuse |
| Empty Chemical Drums and boxes(production) |  |  | Reuse and recycle |

|  |  |  |  |
| --- | --- | --- | --- |
| Tube light waste | 4.5 | 4.6 | Landfill |
| Electronic waste | 16.4 | 17.8 | Recycle and landfill |
| Used Oil (waste oil) | 27.1 | 19.8 | Recycle and incineration |
| Boiler Ash | 170770 | 168310 | Reuse |
| Sludge | 1958 | 2010000 | Landfill |
| Total | 176260 | 2183955 |  |

While evaluating GHG emissions from anthropogenic activities it is necessary to take into consideration the amount of waste generated in an industrial process and its impact post disposal. As per notification released by Haryana State Pollution Control Board (HSPCB) in 2010, the facility comes under highly air emission intensive category. The solid waste generated in the wool processing mill was identified and categorically investigated based on the methods implemented for disposal. The facility has generated hazardous waste like ETP sludge waste from the ETP plant, used oil, tube light waste, boiler ash, electronic waste, and non-hazardous waste like wool process waste, plastic waste, paper waste, and food waste from production and operation activities.

Wool process waste is generated from wet process activities like scouring, chlorination, dyeing, and finishing. Paper waste generated from printing stationery material has been used for recipe cards and shade cards. Plastic waste is generated from packaging activities, including raw material packaging waste, and finished product packaging activity waste. Food waste is generated from canteen and pantry activities. Tube light and electronic waste generated from operation activities like lightening purposes. Electronic waste like computer parts—keyboards, cable wiring, and others. Average waste generation is 14.8 kg from cotton wet processing[23].

Waste generated in facilities (hazardous and non-hazardous) is validated through the waste handler agreement, waste handler site visit report, transaction challan, and manifest copy. The facility has sent food waste to a pig farm for food purposes, and boiler ash has been sent to brick manufacturing units to be used for paver blocks and brick manufacturing. The paper, plastic, and empty chemical container waste is recycled through authorized waste handlers.

# Results

The findings from this onsite survey enabled us to calculate the net emissions produced in the wool processing industry. From September 2022 onwards, the facility has completely phased out using coal as a fuel source. The transition towards green energy fuel sources is seen in the annual fuel consumption of 2022. Replacing coal with biomass is evident as a result of environmental regulations and pressures received from top clothing brands like Inditex, Zara, and H&M to phase out non-renewable fuels like coal. Selective substitution of coal by biomass reduced CO2 emissions significantly. A net reduction of 2704455 t CO2 e was observed in comparison to 2021. The facility has switched to cleaner fuels, like LPG/PNG gas, to diesel fuel and saved 7.4 t CO2 emission. Recycling and reuse of water have resulted in 15% blue water savings.

# Discussions

Use of huge volumes of water is unavoidable in conventional processing stages of wool like scouring, dyeing, printing, chlorination. The use of low material-to-liquid ratio machinery can further reduce water consumption, especially in dyeing and coloration processes. Heating water to processing temperatures for scouring and bleaching wool, dyeing and printing woolen fabrics consumes energy.

Energy consumption is in proportion to the volumes of water required in processing baths. Apart from the core processes like scouring, dyeing and finishing additional water is consumed in ancillary processes like neutralizing, washing and cooling. Combined processes like one bath scouring bleaching, avoiding frequent pH shifts in processing can further reduce additional water and subsequent heating.

Customization in application of dyes and colorants using industry 4.0 techniques like digital printing, digital finishing can further reduce use of resources, water and energy. Designing waterless processes should be the main focus for optimization in energy. This paper addresses four sustainable development goals (SDG) out of seventeen-7-Affordable and clean energy; 12- Responsible production and consumption; 13-Climate action; and 15-life on land.

1. **Conclusion:**
2. The carbon emissions that occurred in each process step throughout wool’s processing phase were computed independently. It is observed that the wool wet processing is responsible for significant carbon emission of about 0.031 tCO2e/product.
3. After determining the different energy types required for the various stages of production, it was found that coal produced the highest carbon emissions, with a carbon emission of 0.066 tCO2e/product.
4. Carbon emissions from additional energy sources during production were 0.0022 tCO2e/product from electricity, 0.0004 tCO2e from biomass, and 0.0001 tCO2e from PNG source.
5. This study evaluated the scope 1 and scope 2 category emissions produced at wool processing stage. The scope 1 and scope 2 emissions produced during wool processing are 56303.2 tCO2e and 1817.10 tCO2e respectively. Future research should include a corporate footprint of wool processing in order to deduce scope 3 emissions and understand total carbon emissions.

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