SCIEPublish

Article

Assessing Energy Emissions and Environmental Impact of Wool Processing: A Case Study of an Indian Textile Mill

Akshay Vade, Shriyasha Tari and Ashok Athalye *

Department of Fibres and Textile Processing Technology, Institute of Chemical Technology Mumbai, Mumbai 400 019, India; txt22an.vade@phd.ictmumbai.edu.in (A.V.); tch22sm.tari@phd.ictmumbai.edu.in (S.T.)

* Corresponding author. E-mail: ar.athalye@ictmumbai.edu.in (A.A.)

Received: 8 April 2024; Accepted: 29 April 2024; Available online: 6 May 2024

ABSTRACT: The objective of this study is to investigate and analyze the effect of varying sources of energy inputs and their impact on carbon emissions during wool fiber processing. The method involved industrial visits to the textile wool processing mill and interaction with the manufacturing as well as commercial sourcing teams to gather relevant data. The results and outcome of this analysis indicate that wool wet processing is responsible for a significant carbon emission of about 0.031 tCO_2e/unit of production. Coal as a source of energy has the highest carbon emission 0.066 tCO_2e/product, while the use of biomass and Pressurized Natural Gas (PNG) had significantly lower CO_2 emissions. Further, this study evaluated the scope 1 and scope 2 category emissions produced at the wool processing stage which accounted for 56303.2 tCO_2e and 1817.10 tCO_2e respectively.

Keywords: Biomass; CO_2 Emission; Green House gases; Renewable energy; Sustainable processing

1. Introduction

The textile wet processing industry is known for its energy-intensive and water-consuming steps. This study investigated process-wise energy consumption, water utilization, and waste generation in the wool wet processing industry through onsite factory assessment. In this study, the recycling and reusing of wastewater streams for industrial use were recorded to achieve savings in blue water consumption. The fuel sources (renewable and non-renewable) used to process wool from pretreatment to the finishing stage were analyzed. The waste generated from facility activities and the strategies used for waste disposal were evaluated. The energy transition from conventional non-renewable fuel sources to biomass was compared. The individual CO_2 emissions from corresponding fuel sources were calculated based on the quantified usage parameters of energy consumption. Based on this comprehensive analysis, a summary report is submitted.

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 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].

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/10.35534/spe.2024.10005

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 [8]. 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 [11,12]. 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 CO_2 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.

2. Materials and 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 on fuel sources, energy and water consumption was collected for two consecutive years 2021 and 2022 and compared to analyze the transition in sustainability measures adopted by the wool processing mill. This mill is engaged in the 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 study. The investigation and site survey of the mill were done as per the protocols mentioned in ISO 14001:2015 management systems protocol [18]

2.1. 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: 25,350 Kcal/nm^3, Supplier: Neelkamal energies; PNG: 9350 Kcal/nm^3, 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 with PNG. Also, coal was partially substituted by biomass in 2022. During the survey, it was recorded that coal was in use from 1 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- Megajoules (MJ) for simplicity in calculations using conversion factors specified by Bureau of Energy Emissions (BEE) [19].

Energy expressed in Megajoules = Energy consumption in independent unit × 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 requires 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 Megajoules (MJ)	
Fuel Source	**2021**	**2022**	**Unit of Measurement**	**Conversion Factor**	**2021**	**2022**
Electricity	2.91×10^6	2.99×10^6	kWh	3.6	1.05×10^8	1.08×10^8
Diesel	2.74×10^3	0	L	35	9.79×10^4	0
Biomass	0	4.08×10^3	mt	239	0	9.76×10^5
LPG	0	3.74×10^4	L	25	0	9.35×10^5
Coal	1.15×10^6	2.32×10^4	mt	21,887	2.51×10^{13}	5.09×10^8
PNG	1.10×10^3	4.58×10^4	SCM	36	4.06×10^4	1.70×10^6

Figure 1 represents the vertical setup of the wool processing mill investigated for this study. As shown in the figure, the input fuel sources like electricity, PNG, LPG and Diesel were used for processing operations. The mill was observed to be majorly dependent on coal to fuel its boiler machinery in 2021. However, the mill phased out coal partially in 2022 as biomass replaced coal. The net impact on climate through scope 1 and 2 emissions is assessed. It is well known that climate change is associated with emissions released from anthropogenic activities. For this study, the carbon emissions resulting from the energy consumption of each fuel source utilized in the wet processing of wool were calculated using a greenhouse gas equivalencies calculator [21].

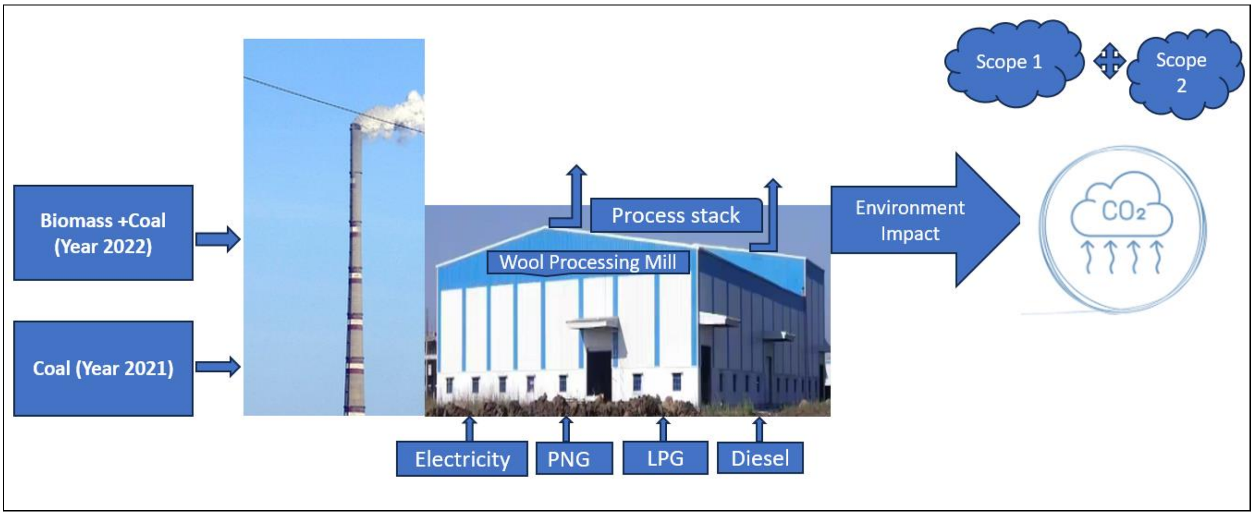

Figure 1. Year-wise Environmental Impact of Wool Processing.

This study evaluated two scopes (scope 1 and scope 2) as defined by GHG for 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's GHG program, the direct GHG emissions released from sources 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 belongs to scope 2 category emissions. The emissions generated from the consumption of various kinds of fuel sources are illustrated in Table 2. The energy consumption of fuel sources is recorded in coherence with the emission factors prescribed by BEE and expressed in their accepted SI units as follows: electricity in kilowatt-hours (kWh), the quantity of diesel and LPG consumed in litre (L), quantity of biomass briquettes and coal expressed in metric ton (mt) and PNG is expressed in Standard Cubic Meter.

Table 2. CO_2 emissions in wool processing and category assessment of emissions.

Energy Consumed	SI Unit	2021	2022	Emission Factor	tCO_2e-2021	tCO_2e-2022	Category-GHG Emission
Electricity	kWh	2.91×10^6	2.99×10^6	0.61	17.67	1.82×10^3	Scope 2
Diesel	L	2.74×10^3	0	2.7	7	0	Scope 1
Biomass	mt	0	4.08×10^3	72.62	0	2.96×10^2	Scope 1
LPG	L	0	3.74×10^4	1.56	0	58.24	Scope 1
Coal	mt	1.15×10^6	2.32×10^4	2.40×10^3	2.76×10^6	5.59×10^4	Scope 1
PNG	SCM	1.10×10^3	4.58×10^4	2	2	93	Scope 1
Total					2.76×10^6	5.81×10^4	

2.2. Inlet Water Consumption and Re-Use

The water mapping diagram shown in Figure 2 represents the water supply and consumption in various departmental activities of the mill. 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 reuse 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. 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 requisite and for drinking purposes. 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.

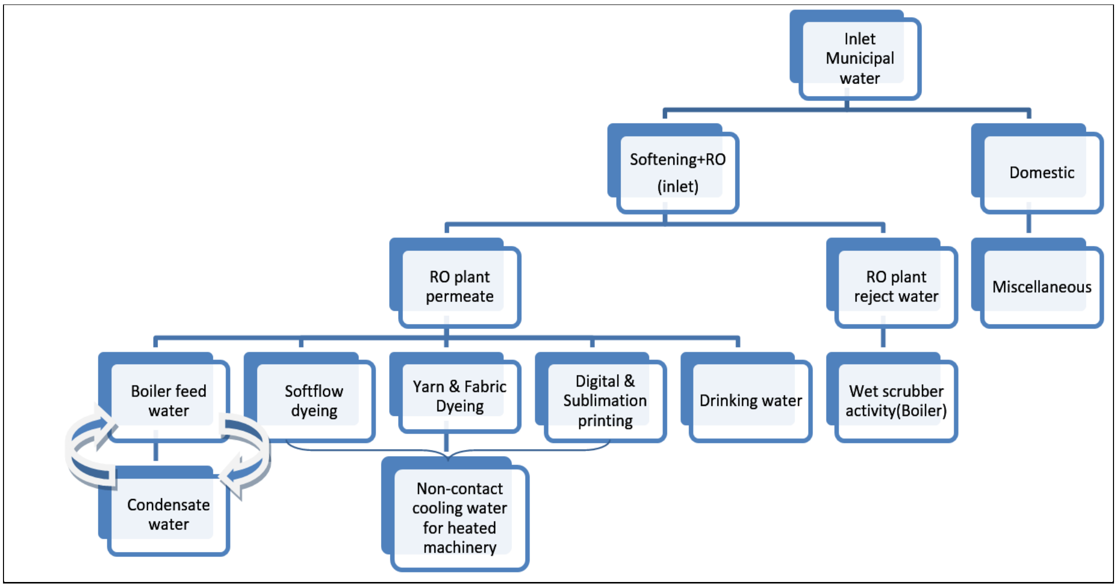

Figure 2. Water Mapping in Wool Processing.

Table 3. Comparison of annual water consumption in facility.

Water Usage	2021 (Kiloliters)	2022 (Kiloliters)
Municipal Water source (Inlet water)	6.36×10^4	5.39×10^4
Condensate water reused for boiler operations(input)	0	2.12×10^4
Reverse reject water reused in wet scrubber	0	2.80×10^3
RO Feed	9.82×10^3	8.74×10^3
Boiler (Steam generation)	7.14×10^3	5.94×10^3
Fabric Dyeing +soft flow	2.42×10^4	2.34×10^4
Digital printing	2.28×10^3	2.29×10^3
Sublimation printing	5.96×10^2	5.56×10^2
Yarn dyeing	1.09×10^4	1.47×10^4
Domestic	1.52×10^4	2.51×10^3
Miscellaneous	6.90×10^2	1.72×10^3

2.3. Waste Generated in Facility-Hazardous & Non-Hazardous

While evaluating GHG emissions from anthropogenic activities it is necessary to consider 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 the 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 hazardous and non-hazardous waste produced in the facility is enlisted in Table 4. 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 is 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 lighting purposes. Electronic waste like computer parts—keyboards, cable wiring, and others. The 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.

Table 4. Waste generation and disposal methods.

Waste Generated	2021	2022	Final Disposal Method
Fabric (material waste)	4.49×10^2	4.39×10^2	Recycle
Plastic (polybag and plastic scrap)	1.15×10^3	1.31×10^3	Recycle
Paper waste	9.35×10^2	9.76×10^2	Reuse and recycle
Food	9.51×10^2	8.53×10^2	Reuse
Empty Chemical Drums and boxes (production)			Reuse and recycle
Tube light waste	4.5×10^2	4.6×10^2	Landfill
Electronic waste	1.64×10^3	1.78×10^3	Recycle and landfill
Used Oil (waste oil)	2.71×10^3	1.98×10^3	Recycle and incineration
Boiler Ash	1.71×10^5	1.68×10^5	Reuse
Sludge	1.96×10^3	2.01×10^6	Landfill
Total	1.76×10^5	2.18×10^6	

3. Theory/Calculation

tCO_2e of an equation:

$$\text{Energy consumption} \times \text{USEPA emission factor} = tCO_2e \quad (1)$$

4. Results & Discussion

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 due to environmental regulations and pressures 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 CO_2 emissions significantly. A net reduction of 2704455 tCO_2e was observed in comparison to 2021. The facility has switched from cleaner fuels, like LPG/PNG gas, to diesel fuel and saved 7.4 tCO_2e emissions. Recycling and reuse of water have resulted in 15% blue water savings.

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. Though there is significant pressure from renowned brands like Inditex for phasing out coal and other non-renewable fuels in production, yet it's difficult for processors to make the diversion. Adopting substitutes for coal in set processes requires significant investment and phasing out existing machinery. Renewable fuel sources like biomass occupy more space. Processors are somewhat reluctant to adapt to these changes and added production costs.

It is observed that the facility has limited sources to maintain energy consumption and emissions data. There is a lack of understanding in the field of emission factors and GHG scopes. Adequate training sessions on topics of energy balance, water balance, waste disposal methods and scope-wise emissions can be provided to factory personnel. It is also seen that the factory is equipped with machinery that is compatible with fossil fuels like coal. The technical upgradation of machinery needs huge capital investment. The small-scale processors are reluctant to incur this cost and make the necessary switch towards sustainability. As per compliance requirements of different brands to fulfill energy. A collective effort from the brands and legal compliances is required to ensure set energy targets, energy mapping and responsible energy consumption. It is seen that the facility has engaged in different social audit activities like Fair Trade, Business, Social and Compliance Initiative (BSCI) based on International Labour Standards, Ethical Trade Initiative (ETI) based codes and legal requirements. 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. All in all, this study 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.

5. Conclusions

The carbon emissions 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 tCO_2e/product. 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 tCO_2e/product. Carbon emissions from additional energy sources during production were 0.0022 tCO_2e/product from electricity, 0.0004 tCO_2e from biomass, and 0.0001 tCO_2e from PNG source. 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 tCO_2e and 1817.10 tCO_2e, respectively. Future research should include a corporate footprint of wool processing in order to deduce scope 3 emissions and understand total carbon emissions. In future studies, the scope and boundary need to be well-defined for life cycle impact inventory. Life cycle impact analysis of product and process is needed to assess the overall environmental impact of the woolen textile industry. An assessment tool specifically designed to monitor energy consumption at different stages of life cycle aspects and impact for continuous monitoring is needed. This assessment tool can be beneficial in analyzing onsite scope wise emissions at all stages.

Acknowledgments

All authors of this article are grateful to the management and staff of Department of Fibres and Textile Processing Technology, ICT Mumbai Campus for their support and guidance in carrying out this work**.**

Author Contributions

Site survey, field visits and data collection and investigation for this case study were performed by A.V. Data analysis and evaluation were performed by S.T. The methods and results presented were reviewed by A.A. A.V. wrote the first draft of the manuscript. All authors read and approved the final manuscript. A.A. is the corresponding author of this manuscript.

Ethics Statement

Not applicable for studies not involving humans or animals.

Informed Consent Statement

Not applicable for studies not involving humans.

Funding

The authors of this manuscript confirm that this study was not funded by any organization.

Declaration of Competing Interest

The information gathered and presented in this article does not potentially provide any personal gain from any source.

References

1. Salem Allafi FA, Hossain MS, Kadir M, Ab O, Hakim Shaah MA, Lalung J, et al. Waterless processing of sheep wool fiber in textile industry with supercritical CO_2: Potential and challenges. *J. Clean. Prod.* **2021**, *285*, 124819.
2. Salem Allafi FA, Hossain MS, Kadir M, Ab O, Hakim Shaah MA, Lalung J, et al. A Review on Characterization of Sheep Wool Impurities and Existing Techniques of Cleaning: Industrial and Environmental Challenges. *J. Nat. Fibers* **2022**, *19*, 8669–8687.
3. Sun J, Wang H, Zheng C, Wang G. Synthesis of some surfactant-type acid dyes and their low-temperature dyeing properties on wool fiber. *J. Clean. Prod.* **2019**, *218*, 284–293.
4. Pailthorpe M, Wood E. Principles of Wool Fabric Finishing Mike Pailthorpe and Errol Wood. Available online: https://www.woolwise.com/wp-content/uploads/2017/07/WOOL-482-582-12-T-15.pdf (accessed on 7 July 2017).
5. Broda J, Gawlowski A, Rom M, Kobiela K. Utilisation of waste wool from mountain sheep as fertiliser in winter wheat cultivation. *J. Nat. Fibers* **2023**, *20*, 2200047.
6. Zhang S, Xu C, Xie R, Yu H, Sun M, Li F. Environmental assessment of fabric wet processing from gate-to-gate perspective: Comparative study of weaving and materials. *Sci. Total Environ.* **2023**, *857*, 159495.
7. Liu C, Holst J, Yao Z, Brüggemann N, Butterbach-Bahl K, Han S, et al. Sheepfolds as "hotspots" of nitric oxide (NO) emission in an Inner Mongolian steppe. *Agric. Ecosyst. Environ.* **2009**, *134*, 136–142.
8. Saggar S, Hedley CB, Giltrap DL, Lambie SM. Measured and modelled estimates of nitrous oxide emission and methane consumption from a sheep-grazed pasture. *Agric. Ecosyst. Environ.* **2007**, *122*, 357–365.
9. Yetişgin SO, Morgan-Davies C, Önder H. Comparison of farm-level greenhouse gas emissions in transhumance and semi-intensive sheep production systems in continental rangelands. *Animal* **2022**, *16*, 100602.
10. Sim J, Prabhu V. The life cycle assessment of energy and carbon emissions on wool and nylon carpets in the United States. *J. Clean. Prod.* **2018**, *170*, 1231–1243.
11. Wiedemann SG, Biggs L, Nebel B, Bauch K, Laitala K, Klepp IG, et al. Environmental impacts associated with the production, use, and end-of-life of a woollen garment. *Int. J. Life Cycle Assess.* **2020**, *25*, 1486–1499.
12. Wiedemann SG, Yan M-J, Henry BK, Murphy CM. Resource use and greenhouse gas emissions from three wool production regions in Australia. *J. Clean. Prod.* **2016**, *122*, 121–132.
13. Gebbels JN, Kragt ME, Thomas DT, Vercoe PE. Improving productivity reduces methane intensity but increases the net emissions of sheepmeat and wool enterprises. *Animal* **2022**, *16*, 100490.
14. Biswas WK, Graham J, Kelly K, John MB. Global warming contributions from wheat, sheep meat and wool production in Victoria, Australia—A life cycle assessment. *J. Clean. Prod.* **2010**, *18*, 1386–1392.

15. Brock PM, Graham P, Madden P, Alcock DJ. Greenhouse gas emissions profile for 1 kg of wool produced in the Yass Region, New South Wales: A Life Cycle Assessment approach. *Anim. Prod. Sci.* **2013**, *53*, 495.
16. Bhatt A, Abbassi B. Review of environmental performance of sheep farming using life cycle assessment. *J. Clean. Prod.* **2021**, *293*, 126192.
17. Atkar A, Pabba M, Sekhar SC, Sridhar S. Current limitations and challenges in the global textile sector. In *Fundamentals of Natural Fibres and Textiles*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 741–764.
18. ISO Environmental management systems std 14001 2015. ISO (the International Organization for Standardization), 2015. Available online: https://www.nerldc.in/wp-content/uploads/ISO_14001_2015_EMS.pdf (accessed on 1 May 2022).
19. Emission Factors for Greenhouse Gas Inventories. 2022. Available online: https://www.epa.gov/system/files/documents/2022-04/ghg_emission_factors_hub.pdf (accessed on 1 May 2022).
20. Gunturu KPK, Kota KK, Sharma M. Energy Efficiency Improvement Opportunities in Indian Textile Industries. *Text. Leather Rev.* **2022**, *5*, 296–326.
21. EPA Center for Corporate Climate Leadership. Simplified GHG Emissions Calculator. Available online: https://www.epa.gov/climateleadership/simplified-ghg-emissions-calculator (accessed on 1 May 2022).
22. ISO14046:2014(E). Available online: https://cdn.standards.iteh.ai/samples/43263/98b5af59d9574880a6d97da0aeb30940/ISO-14046-2014.pdf (accessed on 1 August 2014).
23. Thakker AM, Sun D. Sustainable Development Goals for Textiles and Fashion. *Environ. Sci. Pollut. Res.* **2023**, *30*, 101989–102009.