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Research Article

A Life Cycle Assessment of Resource Use and Environmental Impacts in the Albanian Denim Garment Industry

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Abstract

The textile and clothing industry is among the most resource-intensive sectors, consuming significant amounts of water, energy, and chemical products, particularly in denim production. This study analyses resource use and explores environmentally sustainable alternatives through a case study of a denim manufacturing company in Albania. The company operates under the Cut-Make-Trim (CMT) production model. A Life Cycle Assessment (LCA), in accordance with ISO 14040 and ISO 14044 standards, was conducted using a denim sample as the functional unit. Data were collected across key production stages, including cutting, assembly, industrial washing, dyeing, bleaching, ironing, packaging, and waste management. The results indicate that the washing process is the most resource-intensive stage, with a single pair of jeans requiring approximately 70 litres of water, contributing significantly to water pollution due to chemical discharge. Given a daily production of 2,500 pairs, monthly water consumption ranges between 2.75 and 3.8 million litres, depending on the product model. To reduce environmental impact, sustainable alternatives such as ozone washing, wastewater treatment and recycling systems, and the use of energy-efficient servomotors are recommended.

Keywords: Resource Efficiency; Life Cycle Assessment; Environmental; Footprint; Denim Group Factory; Sustainable Production.

INTRODUCTION

In Albania, the textile and garment sector plays an important role in economic development, employment, and exports [1-4]. Among the items produced by this Industry, the production of denim and footwear is considered the categories that require the most primary resources (water and energy) due to the refining and dyeing processes, also affecting environmental and ecological damage from the discharge of water into the environment [5, 6].

These environmental impacts occur throughout the product's life cycle, from the production of raw materials and the production of fabrics to the completion of clothing, use by the consumer and disposal at the end of life [7, 8].

In Albania, the majority of the industry, around 80%, produces as a cut-make-trim model, minimizing the effect of pollution on the environment [1, 3].

For this reason, our work is based on the environmental impacts directly linked to the production phase, especially during the industrial washing, dyeing, drying and finishing operations [9, 10]. Industrial washing and finishing processes are characterized by high water consumption, intensive use of chemicals, and the generation of wastewater, making them the most environmentally demanding stages of denim production [10].

In response to increasing environmental awareness and the sustainability requirements of European markets, textile manufacturers are facing growing pressure to improve resource efficiency and adopt cleaner production technologies [9]. Although Albania has become an important manufacturing location within European textile supply chains, studies examining the environmental performance of Albanian textile companies remain limited [1, 2].

The novelty of this study lies in providing one of the first detailed, process-based environmental assessments of a denim manufacturing facility in Albania using Life Cycle Assessment (LCA) methodology [11-13], with a specific focus on identifying high-impact production stages and proposing practical, industry-relevant solutions for reducing water consumption and environmental emissions within the CMT production context.

PURPOSE OF THE STUDY

The purpose of this research is closely related to the environmental impacts of the clothing industry and specifically to the production of denim, where the Denim Group Factory Company was taken as a case study, where with its policies it tries to produce green.

During the analysis, we have tried to identify the phases of the product life cycle that significantly contribute to the environmental impact.

Additionally, this research work seeks to provide practical recommendations and sustainable alternatives that can support the reduction of environmental impacts and improve resource efficiency within denim production systems.

MATERIALS AND METHODS

The inventory was developed using production data obtained from the different departments of Denim Group Factory. Information on water consumption, electricity use, chemical inputs, and waste generation was collected and analysed for each stage of the manufacturing process. For the environmental assessment, Life Cycle Assessment (LCA) was used, based on ISO 14040 and ISO 14044 standards [12].

The case study taken for the production of denim at the Denim Group Factory company focused on the main stages involved in the production process (including cutting, sewing, industrial washing, drying, ironing, packaging and waste management) in order to identify the activities responsible for the highest consumption of resources, where a sample

of denim weighing 0.7kg was taken. While regarding sales, consumer use and end-of-life treatment were not considered since the company did not have data.

Furthermore, data on water consumption, electricity use, chemical inputs and waste generation were collected and analysed for each stage of the production process.

Case Study – Denim Group Factory

Denim Group Factory is an Albanian textile company established in 2018, and operating under the Cut-Make-Trim (CMT) production model, see Figure 1. The company employs approximately 85 workers and produces 2,500 pairs of jeans per day. The company produce for European luxury fashion brands (GAS, DIESEL, S.C.O.U.T, JECKERSON, dixie). Monthly production reaches approximately 55,000 of jeans product.

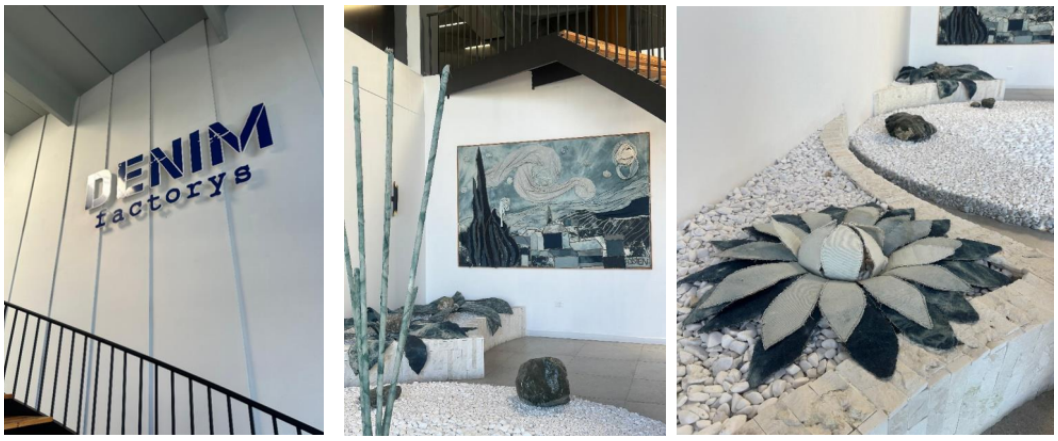

Figure 1. Denim Group Factory

The main production departments are: Product development and modelling; Fabric cutting sector; Sewing production lines; Industrial washing sector; Dyeing sector, Drying sector; Ironing and quality control sector; Packaging and distribution. The company utilizes industrial machinery from Juki, Brother, and Dürkopp-Adler, together with advanced CAD/CAM cutting systems and ozone-assisted washing technologies.

The company has a structured organization chart starting from: Prototype Development Department and Product Modelling; Cutting Sector; Sewing Production Lines; Industrial Washing Sector; Dyeing Sector, Drying Sector; Ironing and Quality Control Sector; Packaging and Distribution and Show Room, see figure 2. The company uses advanced CAD/CAM cutting systems (Lectra package) and ozone washing technology.

The company has a daily production of 2500-3000 denim items depending on the model. The average monthly production is around 55,000 denim products. Based on the data obtained, the industrial washing process consumes around 65 litters of water per pair of jeans, corresponding to an estimated monthly water consumption of 2.75–3.85 million litters. The electricity consumption associated with the washing operations based on billing data was also approximately 45,000 kWh per month.

(a) (b)

Figure 2. Show Room (a), cutting sector (b)

The results demonstrate that industrial washing is the most resource-intensive stage of the production process and the main contributor to the environmental footprint of jeans production.

Industrial Washing and Dyeing Process

The industrial washing and dyeing processes at Denim Group Factory involve a series of mechanical and chemical treatments to achieve specific visual and aesthetic effects on denim garments. Based on production data during the study, water consumption during washing operations varied around 65 l per pair of jeans. Before the dyeing process began, dye solutions were prepared according to the model in the company's laboratories. The formulations were prepared with a dye-to-water ratio of 1:7. The total volume of the solution used in the laboratory testing was 70 mL, water and dye solution.

Then, the dye concentrations were varied for colour intensity. For the orange colour formulation to obtain light, medium and dark shades (Arancio), concentrations of 0.1 g/L, 1 g/L and 10 g/L were used. For the dyeing and finishing, the jeans were mounted on an industrial finishing mannequin. This mannequin helps to maintain the shape of the garment during treatment and facilitates the uniform application of dyes and chemical agents. The mannequin was also used during spray treatments aimed at creating visual effects such as fading, dullness and worn looks. After fixing on the mannequin, the color and finishing effects were applied manually using spray equipment.

The jeans were then transferred to industrial dyeing machines where reactive dyes and auxiliary chemicals were added. The dyeing process used 500 g of sodium sulphite and oxygen peroxide as bleaching agents to modify the colour intensity in the sprayed areas. After dyeing, chemical fixing reagents were applied to improve colour fastness and reduce colour loss during subsequent washing operations.

The garments were then subjected to thermal setting through controlled drying processes. Additional washing treatments were performed to remove surface fibres and soften the fabric structure. In the final process, final drying was performed using industrial dryers before the garments went through the ironing, final inspection and packaging processes, see Figure 3.

(a)

(b)

(c)

Figure 3. Production process (a)-Bleaching, (b)-dyeing, (c)-washing and finishing

The analysis of the collected data indicates that washing, bleaching, dyeing, and finishing processes are the most resource-intensive stages, exhibiting the highest consumption of water and chemicals. As a result, these operations constitute the primary environmental hotspots within the assessed life cycle.

Life Cycle Inventory Analysis

Table 1. presents the Life Cycle Inventory resource requirements associated with each stage of denim production at the Denim Factory Group.

Table 1. Life Cycle Inventory Data for Denim Group Factory (Average Production: 2,500 Pairs of Jeans per Day)

Process	Main Equipment	Resource Consumption	Output/Result
Cutting	Automatic cutting machine	2–3% material loss	Textile waste for recycling or resale
Sewing	120 Juki and Brother sewing machines	0.25–0.30 kWh per pair (625–750 kWh/day)	Semi-finished sewn jeans
Industrial Washing	5 industrial washing machines	50–70 L water, 0.5–1.0 kWh energy, and 0.1–0.2 kg chemicals per pair (125,000–175,000 L water/day)	Denim garments with finishing effects (stone wash, enzyme wash, etc.)
Drying	Industrial dryers	1.5–2.0 kWh per cycle	Dried denim garments
Ironing	Industrial ironing equipment	0.3–0.5 kWh per pair (750–1,250 kWh/day)	Finished and pressed garments
Packaging	Packaging machines	Plastic bags and cardboard packaging	Packaged garments ready for shipment
Waste Management	Waste separation system	Approximately 60% recycled and 40% disposed of in a landfill	Textile scraps, chemical residues, and wastewater

In this process, we used primary operational data collected from the Denim Group Factory to develop the life cycle inventory. The cutting process generates relatively low material losses, estimated at approximately 2-3% of the total fabric, as a result of the use of fabric-saving software (Lectra Diamino) and automatic cutting technologies. Sewing operations were characterized by moderate electricity consumption, ranging from 0.25 to 0.30 kWh per item, and resulted in the production of semi-finished denim products.

Among all production stages, industrial washing represented the highest resource demand. Water consumption ranged from 50 to 70 L per denim item, depending on the model, while electricity use ranged from 0.5 to 1.0 kWh per denim item.

The process also required chemical solutions, including enzymes and finishing reagents in the fixing and dyeing processes, to achieve the desired visual effects.

Based on an average daily production volume of 2,500 pairs of jeans per day, water consumption during washing operations was estimated at 125,000-175,000 L per day. Drying and ironing constitute additional energy-intensive stages within the production system. Drying operations consumed approximately 1.5–2.0 kWh per cycle, while ironing required 0.3–0.5 kWh per item to achieve the final product quality specifications.

The packaging process uses plastic bags and cardboard materials to protect and transport the product.

The company's waste management policies showed that approximately 60% of production waste was directed to recycling streams, while the remaining 40% was transferred to third parties for waste disposal.

Waste generated during production consisted mainly of small pieces of fabric, chemical waste and wastewater coming from washing and finishing operations. The inventory analysis identified industrial washing as the most resource-intensive stage of production and the main contributor to water consumption and chemical use within the production system.

RESULTS AND DISCUSSION

To examine possible improvements in the environmental performance of denim manufacturing, three alternative production scenarios were assessed against the current production system used by Denim Group Factory.

The reference scenario reflects the technologies currently applied in the factory. Scenario A considers the installation of servo motors in sewing machines. The assessment indicates a reduction in electricity consumption of approximately 20–25%, while no changes were observed in water consumption or chemical use.

Scenario B evaluates the introduction of ozone washing combined with laser finishing. According to the results obtained, this scenario provides the largest reductions among the options considered. Water consumption decreases by 80–90%, while chemical use and related pollution are reduced by a similar percentage. In addition, energy consumption is reduced by approximately 15%.

Scenario C examines the use of wastewater filtration and treatment systems. Although this measure does not affect energy consumption, it contributes to a reduction of 70–80% in water-related pollution. Similar reductions are observed for impacts associated with chemicals discharged during the washing process.

The values reported in Table 2 represent estimated reductions derived from the scenario analysis conducted within the LCA framework for improvement and for environmental protection, associated with the washing and finishing stages.

Among the scenarios evaluated, waterless dyeing, ozone washing and Laser Dyeing and Washing (Finishing Processes), Water Recycling and Filtration Systems in Manufacturing, the Use of Enzymes in Material Processing, will achieve the highest reductions in water consumption and chemical use. Wastewater treatment systems mainly improved the quality of discharged effluents, whereas servo motors contributed to lower electricity consumption during garment production.

In the table 3. Is shown alternative production scenarios for environmental improvement, based on innovative technology.

Table 2. Use of Innovative Technology based on Industri4.0 for improvement and clean production

Technology	**Water Use Reduction**	**Water Savings** %
Waterless Dyeing	Uses supercritical CO_2 or plasma-based methods instead of water for dyeing textiles and leather.	90%–100%
Laser Dyeing and Washing (Finishing Processes)	Replaces traditional washing and finishing processes for denim and leather with laser technology.	80%–90%
Digital Textile Printing	Uses water-free technology to apply designs to fabrics, replacing screen printing.	60%–80%
Ozone Treatment for Industrial Washing	Reduces water consumption in product washing by using ozone for cleaning and bleaching.	50%–75%
Water Recycling and Filtration Systems in Manufacturing	Filtration and purification systems that reuse water consumed during production processes.	70%–90%
Use of Enzymes in Material Processing	Reduces the need for water and chemicals in jeans processing.	40%–70%
Use of Recycled Materials	Recycling textiles and leather reduces the need for reprocessing raw materials, saving water, energy, and resources.	30%–50%

Table 3. Comparison of alternative production scenarios for environmental improvements.

Scenario	**Description**	**Water Reduction (%)**	**Energy Reduction (%)**	**Reduction in Chemical-Related Pollution (%)**
Baseline Scenario	Existing production process with current technologies	0	0	0
Scenario A	Installation of servo motors in sewing machines	0	20–25	0
Scenario B	Ozone washing and laser finishing	80–90	15	80–90
Scenario C	Wastewater filtration and treatment system	70–80	0	70–80

CONCLUSION

This paper aimed to analyse the Life Cycle Assessment (LCA) methodology to assess the environmental footprint of denim products manufactured at Denim Group Factory.

From the analysis of data in the company, the industrial washing and dyeing process was identified as the most critical stages with the highest environmental impact due to the

high consumption of water and chemical solutions during the implementation of these processes. The life cycle inventory showed a consumption of approximately 60,000 L of water and 2,000–2,500 kWh of electricity per 1,000 pairs of jeans produced. Considering an average production volume of 2,500 pairs per day, the annual resource consumption is approximately 37.5 million litters of water and 1.25–1.56 million kWh of electricity. In fabric economy as a result of the use of technology and automation in the cutting sector, there was a low waste generation of 2–3% of the total material input.

The comparison of alternative production scenarios confirms that the use of ozone washing, waterless dyeing, as well as wastewater treatment systems and servomotors can reduce the overall environmental footprint of production by approximately 30–40%, in the washing and finishing stages, where the highest levels of water consumption and chemical use are recorded.

The case study shows that the environmental impacts of denim production are closely linked to the resources in the washing, bleaching and finishing processes. The results obtained by the Denim Group Factory show that reductions in water consumption, energy use and wastewater generation can be achieved through the implementation of innovative technologies based on Industry 4.0 for cleaner production and improved process efficiency.

The analysis was based on primary data collected from manufacturing operations at the Denim Group Factory. Distribution, consumer use, and end-of-life stages were not included because primary data were not available. Therefore, the results should be interpreted as a factory-level environmental footprint assessment focused on production processes.

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CONFLICT OF INTERESTS

Authors confirm that there is no conflict of interest associated with this publication.

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