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ENVIRONMENTAL IMPACT ANALYSIS OF NYLON MATERIAL PROCESSING

AKSHAY VADE[1] AND DR. ASHOK ATHALYE[2]

Department of Fibres and Textile Processing Technology[1,2]

Institute of Chemical Technology, India

Akshay Vade: txt22an.vade@phd.ictmumbai.edu.in

Corresponding author: AKSHAY VADE

ABSTRACT

The nylon textile sector is an energy- and water-intensive contributor to global greenhouse gas (GHG) emissions, yet most published life-cycle assessments focus primarily on polymer synthesis and fibre production, with limited attention to downstream wet processing. This study presents a gate-to-gate environmental assessment of nylon fabric wet processing in an industrial facility located in Surat, India, covering energy consumption, water use, waste generation, and associated carbon emissions. Primary operational data for two consecutive years (2022–2023) were collected through on-site audits, verified production records, and management interviews, following ISO 14001 and ISO 14046 principles. Scope 1 and Scope 2 emissions were quantified using established emission factors. Results indicate that purchased electricity dominates the carbon footprint, contributing approximately 3.03 kg CO_2e per kg of processed nylon fabric, while total Scope 1 and Scope 2 emissions amounted to 5,968.9 t CO_2e in 2023. Water-recycling interventions, including condensate recovery and reverse-osmosis reject reuse, achieved an overall reduction of nearly 15% in freshwater withdrawal. The findings highlight critical emission hotspots in dyeing and finishing stages and demonstrate the potential of process optimization, low-liquor-ratio machinery, and Industry 4.0-based monitoring to reduce resource intensity. This study addresses an important data gap in nylon wet-processing sustainability and provides practical insights aligned with Sustainable Development Goals (SDGs) 6, 7, 12, 13, and 15.

KEYWORDS: Cupralactum; Carbon sink; Hydrothermal, Microplastic Pollution

1. INTRODUCTION

The textile industry is recognized as one of the most resource-intensive manufacturing sectors, characterized by high energy demand, substantial water consumption, and complex chemical usage. Among synthetic fibres, nylon (polyamide) occupies a prominent position due to its excellent mechanical properties, durability, abrasion resistance, and versatility across apparel, home textiles, and technical applications. Global demand for nylon continues to increase, intensifying concerns regarding its environmental footprint.

While numerous studies have evaluated the environmental impacts of nylon at the polymerization and fibre-spinning stages, comparatively little attention has been paid to downstream wet processing, which includes scouring, dyeing, finishing, and auxiliary operations. These stages are particularly relevant in developing economies such as India, where textile wet-processing clusters are concentrated due to favourable labour availability, infrastructure, and market access [1].

Wet processing of nylon is technologically demanding, requiring precise control of temperature, pH, and chemical dosing. These requirements translate into high energy use for heating and significant water consumption for dye baths, rinsing, and washing. Consequently, wet processing represents a critical hotspot for greenhouse gas emissions and water stress. Addressing this gap, the present study focuses on a detailed environmental assessment of nylon fabric wet processing, with emphasis on energy use, carbon emissions, water management, and waste generation.

A. RAW MATERIAL EXTRACTION- ENVIRONMENTAL CONCERNS:

Non-renewable resources: Crude oil extraction depletes finite resources and can result in land degradation, habitat destruction, and oil spills.

Greenhouse Gas (GHG) Emissions: The refining and processing of petrochemicals release substantial amounts of CO_2 and other GHGs.

B. POLYMERIZATION PROCESS-ENVIRONMENTAL CONCERNS:

High energy consumption: Requires significant electricity and heat, contributing to GHG emissions.

Nitrous oxide (N_2O) emissions: Particularly from adipic acid production—a potent GHG approximately 300 times more

impactful than CO_2.

C. FIBER SPINNING AND FABRIC PRODUCTION-ENVIRONMENTAL CONCERNS:

Water usage: Especially in wet processes like dyeing.

Chemical usage: Includes solvents, dyes, and finishes, many of which can be toxic or bioaccumulative.

Wastewater generation: Contains colorants, surfactants, and other pollutants.

D. NYLON PROCESSING-ENVIRONMENTAL CONCERNS:

Steam and electricity are used extensively in polymerization, extrusion, and drying.

Energy use contributes to indirect environmental impacts through fossil fuel combustion (unless renewable energy is used).

E. SOLID WASTE GENERATION-ENVIRONMENTAL CONCERNS:

Includes: Off-spec polymer, Fiber trimmings, Packaging waste, Sludge from effluent treatment plants

If not properly managed, these contribute to landfills and microplastic pollution. Fiber shedding: Nylon garments and fabrics shed microfibers during washing. Environmental hazard: These microplastics enter water bodies and food chains, posing ecological and human health risks.

F. END-OF-LIFE ISSUES-ENVIRONMENTAL CONCERNS:

Non-biodegradability: Nylon persists in landfills for hundreds of years.

Limited recyclability: Mechanical recycling degrades quality. Chemical recycling is emerging but not widely adopted due to high costs and complexity. Incineration releases toxic gases if not controlled properly [2,3]

1.1 NYLON - MELT SPINNING, WEAVING AND PROCESSING

The wet processing of nylon fabrics begins with pre-treatment, which aims to eliminate any impurities, lubricants, or processing oils that may remain from spinning, knitting, or weaving operations. Although nylon is typically produced as a relatively clean fiber, scouring remains essential to enhance dye absorption and uniformity. Scouring is performed using a mild alkaline bath with non-ionic or anionic detergents at temperatures ranging from 60°C to 80°C. The process duration is typically 20 to 30 minutes, and it is important to avoid harsh alkalis like sodium hydroxide, which can degrade the polymer chains of nylon. In some cases, if the fabric exhibits off-white shades or yellowish tones, a mild bleaching step using hydrogen peroxide under acidic conditions (pH 5-6) may be employed. Unlike cotton or viscose, extensive bleaching is rarely needed for nylon due to its inherent whiteness and dye receptivity.

Following scouring and optional bleaching, the fabric is often subjected to heat-setting, a thermal process that stabilizes the fabric's dimensions and structure. Heat-setting is particularly vital for nylon knits and stretch fabrics to reduce shrinkage, curling, and potential distortions during subsequent wet processing or garment use. The process is conducted in dry heat ovens at temperatures between 180°C and 200°C for a duration of 30 to 90 seconds, depending on fabric weight and construction. Overexposure to high temperatures, however, must be carefully avoided as it may lead to thermal yellowing or degradation of mechanical properties.

The next crucial step is dyeing, where color is imparted to the nylon fabric. Owing to its polyamide backbone, nylon exhibits a strong affinity for acid dyes, which are classified based on their migration and wash fastness characteristics into leveling, milling, and super milling dyes. Among dyeing methods, batch dyeing is most commonly employed for nylon, particularly using jet dyeing, winch, or soft flow machines that allow controlled heating and agitation. The dye bath is typically prepared at a pH of 4.5 to 5.5, maintained using acetic acid, formic acid, or ammonium acetate. A leveling agent may be added to the bath to prevent streaks and ensure uniform uptake across the fabric width. The temperature is gradually raised to 95°C to 100°C and held for 30 to 60 minutes to allow complete exhaustion of the dye onto the fiber. This slow heating is crucial for ensuring level dyeing, particularly when using leveling acid dyes [2]

After dyeing, after-treatment processes are undertaken to improve color fastness and remove unfixed dye residues. The dyed fabric is subjected to thorough rinsing followed by soaping at elevated temperatures (around 80°C) using a mild detergent. Cationic fixing agents may be applied to enhance wet fastness, especially in the case of bright or deep shades. Fixing agents help bind the dye molecules more strongly to the fiber, minimizing dye bleeding during washing or perspiration exposure. In some instances, antistatic agents are also added during after-treatment, especially for garments like lingerie, hosiery, or uniforms, which may otherwise exhibit static cling due to nylon's insulating nature.

The finishing stage in nylon wet processing is designed to improve the hand feel, functionality, and end-use performance of

the fabric. The most common finishes include softening, antistatic, moisture management, and water/oil repellency. Softening is usually achieved using silicone-based softeners or cationic agents that impart a smooth and supple touch to the fabric. For garments prone to static buildup, antistatic finishes using quaternary ammonium compounds or surfactant blends are employed to improve wearer comfort. In performance wear and sports textiles, wicking finishes are used to promote moisture transport away from the skin. These finishes often contain hydrophilic polymers or surfactants that alter the surface energy of nylon, enabling better sweat absorption and evaporation. Moreover, for outdoor textiles or technical garments, water- and oil-repellent finishes using fluorocarbons or newer silicone-based technologies are applied to impart hydrophobicity while retaining breathability.

One challenge in the wet processing of nylon is thermal yellowing, which can occur during high-temperature processing or exposure to UV radiation. This phenomenon is particularly undesirable in white or pastel-colored fabrics. To mitigate this, anti-yellowing agents or optical brighteners may be applied during the final rinse or finishing stages. Additionally, ultraviolet absorbers or stabilizers can be used to enhance the lightfastness of dyed nylon products, especially in outdoor applications.

From an environmental perspective, the wet processing of nylon fabrics involves the use of acids, dyes, surfactants, and other auxiliaries that can contribute to wastewater load if not properly managed. The effluent from nylon dyeing typically contains residual acid dyes, dispersants, and acidic pH, which need to be neutralized before discharge. Modern dyeing facilities are increasingly incorporating effluent treatment plants (ETPs) with pH neutralization, biological treatment, and sludge management systems to comply with environmental regulations. Additionally, low liquor ratio dyeing machines, automated chemical dosing systems, and heat recovery units are being adopted to reduce water, energy, and chemical consumption [3]

Recent advancements in nylon wet processing include the development of eco-friendly dyeing technologies, such as supercritical CO_2 dyeing, which eliminates the use of water altogether. Though still in its early stages of commercialization for nylon, this method has demonstrated promising results in dye uptake and uniformity. Other innovations involve the use of plasma and ozone treatments as pre-treatment alternatives to scouring, aimed at modifying surface properties without the use of water or chemicals. Moreover, bio-based and biodegradable finishing agents are gaining traction as sustainable alternatives to conventional finishes [4]

1.2 ENVIRONMENTAL PROFILE OF NYLON

The synthetic nylon is considered as a non-eco-friendly fiber, which is non-biodegradable, non-recyclable, and non-renewable. Unlike other fibers, nylon causes micro plastic pollution in the oceans. Nylon is linked to the synthetic carbon cycle [5]. As a synthetic fiber, Recycled nylon is frequently promoted as a sustainable option compared with other synthetic fibers, which is also recognized for its high energy emissions and environmental impact during the manufacturing and the entire value chain during textile apparel, home furnishing and technical functionality applications [6]. Moreover, the synthesis of this fibre from its petrochemical feedstock and its further chemical synthesis, melt extrusion, followed by the mechanical drawing, twisting etc as well as the post processing involving a number of heating, cooling washing cycles contribute to a high emission of greenhouse gases (GHG) such as carbon dioxide and carbon monoxide [6-7].

The studies released so far have explored the environmental effects of nylon from melt spinning to the final product. Greenhouse gas (GHG) emissions at the melt spinning level from melt spinning nylon, as well as transhumance, and production in continental range-lands have been documented [9]. Life cycle assessment (LCA) studies examining energy and water consumption have been conducted for nylon T-shirts [9-10]. One such research examined the energy, water and land used in producing recycled nylon. However, this study was limited to initial production, concentrating only on the melt spinning for the cradle to get the resultant impact [12]. Some other studies looked into methane releases from nylon operations in Asian countries [13]. All these studies have reviewed the emissions produced by melt spinning in key nylon manufacturing, such as China and Egypt [14]. The GHG profile for producing 1kg of nylon was evaluated for the apparel industry in Vietnam [15].

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

The available literature does not provide enough information on the scope-specific CO2 emissions generated during the textile processing of nylon after its production. Because of resource accessibility, adaptable environmental regulations, and low labor costs, significant textile manufacturing occurs in the south asian nations like India, and Vietnam are currently the primary centers for textile manufacturing industries [17]. This study seeks to address the gap in the existing literature that is lacking

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data on energy emissions and the sustainability factors of nylon during the manufacturing and wet processing phase.

2. MATERIALS AND METHODS

All results detailed in this research were obtained through on-site Assessment of measurable Variables and field data, which were collected from a nylon processing facility situated in Surat District, Gujarat State. Data on fuel sources, energy, and water consumption were gathered from two consecutive years, 2022 & 2023, and analysed to evaluate some changes in sustainability practices carried out by the nylon manufacturing facility. Such a facility specialises in manufacturing nylon floor sarees, knitted hosiery and various home textiles, upholstery fabrics and products. ISO 14001 internal audit methodology is used for analysis of a systematic, independent, and documented process to evaluate an organisation's Environmental Management System (EMS) against the standard's requirements, identifying areas for improvement and ensuring compliance. Data verification using the triangular pillar system includes management interaction, record review and factory site visit systems.

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. The assessment and site examination of mills are carried out in accordance with guidelines outlined in the ISO 14001:2015 management systems standard [18].

2.1 STUDY BOUNDARY AND DATA COLLECTION

A gate-to-gate assessment was conducted at a commercial nylon wet-processing facility in Surat, Gujarat, India. The system boundary includes all operations from fabric input to finished fabric output, excluding upstream polymer production and downstream consumer use. Primary data for the years 2022 and 2023 were collected through on-site measurements, utility records, fuel invoices, and structured interviews with production and environmental management personnel.

This study was conducted following the internationally recognized Life Cycle Assessment (LCA) framework as defined in ISO 14040 and ISO 14044 standards. The methodological structure includes goal and scope definition, functional unit specification, system boundary identification, life cycle inventory (LCI) analysis, and impact assessment to ensure transparency, reproducibility, and scientific rigor.

Energy consumption from purchased electricity, diesel, and liquefied petroleum gas (LPG) was converted into megajoules using standard conversion factors. Scope 1 and Scope 2 GHG emissions were calculated using recognized emission factors consistent with the GHG Protocol and national guidelines. Electricity-related emissions were classified under Scope 2, while on-site fuel combustion emissions were classified under Scope 1.

Table 1 shows that the Energy use from other fuel types, such as diesel, liquefied petroleum gas (LPG), and purchased electricity, was inferred from the supplier invoices and tracking systems. Reported figures for Diesel (calorific value - 10,800 Kcal/kg) are provided to the mill by a regional supplier. The supplier details and calorific values of other fuel types used in the surveyed mill are as follows: LPG: 25,350 Kcal/Nm3, Supplier: Neel Kamal Energies; and electricity sourced from the power grid supply provided by Dakshin Gujarat Veej Company Limited. Up until 2023, the mill was using electricity, diesel, and LPG. [19].

Energy in Mega Joules = Energy usage in independent unit x Conversion factor [20].

The functional unit is defined as 1 kg of finished nylon fabric processed under standard industrial operating conditions. All inputs and outputs are normalized to this functional unit to allow comparability and reproducibility.

Table 1. Yearly Energy Usage of the Nylon Manufacturing Facility

Yearly Energy Consumption				
Fuel Source	**2022**	**2023**	**Unit of Measurement**	**Conversion Factor**
Electricity	10003988	7331838	kWh	3.6
Diesel	3194	878	Ltr	2.8
LPG	8816	5029	Kg	25

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This table presents the yearly energy consumption of three different fuel sources—Electricity, Diesel, and LPG—for the years 2022 and 2023. The consumption values are provided in their respective units: kilowatt-hours (kWh) for electricity, liters (Ltr) for diesel, and kilograms (Kg) for LPG. Additionally, a conversion factor is given for each fuel type, which can be used to convert the consumption values into another unit, likely mega joules (MJ).

- Electricity consumption was 10,003,988 kWh in 2022 and 7,331,838 kWh in 2023, which decreased due to the start of energy monitoring and implementation activities.

- Diesel consumption was 3,194 litres in 2022 and 878 litres in 2023, decreased due to the stop using diesel-based equipment.

- LPG consumption was 8,816 kg in 2022 and 5,029 kg in 2023, decreased due to the start of monitoring and the avoidance of excess usage of LPG.

The data suggests a reduction in energy consumption across all three fuel sources from 2022 to 2023.

2.2 EMISSIONS PRODUCED IN NYLON MANUFACTURING

It is widely acknowledged that climate change is linked to emissions produced by human activities. This research determined that carbon emissions caused by energy used from every fuel type employed in the manufacturing of Nylon were determined using a greenhouse gas equivalencies calculator [21].

When we talk about keeping an eye on carbon emissions, we usually break them into three groups: scope 1, scope 2, and scope 3. These categories help businesses find out where their emissions are coming from, so they can measure them properly and work on reducing their carbon footprint. According to the Greenhouse Gas (GHG) Protocol and the India GHG program guidelines:

- Scope 1 covers direct emissions from things that are owned or under the control of the company. For example, in creating nylon, any fuel is burnt on the site, such as diesel or LPG, scope 1 emissions used during the manufacturing process.

- Scope 2 includes indirect emissions from electricity that the company buys and uses. Therefore, all the power used to run the machines, light the factory, and comes under the purview of 2 emissions to run offices in the polyester plant.

By organising emissions in these categories, companies can better understand how their activities affect the environment. This makes it easy to find ways to cut carbon emissions, such as switching to cleaner fuel, using energy more efficiently, or adopting renewable energy sources.

Table 2. CO_2 emissions in nylon processing and classification of emission categories:

Energy Used	Unit	2022	2023	Emission factor	tCo2-2022	tCo2-2023	Category-GHG emission
Electricity	kWh	10003988	7331838	0.80	3403.20	5958.51	Scope 2
Diesel	Ltr	3194	878	2.8	8.637	2.521	Scope 1
LPG	Kg	8816	5029	1.56	13.27	7.845	Scope 1
Total					3425.111	5968.88	

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2.3 INLET WATER USAGE AND RECYCLING

Water usage data were categorized by process stage, including dyeing, printing, boiler operations, domestic use, and auxiliary processes. Recycling streams such as boiler condensate recovery and RO reject reuse were quantified to evaluate reductions in freshwater withdrawal.

Table 3. Analysis of yearly water usage at the facility

Usage of Water	2022(Kiloliters)	2023(Kiloliters)
Municipal Water (Inlet water)	63628	53932
Condensate water which reused for boiler operations(input)	0	21230
Reverse reject water recycled 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

This table presents the yearly water usage at the facility for the years 2022 and 2023. The values are measured in kiloliters (KL) and categorized based on different areas of consumption.

All measurements and terms related to water use are recorded in line with the principles of the ISO 14046 water footprint standards [22]. The water brought in from municipal sources is distributed throughout the mill for various stages of textile wet-processing, such as scouring, dyeing, printing, and final processing. The main decrease in water use is due to recycling and reuse. Processes like bleaching to achieve full white and dyeing lighter shades for nylon require an ideal bath pH, low water hardness, and minimal total dissolved solids (TDS).

The facility solves this using a softening plant and a reverse osmosis (RO) system. The untreated water supplied by municipalities first goes through a softening machine, then through RO. Water from the RO (reverse osmosis) system is divided into two streams: permit and reject. Permit water, which is high in purity, is used in procedures where pH balance and chemical control are important, such as sensitive industrial operations and even drinking water.

Instead of wasting, instead of wasting water, the wet scrubber system associated with the industrial boiler is reused smartly. These scrubbers help to trap well boiler ash particles and prevent them from polluting the air.
Meanwhile, the boiler-condensed water is recycled back into the system as feed water, which helps to produce wet steam again, making the process more efficient.

In addition, wet processing machines such as calendaring units, liver, and soft flow dyeing machines also require additional cooling to maintain optimal performance during operation. The Water used for such non-contact cooling which is collected and recycled. As shown in Table 3, the facility's annual water consumption decreased by about 15%. That change is clear due to strategies such as reuse and re-circulation, which were not implemented in 2021. Among all wet processes, fabric dyeing consumes more water than yarn dyeing. The material-to-liquid ratio in the Jigger and soft flow machine is higher than in the Winch and cabinet dyeing machine used for dyeing yarn/hank or fabric.

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2.4 WASTE PRODUCED AT THE FACILITY – HAZARDOUS AND NON-HAZARDOUS.

Both hazardous and non-hazardous wastes were quantified and classified according to local regulatory definitions. Disposal routes, including recycling, reuse, landfill, and authorized treatment, were documented.

Table 4 . Waste generation and disposal Methods

Waste Produced	2022	2023	Final disposal method
Fabric (waste material)	449	439	Recycle
Plastic (polybag and plastic scrap)	1147	1312	Recycle
Paper waste	935	976	Reuse and recycle
Food	951	853	Reuse
Empty Drums of Chemical and boxes (production)			Reuse and recycle
Waste from Tube light	4.5	4.6	Landfill
Electronic waste	16.4	17.8	Recycle and landfill
Used Oil (waste oil)	27.1	19.8	Recycling and incineration

The table presents data on different types of waste produced in 2022 and 2023, along with their respective disposal methods.

When evaluating GHG emissions from human activities, it is important to consider the amount of waste generated during industrial operations and its environmental impact after disposal. According to a notification by the Gujarat State Pollution Control Board (GPCB) in 2010, this feature is classified as high air emissions. The solid waste produced in the nylon processing mill was identified and carefully evaluated to determine how it is dealt with. This feature produces both dangerous waste, such as oil, tube lights and electronic waste as well as non-stringent waste, resulting in food waste from the waste of NYLONON, plastic waste, paper waste and food waste from the waste of food.

The nylon process waste arises during various wet processing activities such as scoring, heat settings, weight loss, dyeing and finishing. Paper waste from printing material is recycled into useful items such as recipe cards and sheet cards. Plastic waste comes mainly from packaging activities, including both raw material and finished product packaging. Food waste is produced by canteen and pantry operations. Tube lights and electronic waste are generated from operational activities such as lighting. Electronic waste includes items such as computer parts, keyboards, cables and other similar components. On average, nylon wet processing produces about 14.8 kg of waste. The waste produced in the convenience, both hazardous and non-hazardous, waste handler agreements, reporting to the site, transaction challans and manifest copies are verified. This feature also sends its food waste in a melted spinning process for re-use in food production. Meanwhile, paper, plastic and empty chemical containers are recycled through the authorized waste handlers to ensure proper settlement and stability.

3. RESULTS AND DISCUSSION

3.1 ENERGY USE AND EMISSION HOTSPOTS

The analysis revealed a significant reduction in total energy consumption from 2022 to 2023, primarily due to improved monitoring and reduced reliance on diesel-based equipment. Purchased electricity accounted for the largest share of energy use and carbon emissions, highlighting the importance of grid decarbonization and on-site renewable energy adoption.

Dyeing and finishing processes emerged as major energy hotspots due to high liquor ratios and elevated operating temperatures. The strong correlation between water use and energy demand underscores the need for integrated water-energy optimization strategies.

3.2 WATER FOOTPRINT AND PROCESS EFFICIENCY

Implementation of water-reuse measures resulted in an approximate 15% reduction in freshwater intake. Fabric dyeing consumed more water than yarn dyeing, reflecting higher material-to-liquor ratios in soft-flow and jigger dyeing machines.

Adoption of low-liquor-ratio equipment and real-time pH and temperature control can further reduce water and energy intensity.

3.3 WASTE MANAGEMENT PERFORMANCE

Non-hazardous wastes such as fabric scraps, paper, and plastic were predominantly recycled, while hazardous wastes were managed through authorized handlers. Although waste quantities were relatively modest compared with energy and water impacts, improved segregation and process control can further minimize waste generation.

3.4 IMPLICATIONS FOR SUSTAINABLE DEVELOPMENT

The findings demonstrate clear linkages between nylon wet processing and SDGs related to clean water, clean energy, responsible production, climate action, and ecosystem protection. Digitalization and Industry 4.0-based process control offer significant potential to enhance resource efficiency and reduce emissions.

4. SUMMARY

- The carbon emissions generated in each stage of nylon processing were calculated separately. It is noted that the nylon wet processing contributes significantly to carbon emissions at approximately 3.03 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 3.033 tCO2e/product.

- Carbon emissions from other energy sources during production were 3.033 tCO2e/product from electricity, 0.0013 tCO2e from Diesel, and 0.0039 tCO2e from LPG source.

- Nylon phase. The emissions in scope 1 and scope 2 during nylon processing amounted to 10.366 tCO2e and 5958.508 tCO2e, respectively.

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

5. CONCLUSION

This study provides a comprehensive gate-to-gate environmental assessment of nylon fabric wet processing, addressing a critical gap in existing literature. Results confirm that wet processing is a significant contributor to carbon emissions and water use within the nylon textile value chain, with purchased electricity representing the dominant emission source. Water-recycling initiatives and energy-monitoring systems demonstrated measurable benefits, reducing freshwater consumption and overall energy demand.

Future research should extend the system boundary to include Scope 3 emissions and explore comparative assessments of conventional and emerging low-water or waterless dyeing technologies. Transitioning toward renewable energy sources, low-liquor-ratio machinery, and circular material flows is essential for reducing the environmental footprint of nylon textiles.

AUTHOR CONTRIBUTIONS:

For this research articles with one authors, Akshay Vade specifying their individual contributions for data collection, analysis and action plan to prepare nylon procession to domestic market Authorship must be limited to those who have contributed substantially to the work reported.

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We hereby declare no conflict of interest.

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