INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)
(Int Peer Reviewed Journal)
Vol. 04, Issue 12, Decembaer 2024, pp : 1451-1457
www.ijprems.com
editor@ijprems.com
e-ISSN : 2583-1062
Impact Factor : 7.001

AN ASSESSMENT OF INTEGRATED COTTON TEXTILE MILL FOR THE WATER AND ENERGY FOOTPRINT AND ITS RELATIONSHIP TO SUSTAINABLE DEVELOPMENT GOALS

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DOI: https://www.doi.org/10.58257/IJPREMS37049

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 kgCO_2e/unit of production. Purchase electricity as a source of energy has the highest carbon emission 0.112 kgCO_2e/product, while the use of biomass and Diesel (PNG) had significantly lower CO_2 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

1. INTRODUCTION

Various kinds of fibers (natural, synthetic), types of substrates (fiber, yarn, fabric, garment), and processing techniques (batch, semi-continuous, continuous) result in textile processing being very divided and complicated. Typically, the most commonly used fibers for clothing and home textile products, such as polyester and cotton, are frequently analyzed for their energy and water usage; the energy effects of other significant fibers, notably polyester/cotton mixtures, have been largely overlooked.

Cotton wet processing Cotton is a natural fiber mainly taken from the fibers of cotton plants during farming and gathering. Raw cotton has cellulose, wax, protein, pectin, seeds, dirt, and plant material as contaminants [1]. These contaminants are known as cotton scouring, and to prepare for dyeing and finishing processes, this cotton grease is eliminated in the scouring phase through hot water treatments with gentle detergents [2]. Cotton is primarily colored with reactive dyes, which form a strong covalent bond [3].

Typically, procedures such as desizing, scouring, bleaching, mercerization, and calendaring are performed to enhance the commercial and functional value of cotton. The processing steps, including cleaning cotton by eliminating impurities (scouring), mercerization, dyeing and printing (coloration), and finishing, are collectively referred to as the wet processing of cotton [4].

1.1 Environmental Profile of Cotton

The Egyptian cotton defines cotton as an eco-friendly fiber, which is biodegradable, recyclable, and renewable. Unlike other fibers, cotton does not cause micro plastic pollution in the oceans. Cotton is linked to the natural carbon cycle. When it breaks down, cotton enhances the soil's nutrient content by acting like a fertilizer and consequently returns carbon to the soil [5].

As a natural fiber, cotton is frequently promoted as a sustainable option compared to synthetic fibers, which are recognized for their energy emissions and environmental effects [6]. Even though cotton comes from natural sources, the cultivation and harvesting of cotton plants, as well as the cotton production industry, contribute to greenhouse gases (GHG) such as methane and nitrous oxide [6-7].

2. LITERATURE REVIEW

The studies released so far have explored the environmental effects of cotton from cultivation to the final product. Greenhouse gas (GHG) emissions at the farm level from growing and harvesting cotton, as well as transhumance, and production in continental rangelands have been reported [9]. Lifecycle assessment (LCA) research focusing on the energy and water usage has been conducted for cotton carpets and clothing [9-10]. One study examined the energy, water, and land utilized in producing Egyptian cotton. However, this study was limited to initial production, concentrating only on the farm to gate impact [12]. Another study looked into methane emissions from cotton operations in Asian nations [13]. All these studies have reviewed the emissions produced by grazing animals and pastures on farms in key cotton growing and harvesting areas such as China and Egypt [14]. The GHG profile for producing 1kg of cotton was evaluated for the Yass region in New South Wales [15].

Thus, the research conducted to date has concentrated on assessing environmental effects only until the cotton fiber production phase. Furthermore, the reported greenhouse gas evaluations and life cycle assessment studies come from significant cotton-producing areas such as China. A review of the environmental performance related to cotton farming and harvesting indicates that most life cycle assessment studies have defined the cradle-to-farm gate boundaries for their evaluations. This comprehensive review concerning cotton farming and harvesting states, “Additional research is required to identify the effects of “post-farm” processes like the processing of cotton products before they reach consumers and to take into account environmental effects beyond just climate change” [16].

There is insufficient information in the available literature regarding the scope-specific CO2 emissions generated during the textile processing of cotton after its production. Because of resource accessibility, adaptable environmental regulations, and low labor costs, significant textile processing occurs in the global south. South Asian nations such as China, India, and Bangladesh are currently the primary centers for textile processing industries [17]. This research aims to fill the void in the current literature that is missing data on energy emissions and the sustainability aspects of cotton during the wet processing phase.

3. METHODS

All results detailed in this research were obtained through on-site measurement of measurable parameters and field information gathered from a cotton processing facility situated in Ludhiana District, Punjab State, India. The information on fuel sources, energy and water usage was gathered for two back-to-back years, 2021 and 2022, and analyzed to evaluate the changes in sustainability practices implemented by the cotton processing facility. This facility specializes in processing cotton floor coverings, bathmats, door mats, durries, flokati rugs, carpets, and various upholstery fabrics and home textile The specifics of tools and equipment utilized for gauging power, fuel, and water usage according to the established guidelines of regulatory authorities are outlined in the following sections of this chapter. The assessment and site examination of the mill were conducted following the protocols indicated in ISO 14001:2015 management systems protocol [18].

3.1 Energy Consumption

Table 1 shows the quantity of Coal needed for producing steam in boiler operations for cotton Mercerization, dyeing, and finishing processes. This was measured using the Thermax A2Z Flo-S Steam Flow Meter. Energy use from other fuel types such as biomass, liquefied petroleum gas (LPG), and pressurized natural gas (PNG) was inferred from supplier invoices and internal tracking systems. The emissions generated by any fuel type have a reverse correlation with the calorific value of fuels. Calorific value serves as a key measure of fuel efficiency. Bituminous and Indonesian coal are usually provided in textile mills. The mill mentioned in this study utilizes Indonesian coal with a calorific value of 5500 Kcal/kg.The use of locally sourced agro residues as Biomass is growing in India. This encompasses rice husks, coconut shells, groundnut shells, coffee husks, wheat stalks, etc. The reported figures for biomass usage in Table 1 mainly originate from the use of paddy husk, which has a calorific value of 3568 Kcal/kg. Diesel (calorific value - 10,800 Kcal/kg) is supplied to the mill by a local distributor. The supplier information and calorific values of other fuel types 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 obtained from the power grid supply provided by Punjab State Power Corporation Limited. Up until 2021, the mill was utilizing coal, electricity, diesel, and PNG. In 2022, the cotton processing mill completely eliminated diesel and switched to PNG. Additionally, in 2022, coal was partly replaced by biomass. The survey noted that coal was utilized from 01 January 2022 to 30 August 2022. To decrease coal usage, biomass was used from 1st September 2022 to December 2022. A record of separate energy usage from Independent fuel sources was represented in a single uniform unit—mega joules (MJ) for ease of calculation using conversion factors defined by the Bureau of Energy Emissions (BEE) [19].

Energy in Mega Joules = Energy consumption in independent unit x Conversion factor As can be clearly observed in

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Table-1, in the energy consumption (shown in MJ) column, the highest energy consumption came from coal usage in 2021. According to the research by BEE, the jet dyeing process needs 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 cotton 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

3.2 Emissions produced in cotton processing

It is widely recognized that climate change is linked to emissions generated from human activities. For this research, the carbon emissions caused by energy use from each fuel type employed in the wet processing of cotton were calculated using a greenhouse gas equivalencies calculator [21].

Three "scopes" (scope 1, scope 2, and scope 3) are established for greenhouse gas accounting and reporting to differentiate between direct and indirect emission sources, improve transparency, and provide utility for different kinds of organizations, as well as various climate policies and business objectives. According to the greenhouse gas protocol and the guidelines of the India GHG program, direct greenhouse gas emissions from sources owned or controlled by the company are classified as scope 1.

Fuel types such as Diesel, Biomass, Coal, and LPG used in the wet processing phases of cotton contributed to scope 1 category emissions. The greenhouse gas emissions from the generation of electricity, steam, and dry heat that a company purchases and uses fall under scope 2. Electricity utilized for processing and non-production tasks in the cotton processing mill is categorized as scope 2 emissions.

Table 2: CO2 emissions in cotton 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	

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2.2 Inlet water consumption and re-use

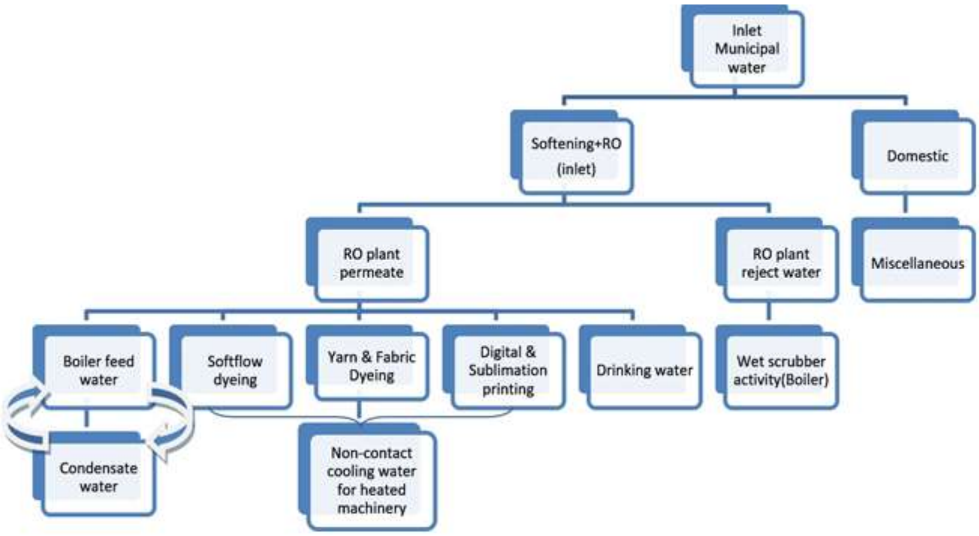

Figure 1– Water Mapping in Cotton Processing

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 boiler operations(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 measurements and terms related to water use are recorded in line with the ISO 14046 water footprint principles [22]. The water brought in from municipal sources is circulated throughout the mill for stages of textile wet-processing such as scouring, dyeing, printing, and finishing. The main decrease in water use is due to recirculation and reuse. Processes like bleaching full white and dyeing lighter shades on cotton require ideal bath pH, low water hardness, and total dissolved solids (TDS).

To address this, the facility has a softening plant and a reverse osmosis (RO) system. The untreated water supplied by municipalities first goes through a softening machine, then through RO. The water coming out of RO has two outputs: permeate and reject. Permeate water is used for processes sensitive to pH and chemical treatments where water quality is important, as well as for drinking. The rejected water is reused in the wet scrubber processes. Industrial boilers have wet scrubbers to capture fine ash particles and prevent air pollution. The condensing water from the boiler is reused to feed the boiler for producing wet steam.

Wet processing equipment used for calendaring and dyeing with a jigger and soft flow dyeing machine needs additional cooling. Water used for this non-contact cooling is collected and reused. As shown in Table 3, the facility's annual water consumption was decreased by about 15%. This change is clear because of strategies like reuse and recirculation, which were not in place in 2021. Among all wet processes, fabric dyeing uses the most water compared to yarn dyeing. The material-to-liquid ratio in the Jigger and soft flow machine is greater than that in the Winch, cabinet dyeing machine used for dyeing yarn/hank or fabric.

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	

4. RESULTS

The results from this onsite survey allowed us to determine the net emissions generated in the cotton processing sector. Starting from September 2022, the facility has entirely eliminated the use of coal as a fuel source. The move towards green energy sources is reflected in the annual fuel usage of 2022. The replacement of coal with biomass is clear due to environmental regulations and demands from leading clothing brands such as William Sonoma, Next Brand, C&A, Tommy Hilfiger, Ralph & Lauren, and Bestseller to eliminate non-renewable fuels like coal. The selective replacement of coal with biomass led to a significant reduction in CO2 emissions. A total decrease of 2,704,455 t CO2 e was noted compared to 2021. The facility has transitioned to cleaner fuels, including LPG/PNG gas, and diesel fuel, resulting in a savings of 7.4 t CO2 emissions. The recycling and reuse of water have achieved a 15% reduction in blue water usage.

5. DISCUSSIONS

Use of large amounts of water is necessary in traditional processing steps of cotton such as scouring, Mercerization, dyeing, and printing. The application of machinery with a low material-to-liquid ratio can further lessen water usage, particularly in dyeing and coloration methods. Heating water to required temperatures for scouring and bleaching cotton, as well as dyeing and printing cotton fabrics, requires energy.

Energy usage correlates with the quantities of water needed in processing baths. In addition to the main processes like scouring, dyeing, and finishing, extra water is used in supporting procedures like neutralizing, washing, and cooling. Integrated processes such as one-bath scouring bleaching and minimizing frequent pH changes during processing can further decrease additional water usage and subsequent heating.

Tailoring the application of dyes and colorants through Industry 4.0 methods like digital printing and digital finishing can further minimize resource, water, and energy use. Developing waterless processes should be the primary goal for improving energy efficiency. This paper discusses 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.

6. CONCLUSION

- The carbon emissions generated in each stage of cotton processing were calculated separately. It is noted that the cotton wet processing contributes significantly to carbon emissions at approximately 0.031 tCO2e/product.
- After identifying the various energy types needed for the different production phases, it was discovered that coal resulted in the highest carbon emissions, totaling 0.066 tCO2e/product.
- Carbon emissions from other energy sources during production were 0.0022 tCO2e/product from electricity, 0.0004 tCO2e from biomass, and 0.0001 tCO2e from PNG source.
- This study assessed the emissions in the scope 1 and scope 2 categories produced during the cotton processing phase. The emissions in scope 1 and scope 2 during cotton processing amounted to 56303.2 tCO2e and 1817.10 tCO2e

respectively. Future studies should assess the corporate footprint of cotton processing to determine scope 3 emissions and grasp total carbon emissions.

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