Hazardous Waste Generated in the Peruvian Textile Industry: Haute Couture, Alpaca Fiber and Tannery

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***Abstract*—**The research cites the various hazardous waste generated in the textile industry. The method used is descriptive and comparative, the process consisted of the search and evaluation of information, both nationally and internationally. The results indicate: (1) Waste is generated from the alpaca fiber industry in the various stages of camelid rearing, they stand out for their dangerousness: excreta, residual fiber and yarn scraps. (2) The main hazardous waste generated by the tannery industry are grease, hides, hair, plastic containers with traces of toxic substances, chips and pieces of leather with chrome. (3) Three companies' Solid Waste Management Plans were analyzed, randomly selected, and none of them detail waste treatment processes and warn of the lack of supervision by the authorities. It is concluded that the hazardous waste generated can affect human and environmental health. There is the possibility of taking advantage of certain hazardous waste such as manure and alpaca fiber, after treatment; while non-hazardous waste from the tannery such as yarn, panel weaving, cloth, scraps, and thread, can be used to produce new products, generating a production chain in favor of the entrepreneur himself.

***Keywords*—**Alpaca fiber, excreta, Haute couture, hazardous waste tannery, hazardous waste treatment, textile waste,

I. Introduction

IN the last ten years, the textile industry has been characterized for an increase in the volume of production due to the consumption of new fibers and the use of dyes that generate environmental impacts by constituting inadequately managed solid waste. This industry uses a greater number of chemical substances such as solvents and dyes, since there are about 10,000 types of it and a production of 70,000 tons approximately of these synthetic product [54]. This industry is considered the second most polluting economic activity of water resources after agriculture.

According to the Environmental Justice Foundation (EJF), cited by Osorio [44], textile waste occupies almost 5% of the landfill space, one million tons of textiles end up in open dumps every year, 20% of industrial freshwater pollution comes from textile treatments and dyeing in denim productions.

The tannery industry has been classified as a highly polluting sector in 2006 as being responsible for 50% of environmental degradation [25], since they generate hazardous waste containing high concentrations of chromium, fecal waste, and toxic organic compounds.

The alpaca fiber industry generates waste in the various stages of camelid breeding, they stand out for their dangerousness: excreta, residual fiber and yarn scraps; however, several of them can be used to minimize their amount of waste and obtain economic benefits [11].

Due to the problems exposed, this study aims at the various hazardous waste generated in the textile industry: Haute couture, alpaca fiber and tannery; and propose improvements for its management that will have an impact on reducing the risk of affecting human and environmental health due to the inadequate management of hazardous solid waste.

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II. Method

The method used is descriptive and comparative, the process consisted of the search and evaluation of information in theses, articles among other documents of the object of research, both nationally and internationally. The methodical review of research is replicable, scientific, and transparent. The methodology determines a relevance and importance of the information, which ensures the originality of the construction of this article [21], which is composed of three phases:

A. Problem Statement

The problem statement is what the hazardous waste generated in the textile industry: Haute couture, alpaca fiber and tannery is; and what treatment alternatives decrease the risk of affecting human and environmental health can.

B. Literature Review

A bibliographic review of scientific papers, theses, legal devices, electronic databases such as "Google Scholar", scientific content databases such as Proquest, Redalyc, ScienceDirect, and Scielo were reviewed. To do the search, the following terms were used: Haute couture, tannery, excreta, alpaca fiber, hazardous waste, textile waste, hazardous waste treatment.

C. Information Analysis

The analysis of the most important documents made it easier to define the main ideas, aspects, inferences, key concepts or other valuable information for the detailed analysis of the cases studied. The hazardous waste generated in the production stages of the textile, tannery and alpaca fiber industry was identified in order to propose alternative solutions, through physicochemical and biological treatments. Management instruments of three textile companies were evaluated: San Gabriel, Indutex and Sur Color Star; randomly selected, obtained from the portal of access to public information of the "Ministerio de Producción" (PRODUCE), organization from Peru.

III. Results

A. Haute Couture

In a textile industry, solid wastes such as cardboard, paper and plastic are generated whose origin are from empty containers, coils and reels to name a few examples. In addition, sludge from wastewater, municipal solid waste, oiled rags contaminated with toxic substances; in the case of companies that are dedicated to clothing, needles, blades, scrap, lint, waste thread and fabrics are generated [14]; also, hazardous waste from chemical products used during the different processes of this industry.

The DETOX project initiated in 2011 encouraged by the NGO Greenpeace [26], sought to solve the environmental problem generated by the textile industry. This was based on signing agreements with companies in the sector to eliminate toxic substances from their processes; in 2018 the project was suspended as great advances were reported in pursuit of the objective and it was decided to reduce the pressure.

Waste Generation Processes

In the process of bleaching garments, the following are used: Acids, bleaches, solvents, which contain hypochlorites and peroxides, and in the case of dyeing liquid effluents also contain hypochlorites and peroxides. In the printing process, acrylic dyes are used that leave a large number of acidic solutions, alkalis, etc., and generate the release into the environment of dyes and pigments. Both processes generate inputs that must be treated as solid waste within the framework of the provisions of Peruvian regulations.

Regarding water consumption, the processes which use it most are: Bleaching, heating, and dyeing [2]. Therefore, in these stages the greatest release of pollutants into wastewater occurs [25]. The manufacture of fabrics, which according to Cordero [14], is the most important stage and in turn, the most polluting; toxic substances are used for the refinement and gumming of the fiber, as well as for the finishes of the fabric. As for washing, acid effluents and toxic substances are discarded; these may be part of organic matter and suspended solids.

Cordero [14] notes that, in the elaboration of yarns, they can come from vegetable, animal or petroleum-derived fibers, which need prior treatment. During the different manufacturing processes, chemical substances such as oils, lubricating emulsifiers, acrylic emulsions, and others. are used for the application of dyes, friction resistance, yarn waxing, among others.

Types of Hazardous Waste Generated

In Peru, the textile industry is one of the largest generators of foreign exchange as a result of exports, but also one of the largest consumers of water and generators of effluents with residual materials from production processes such as azo dyes (Allura red) that can cause allergic reactions in children [49].

The problem is not only related to the generation of hazardous waste during the processes, but also in the mismanagement and inadequate disposal of these during the process, as shown by a Greenpeace research [26], which concluded that two textile companies in China dumped ethoxylated nonylphenols and other ethoxylated alkylphenols in the rivers of the area. This presence is due to the fact that they were incorporated into the plastisol impressions of the tissues. Plastisol formulations containing phthalates are used to stamp images on tissue, carcinogenic amines were also found in dyes [25]

The most common plasticizers in stamping are phthalates, i.e., DEHP or di phthalate (2-ethylhexyl), BBP (benzylbutylphthalate), DINP (diisononylphthalate) and DHP (diheptil phthalate) [24]. The physicochemical properties of polyethoxylated nonylphenols (NPEs) depend on the number of ethoxyl groups present in their structure. In particular, the water solubility of these compounds increases as the number of ethoxyls in their chain increases; that is why NPEs with fewer ethoxyl groups are more persistent and dangerous for organisms in water bodies [13].

Potential Effects of Waste on Human Health and the Environment

Nonylphenol (NP) is a compound free of ethoxyl groups and derived by the breakdown of NPEs, it has been classified as very toxic and presents adverse effects even at acute exposures and low concentrations. Also, high concentrations cause considerable damage to the upper respiratory system, eyes, and skin [8]. The release of ethoxylated nonylphenols into wastewater causes them to degrade into persistent nonylphenols, these are bioaccumulative in the fish food chain, accumulate in sediments and function as endocrine disruptors [25]. The continued use of this type of toxic chemicals can affect the health of people and the environment, there is still no strict global regulation, causing a situation of very limited control over the way in which clothing is really being produced [12].

According to Greenpeace [26], the perfluorinated and polyfluorinated chemicals (PFCs) are widely used in the mountain equipment sector for use as a waterproofing and anti-stain, these have high persistence in the environment, they have even been found in the snow of the most remote places and mountain lakes. In addition, Greenpeace indicates that ionic PFCs have been found in a wide variety of both aquatic and terrestrial species, given their capacity for bioaccumulation, as well as in human blood and breast milk in the general population of many countries of the world. Another toxic compound is antimony trioxide, in this regard, Greenpeace [23], [24] mentions that antimony can be released from garments containing it at relatively low temperatures in contact with liquids such as sweat, saliva or blood. In addition, it indicates that antimony trioxide is listed by the International Agency for Research on Cancer (IARC) as a probable human carcinogen.

On the basis of the compounds mentioned in the foregoing paragraphs, Table I presents information referring to the waste generated in the textile industry and its impact on the environment.

TABLE I
WASTE GENERATED IN THE TEXTILE INDUSTRY AND ITS IMPACT ON THE ENVIRONMENT

Waste generated	Consequence	Impact on the ecosystem
Persistent nonylphenols	Bioaccumulation in fish, endocrine disruptors	In the ecosystem it takes months or even longer to biodegrade from the surface of the water or soil sediments. Its bioaccumulation is significant in aquatic organisms and birds [41].
Phthalates	Damage to sperm DNA	DEHP (Bis Phthalate (2-Ethylhexyl)) has low solubility in water, so it has a greater affinity to adsorb in organic matter and the particulate phase of the media. BBP (Butylbenzylphthalate) enters the environment from waste deposited in landfills, incineration; and sludge in WWTPs, which could end up in landfills or being used as organic soil amendments [27].
Sodium hypochlorite	Irritation in the eyes, skin, and respiratory and gastrointestinal tract	The available chlorine (ClO-) of the hypochlorite solution reacts rapidly with organic compounds present mainly in wastewater. This reaction produces oxidized organic compounds such as chloramines, trihalomethanes, oxygen, chlorates, bromates and bromoorganics. Caustic soda forms hydroxides with the salts of the water, many of them precipitable. It increases the electrical conductivity of water. In the case of fauna, caustic soda is dangerous for the environment, especially for aquatic organisms (fish and microorganisms). In plants it causes necrosis, chlorosis, and defoliation [37].
Peroxides	Irritation in eyes, skin, throat, airways. In addition, it can cause mild or severe gastrointestinal damage.	Hydrogen peroxide when released into water degrades rapidly, although it is true that it does not accumulate in the food chain, research by Quiantidoc AS in Norway determined that the exposure of fish to a strong oxidizing agent such as peroxide can damage the gills and the mucus layer (physical and chemical barrier between the fish and the medium), making some individuals susceptible to aquatic pathogens [9].
Antimony trioxide	Consequences on the skin and gastrointestinal problems.	Antimony, after remaining in the air, is deposited both in soils and in sediments of rivers, lakes and streams, adhering firmly to soil particles containing iron, manganese or aluminum; therefore, the concentrations of this dissolved metal in water bodies are very low. However, certain amounts of antimony in the environment become less firmly attached to the particles and can be absorbed by plants and animals.
Perfluorocarbons (PFCs)	Bioaccumulation in aquatic and terrestrial species.	PFCs are highly resistant to chemical, biological and thermal degradation, these properties pose a risk to the environment due to their great persistence, they are contaminants in general, including fresh water, groundwater, sediments and seabed. This substance has been found in tissues of aquatic invertebrates, fish, birds, mammals and humans having an adverse impact on their development and on the adult stage of some animals since they can act as hormone disruptors [25].

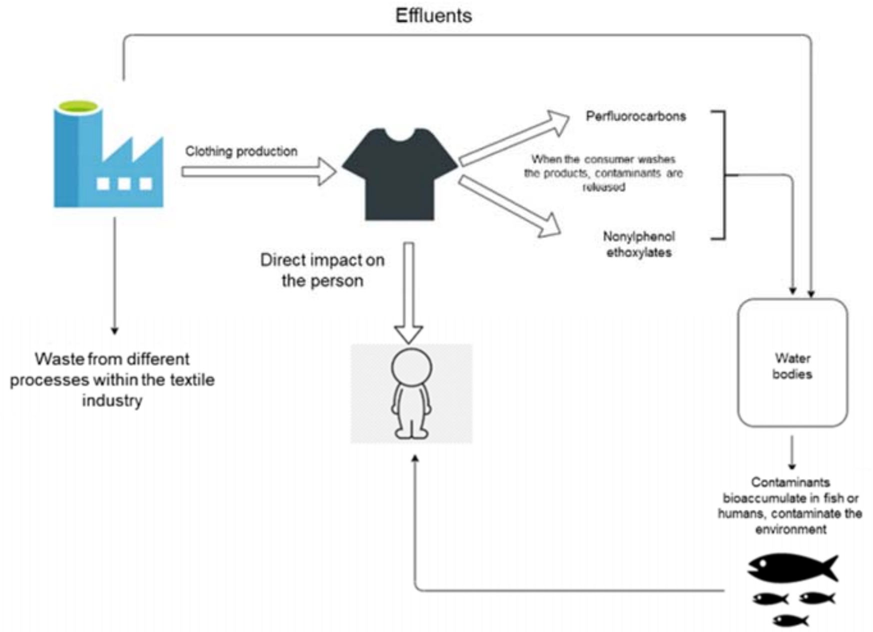

Fig. 1 Route followed in the environment by the waste generated in the textile industry

Cases

According to Greenpeace [25] in Mexico, the company Lavamex is dedicated to the production of denim products, in the plant located in "Aguascalientes", and they have identified samples of wastewater with the presence of hazardous substances, particularly nonylphenols and ethoxylated nonylphenols. In the same way, the research was carried out to the Kaltex group, which manufactures synthetic fibers, threads, fabrics, garments in general and performs physical and chemical finishes. Also, toxic components were found in the wastewater discharges of the plant located in Querétaro from the printing and dyeing process; some examples of toxic components were phthalates, trichlorinated benzenes and trichloraniline, compounds that are not regulated in Mexico.

The report "Toxic Stitches: The Parade of Pollution" prepared by Greenpeace [25] highlights the case of the Yangtze and Pearl rivers in China, where several dangerous substances were detected from two textile factories supplying large brands, specifically PFC and alkylphenol substances were found, both of high danger to human health, since even at low levels they can affect. In addition to what was found in the discharges of these factories, the presence of numerous containers of dangerous substances (dyes, solvents, etc.) in the vicinity of the rivers was also reported, verifying the lack of control of the authorities and also the lack of corporate environmental responsibility of those brands that have production plants in various countries.

Fig. 1 shows the route followed by the waste generated in the textile industry.

B. Alpaca Fiber

According to the “Ministerio de Desarrollo Agrario y Riego” (MIDAGRI) [38] by 2021, Peru is the main producer of South American camelids in the world, accounting for 72% of the total alpacas in the world (4.3 million of them, approximately).

The “Ministerio de Desarrollo Agrario y Riego” (Ministry of Agrarian Development and Irrigation) cites the IV National Agrarian Census [30] that the regions with the largest population of alpacas are: Puno (40%), Cusco (15%) and Arequipa (13%). The main product obtained in a non-invasive way is its fiber, which allows to obtain expensive garments of high quality [46]. For 2020, exports of fiber, yarn and alpaca fabrics totaled USD 38, 32 and 6 million, respectively [45].

Peruvian Regulatory

For the management of solid waste there is Legislative Decree N° 1278 [17], Law on Integral Management of Solid Waste, published in 2016; This legal device cites in its article 9: "the usable discard material from the production process can be an input for other activities", also article 55 specifies that "companies must include the Solid Waste Minimization and Management Plan within the Environmental Management Instrument considering strategies and actions to prevent, minimize and valorize solid waste". However, there is no specific standard for the alpaca fiber industry generated by the competent sector, PRODUCE, and therefore not for the by-products generated by this industry, for example the handling of fabric scraps.

The agriculture sector (“Ministerio de Desarrollo Agrario y Riego”) [38] in 2006 published a D.S. N° 044-2006-AG, a legal device for the management of waste generated by its administrators and updated it in 2012 (through D.S. N° 016-2012-AG), which typifies important data (see Table II).

TABLE II
PERUVIAN REGULATIONS FOR WASTE MANAGEMENT IN THE ALPACA FIBER INDUSTRY [16] – [18]

Waste	Regulations	Description
Alpaca fiber droppings and residual fiber	D.S. N° 044-2006-AG	The Technical Regulation for organic products, in Article 23: Handling of animal excreta, establishes that: "excreta must complete a fermentation or decomposition process to prevent infectious foci". Article 11: Soil fertility management states that: "the use of organic fertilization with animal manure and plant remains is allowed, both must preferably be of diverse origin and come from the agricultural establishment itself".
	D.S. N° 016-2012-AG	The Regulation on the Management of Solid Waste in the Agricultural Sector, in Article 24: Treatment of Organic Waste, mentions that: "organic waste generated from the Agricultural Sector must be treated, recover recoverable material and substances, facilitate its use as an energy source and favor the disposal of rejection". Article 29: Management of waste from breeding and slaughtering activities of animals larger than slaughter mentions that: "animal droppings can be used as mineral and energy fertilizer, and that the treatment of droppings can be given by composting, artificial drying, anaerobic fermentation, etc.”.

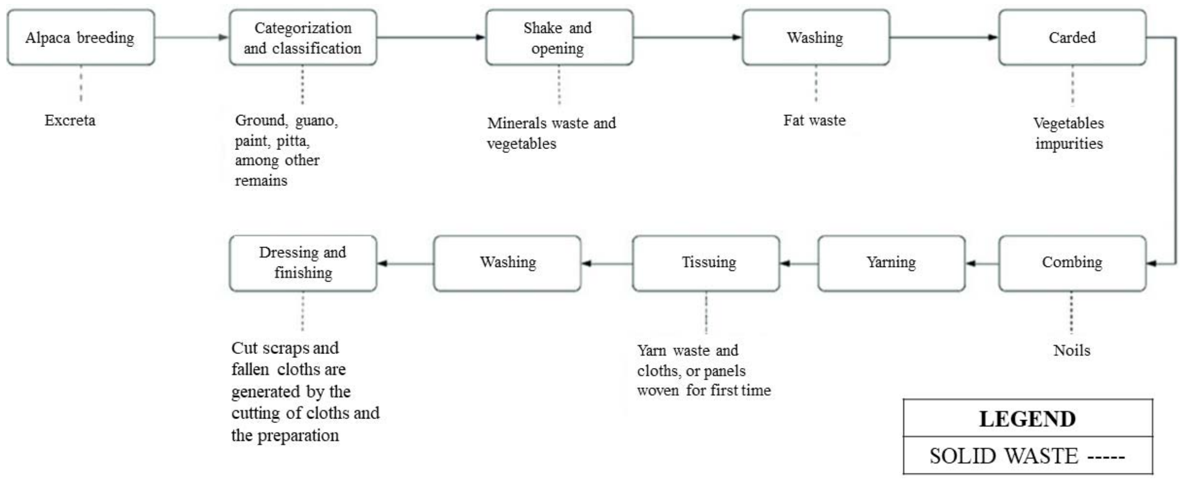

Fig. 2 Solid waste generated in the alpaca fiber industry

Table II shows that there are legal devices for the management of waste generated by the alpaca fiber industry by the MIDAGRI sector; but they do not align with the vision of minimizing hazardous waste generator in industrial processes in general, proposed by D.L. N° 1278. Both devices mentioned REFEr to the treatment of the waste generated rather than to the reduction or reengineering of the production process that would avoid the generation of certain types of hazardous waste.

Waste Generation Processes

In the process of obtaining alpaca fiber garments, waste is generated from the breeding of camelids to the manufacture of the garment (see Fig. 2).

Fig. 2 presents that the manufacture of clothes generates waste, fabric scraps, and pieces of waste. For the purposes of this study, taking as a reference the existing bibliographic information, the residues of the different stages have been grouped into three types of waste that can be used (see Table III).

TABLE III
GROUPED USABLE WASTE

Waste generated	Stage
Alpaca excreta	Alpaca breeding
Residual fiber	Categorization and classification Smoothing and opening Washing Carding Hairdo
Panels, cloths, scraps, and thread	Tissue Preparation and finishing

Excreta is the main hazardous waste generated in the breeding of alpacas, and the residual fiber, mixture of earth, guano, fat residues, mineral and vegetable residues and noils from differentiated stages, can be used for the production of biogas and biofertilizer using a biodigester [33]-[48]. Likewise, the panels, cloths, scraps, and thread generated in the last stages of the alpaca fiber process can be used for the generation of new garments and articles [15].

Types of Hazardous Waste Generated

One of the problems of livestock farms is the management of waste generated in the form of excrement and slurry (mixture of excreta and urine from animals). Excreta emit greenhouse gases that contribute to climate change and can reach bodies of water by leaching or runoff, eutrophying them. Finally, the accumulation of fresh excreta can intoxicate the cattle themselves who consume it due to the nitrate and nitrite content [33].

Potential Effects of Waste on Human Health and the Environment

The main damages to health caused by the inadequate disposal of solid waste occur due to its inadequate disposal in open dumps, leading to potential acute respiratory diseases, intestinal parasitism, skin lesions, and even the contagion of various diseases through the vectors that lodge in the waste [20]. The generation of solid waste causes significant impacts to the environment, although the effects generated by the management and final disposal of solid waste depend on the particular characteristics of the geographical area that is analyzed, the main problems that are generated are the deterioration of urban centers and the natural landscape, among them are mainly the pollution to the environmental components: the water bodies, the air resource, the soil system, and the flora and fauna that inhabit these ecosystems [22].

C. Tannery

In Peru, the tannery industry is an ancient activity that has been perfected over time. This industry has developed in most regions, but especially in Trujillo, Arequipa, and Lima [47]. According to the Technical Report for the Tannery Industry in Peru, it is noteworthy that approximately 50% of the leather produced in Peru comes from formal companies, the other 50% is not known due to the lack of information on formal and informal companies [40].

Peruvian Regulatory

In accordance with the current regulations for the management of waste generated for this process, D.S. N° 003-2020-PRODUCE is published, which are the Maximum Permissible Limits and Reference Values for industrial activities of cement, beer, tannery, and paper (See Table IV). All national or foreign companies, public or private, engaged in industrial manufacturing activities of tannery production, must comply with this legal provision. The established values are evaluated with the information generated in the monitoring by the industry, in order to determine corrective and sanctioning actions in case of non-compliance by the competent authority.

TABLE IV
PERUVIAN REGULATIONS FOR THE MANAGEMENT OF WASTE FROM THE TANNERY INDUSTRY

Waste	Regulations	Description
Oils, greases, N-NH4, chromium VI and total chromium	D.S. N° 003-2002-PRODUCE	Industries have the obligation to emit waste under the values established in the Maximum Permissible Limits and Reference Values for the industrial activities of Tannery.

Table IV shows the regulations for the management of waste from the tannery industry, which cites that "companies have the obligation to comply, in case of emitting their waste above the established levels, the company can be sanctioned" [16]. In the tannery subsector, fecal coliform values for sewerage effluents have not been set.

Waste Generation Process

In the process of obtaining leather, waste is generated from the collection of the raw material to the leather warehouse as shown in Fig. 3.

Overall, the tannery process generates 80% of the chromium-free residue (hair, defleshing and trimmings), 10% represents spent salt and 10% residues are residues with chromium: for example, shavings, trimmings, unused split skin, and sanding powder [32]-[36].

TABLE V
GROUPED USABLE WASTE

Residue	Process
Skin, fat, hair and feces	Soaking Bush Stark Divided
Shavings and pieces of skin with chrome	Purge Tanning Reduced
Plastic packaging	Disengaged Neutralized Retannage

For the purposes of this research, taking as a reference the existing bibliographic information, the classification of waste based on its dangerousness was considered, which will allow an adequate management system for the treatment of this waste (see Table V). Table V presents two types of waste generated among non-hazardous as skins, fats, hair, and feces, which are generated from the soaking process until process of divided. Likewise, hazardous waste was generated, mainly, shavings or pieces with chromium which can be reused; however, these require a more elaborate and sophisticated treatment prior to their recovery.

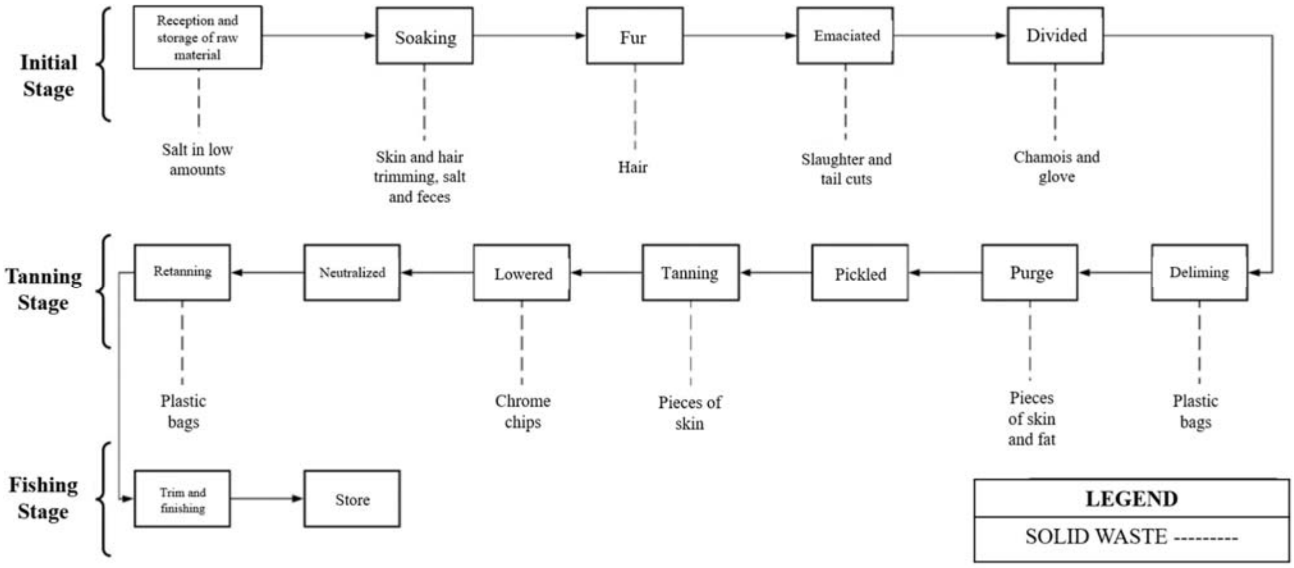

Fig. 3 Solid waste generated in the tannery industry

Types of Hazardous Waste Generated

Among the main hazardous waste of this industry are:

- *Residues of shavings and pieces of skin with chromium*: In the tanning process it is about stabilizing the collagen of the skin by means of tanning agents. The most used chromium salts can be used for vegetable tanning agents. The process can take between 8 to 24 hours. The lowering process consists of the longitudinal division of wet or dry leather that is too thick, for the manufacture of articles such as leather for shoe insteps, gloves, or others. In this process, machines with cutting blades are used to reduce the leather to the desired thickness. At this stage the wet blue shaving is released which is a by-product composed of a collagen - chromium bond.

The retanning process is used to obtain a fuller leather, with greater resistance to water, tanning agents such as chromium are used which improve the distribution of surface ionic loads of the leather improving its behavior against dyes [53]. Finally, there is the finishing cutting operation that allows to give a uniform look to the leather. It generates remains of finished leather, which provide pieces of leather with Cr+3 content to obtain the final product [4].

- *Plastic packaging waste:* In the tanning stage we have processes such as de-anchoring, whose purpose is to remove the chemicals from the lime inside the skins using ammonium sulfate. At this stage there is also the pickling process, which consists of conditioning the skin for tanning, thus dissolving the remaining salt, where aqueous solutions of sulfuric acid are used. During the storage of chrome-tanned leathers, acids are formed that impair the quality of the fibers. In the neutralizing process, the acidity must be raised from a pH of 3.8 to 5.2. The acidulants used are sodium bicarbonate, sodium carbonate, sodium formate, borax, among others. Within this stage, the containers, and containers of each of the chemical inputs that were used were handled as hazardous waste [34].
- *Residues of skin, fats, hairs, and feces:* Organic waste (fats, skins, hairs, feces) without the presence of chromium can be treated by biological techniques such as composting, but, when it contains chromium, it is not useful, since chromium, a toxic element, remains in the product and does not represent an environmentally favorable alternative [31]-[36].

Potential Effects of Waste on Health and the Environment

Process impacts on the use of chromium, which is a heavy metal that accumulates in the soil, are identified. Humans and animals are exposed to chromium via inhalation (in the air or in tobacco smoke), through the skin (occupational exposure), or by ingestion (usually from agricultural products or in water). The systematic toxicity of chromium is due especially to hexavalent derivatives that, unlike trivalent derivatives, can penetrate the body by any route much more easily. The trivalent chromium present in tanned leather residues can undergo modifications in its chemical properties depending on the environment in which it is located. In fact, when it is found in a basic medium or combusted in the presence of lime or another alkaline substance, it tends to transform into hexavalent chromium, a much more toxic form of this metal [52].

D.Case Studies: Textile Companies San Gabriel, Indutex and Sur Color Star

San Gabriel Company

Textiles San Gabriel S.A. is dedicated to the manufacture of fabrics and knitted articles, this company generates a diversity of waste due to its production process that has as raw material textured threads, polyester, and cotton.

Waste Generation Processes

In the fabric manufacturing process, a diversity of waste is generated, which is associated with the production process, maintenance of facilities, used machinery, among others, as shown in Fig. 4.

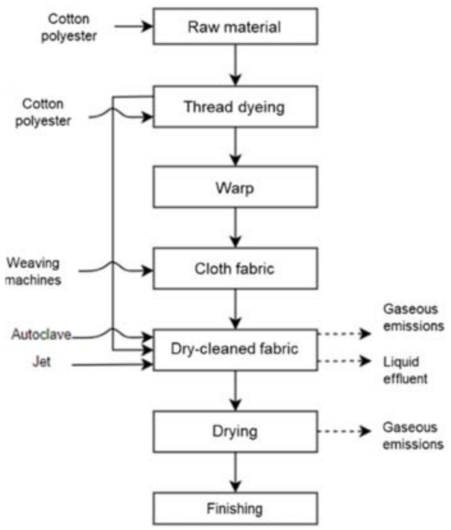

Fig. 4 Diagram of the production process of the company Textiles San Gabriel S.A.

The company classifies its waste according to its dangerousness, its physical characteristics, and its potential for use. The Solid Waste Management Plan of Textiles San Gabriel S.A. [51] cites the responsibilities and describes the actions with respect to the management of solid waste that comes from its production process, in which the aspects related to the generation, segregation, collection, intermediate storage, central storage, transport, treatment and final disposal of solid waste were considered.

According to the Ministry of Production, as of 2021 there has been no verification of its compliance with the Solid Waste Management Plan of Textiles San Gabriel S.A.

Indutex Company

Indutex S.A. is dedicated to the manufacture of industrial yarns, fabrics and friction materials based on asbestos fibers and glass fibers.

Waste Generation Processes

The industrial plant is distributed in five sections or production areas: asbestos yarn section, glass fiber yarn section, drawing section, fabric section and brake section.

- Asbestos yarn section: Raw materials such as chrysotile asbestos fibers, rough cotton, polyester and copper and brass wires are used for the manufacture of two types of yarns: asbestos-cotton and asbestos-cotton-copper, used as raw material for the manufacture of fabrics.
- Fiberglass yarn section: It begins with the cutting of the glass fibers, then enters an opening machine and is mixed with the cotton to obtain threads in cones for later commercialization.
- Drawing section: Reels are made with copper wire finally rewinded, this section is the only one of all the processes of the industrial plant that generates at a certain moment some level of liquid effluents from the cooling system.
- Fabric section: Four production items are presented (manufacture of fabrics, ribbons, braids, and WOVEN fabrics). During the process, the fabric is moistened in the form of a spray to prevent the asbestos fibers from falling off, and then dried with hot air and a drying chamber that works with liquefied petroleum gas (LPG) burners.
- Brake section: The process begins with the calendering of the special fabrics from the loom section, the manufacturing parts are heated and impregnated with a special oil and cured at high temperatures in order to obtain the required characteristics according to the required specifications of the product.

The company classifies its waste into non-hazardous household solid waste (general, organic, and inorganic stationery waste) and industrial solid waste (asbestos, glass fibers, copper and oily waste). The company cites in its Solid Waste Management Plan [29] seven stages: the minimization, segregation, collection, storage, marketing, transport, treatment, and final disposal of solid waste from its production process, as well as the responsibilities, training of the company's personnel and the supervision and registration of information.

According to the "Ministerio de la Producción", until 2021 there has been no verification of compliance with the Solid Waste Management Plan of INDUTEX S.A.

Company Sur Color Star S.A.

It is one of the most important units of the Peruvian textile sector, linked to another renowned Peruvian company (Topitop). Its specialty is the generation of yarns from textile fibers, widely accepted in export markets such as the United States, Europe, Venezuela, and Brazil, since September 2007, for which it uses spinning processes aimed at the specific treatment of cotton yarns.

Waste Generation Processes

The production of yarns is carried out in eleven processes, where three of them generate waste according to the Solid Waste Management Plan of the company Sur Color Star S.A. [50]. Waste is generated from opening, cleaning, and discarding, to carding and filters as shown in Fig. 5.

There is a characterization of waste and the Solid Waste Management Plan: Sur Color Star S.A. in compliance with article 43, paragraph 1 of D.S. No. 057-2004-PCM, Regulation of the General Law on Solid Waste No. 27314. This inform carries out the Manifests in compliance (specification sheets of waste management) that it reports to the "Ministerio de la Producción" for the months of January, April and May 2016. This inform contains information about waste such as oils, paper, cardboard, plastic, contaminated rags for the following characteristics such as quantity, hazard, type of container, type of vehicle. However, the company in question and others in the sector continue to develop solid waste management instruments in accordance with a rule repealed in 2016. On the other hand, according to the information provided by "Ministerio de Producción" [40] there are 225 registered companies in the textile subsector, among them 10 have solid waste management instruments approved until 2000. At the end of 2017, there were 143 companies with approved instruments; that represents less than 10% of the total number of registered companies. According to the "Ministerio de la Producción", as of 2021 there has been no verification of its compliance with the Solid Waste Management Plan of Sur Color Star S.A.

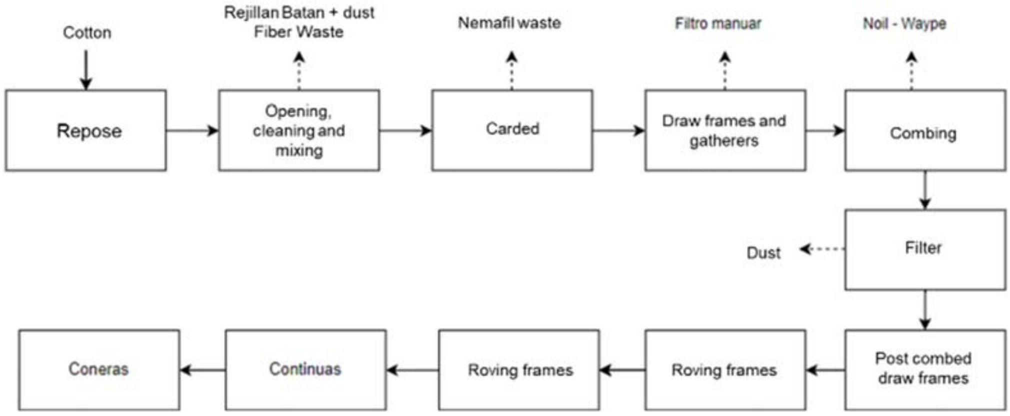

Fig. 5 Diagram of the production process of the company Sur Color Star S.A.

IV. Discussion and Results

A. Haute Couture

Haute couture brands, due to the level of production generate large volumes of waste, many of them are hazardous, but with problems of treatment and final disposal of the same in countries of reduced economy and lack of regulatory framework. Irregularities are evident in the environmental monitoring of this industry, added to this, different chemical compounds were found that have a serious or difficult treatment effect.

Dyes are one of the main polluting chemical compounds in the textile industry, it is estimated that 50% of the dyes used in the textile industry end up in the discharged waters of this sector [7], being one of the main compounds, they require special treatment, because they are not biodegradable and tend to accumulate in living organisms. There are currently a variety of treatments for effluents with high dye load, such as the use of microorganisms or advanced oxidation processes. Arias et al. [7] mention that photocatalysis for the treatment of these textile effluents is a suitable alternative since it is carried out in situ and also treats other chemical compounds from the textile industry.

Phthalates, alkyphenols, perfluorinated, chlorobenzene, chlorinated solvents and among others mentioned in the results found, are considered chemical substances that must be eliminated from the textile industry, because they tend to be persistent in the environment, bioaccumulate, be endocrine disruptors or affect functions of both animals and humans [25]. The main strategy to eliminate the use of these substances is to apply regulations or controls for their use, such as perfluorinated substances, which are restricted by the Stockholm Convention, or pentachlorobenecne, which is classified according to the European Union [53] as a "priority hazardous substance". The norm and regulation is therefore the main strategy to eliminate the risks of environmental damage product of the hazardous waste generated in the textile industry, Masini [35] collects control tools for it, the "Safety Data Sheet" indicates relevant information of the chemical substances to be used, another control is framed in the Registry, Evaluation, Authorization, and Restriction of Chemicals (REACH), which is a European regulation that censuses the production and use of chemical substances and identifies their impact on the environment. The most specific regulations and controls for the textile industry come from specialized institutions, such as OEKO-TEK, which provides certifications to textile companies, based on product manufacturing and health care. The GOTS standard (Global Organic Textile Standard) aims to ensure the organic condition of textile products, comprising all textile production processes, also involves that the chemical inputs used meet certain criteria, so as not to make use of hazardous chemicals. Therefore, it is necessary to implement technical aspects such as effluent treatments or water bodies, prioritizing the preventive nature. The reason is to adapt to international regulations is an important tool for the management of this hazardous waste. On the one hand, the environmental risks caused by it are reduced, and on the other, companies gain certifications and improvements in their institutional image.

B. Alpaca Fiber

In this section, we will present some alternative solutions for waste management in the alpaca fiber industry.

Alpaca Excreta

A suitable alternative for correct waste management is to convert this agricultural waste into an energy source or an effective fertilizer through the process of anaerobic digestion.

This process is carried out in a biodigester, which is basically an airtight and closed container (reactor), where the organic material is deposited, which will undergo a decomposition process; and from which beneficial products such as biocoating and biogas are obtained. The first is a fertilizer originated from the decomposition of organic materials, which promotes the absorption of nutrients and development in plants [34]. The second has a high concentration of methane and is a substitute for gasoline, diesel, coal and other fuels from fossil sources [10].

The biofertilizer is divided into biol and biosol. The biosol is the sludge resulting from anaerobic digestion and the biol is the liquid fraction resulting from it [33]. The latter can be used as a crop fertilizer (alfalfilla, potato, vegetables, etc.). They have been shown to improve growth and quality of crop, and act as a repellent [6]. It also helps in the retention of soil moisture and creates optimal microclimates for plants [5].

Biogas and biol are products of a decomposition process that occurs in a biodigester. The approximate cost for a biodigester is 6,789.60 PEN, if listed with an external company. On the other hand, if the construction of the biodigester itself is decided, 2,502.00 PEN is incurred, which is divided into 1,927.00 PEN of construction materials (see Table VI) and labor costs for construction estimated 560.00 PEN, it should be noted that it does not include the costs of the distribution of biogas. Table VI shows the price of materials for the construction of a Chinese-type biodigester, based on the quantities required.

TABLE VI
MATERIALS FOR THE CONSTRUCTION OF A CHINESE-TYPE BIODIGESTER

Description	Units	Quantity	Unit price (PEN)	Total price (PEN)
Cement bags 42.5 kg	bags	5	21.3	106.5
King kong brick	Parts	550	0.63	346.5
Electro-welded mesh	unit	3	260	780
Reinforcing iron	unit	8	20	160
Sand	m^3	3	50	150
Stone	m^3	1	50	50
Polyethylene plastic	m^2	24.5	12	294
Waterproofing	Buckets	2	20	40
			Total	1,927

Table VII presents the labor costs for the construction of a Chinese type biodigester, the cost is influenced by the number of working days of each employee.

TABLE VII
LABOR COST FOR THE CONSTRUCTION OF A CHINESE-TYPE BIODIGESTER

Description	Labor Price (PEN)	N° days	Total price (PEN)
Basic salary of two workers	70	3	210
Journal salary of a worker's teacher	50	3	150
Journal salary for the installation of the distribution	50	2	100
		Total	560

Biogas Production

Using the biodigester at 25 °C and atmospheric pressure, the volume of biogas that can be produced from 1 kg of fresh manure (EF) is equivalent to 0.2 kg of total solids (ST), and in turn 1 kg of the latter is equivalent to 0.20 m³ of biogas. The General Directorate of Agricultural Policies [54], mentions that an alpaca excretes, between feces and urine, 3 kg a day. Considering 70 kg, as the weight of an adult alpaca, this produces 4.29 kg manure daily/100 kg of weight.

$$4.29 * 0.2 * 0.2 = 0.17 * 365 = 5.22 \frac{Kg\ EF}{day} \frac{Kg\ ST}{day} \frac{m^3\ biogas}{Kg\ ST} \frac{m^3\ biogas}{day} \frac{days}{1\ year} \frac{1\ year}{12\ months} \frac{m^3\ biogas}{month} \quad (1)$$

Therefore, each alpaca potentially produces 5.22 m^3 of biogas per month in the biodigester (1).

Biol Production

In the case of biofertilizers, such as biol, Aparcana [5] mentions that they are composed of dissolved solids of degraded organic matter and water, representing up to 90% of the total incoming waste.

$$4.29 * 0.9 = 3.86 * 365 = 117.44 \frac{Kg\ EF}{day} \frac{Kg\ biol}{kg\ EF} \frac{kg\ biol}{day} \frac{days}{1\ year} \frac{1\ year}{12\ months} \frac{Kg\ biol}{month} \quad (2)$$

Therefore, they would be obtained potentially 117.44 kg of Biol from 4.29 kg of alpaca manure (2).

Residual Fiber

These can be used for the production of biogas and biofertilizers, as evidenced by the study carried out by the Catholic University of Santa María together with the textile company Inca Tops in Arequipa - Peru, from the solid waste generated during the processing of alpaca fiber and sheep's wool [28]. They used three dry anaerobic digestion reactors each with different inoculum, bacteria, fungi, and consortium, to evaluate the composition and production of biogas; being the reactor with the consortium inoculum the one with the best biogas composition (33.38% methane, 6% carbon dioxide, 1.44% oxygen and 0.89 ppm sulfur dioxide).

The use of biogas in the textile industry as a fuel can be the beginning towards a transition from conventional to renewable energy, and the residue from digestion can be used as a biofertilizer to be applied directly on leaves and stems, providing a high content of micro and macronutrients [48]. This research and the first pilot plant tests demanded a total investment of 380,000 PEN (98,127.82 USD), of which the Innóvate Peru Program contributed about 70% of the resources, through the Business Innovation Contest [39].

Yarn Waste, Weaving Panels, Cloths, and Scraps

The waste from the yarn, weaving, finishing, and tailoring of the company Incalpaca TPX is used after segregation, and waste of type A (R-A) and B (R-B) is obtained such as yarns, weaving panels and scraps; type C (R-C) as discarded yarns, edges, R-A and R-B.

The R-A generates new fiber and threads to make shawls, blankets and blankets through carding and spinning; the R-B does not require treatment which allows to elaborate cartridge cases, necklaces, key chains, purses, slippers, stuffed animals, and bracelets; R-Cs are sold for upholstery. The amount of R-A and R-B generated during the period 2018-2019 was equivalent to 22.52% of the total amount of waste. The R-A generated 87,624 products with sales of 3,022,823.4 PEN (780,587.04 USD), and the R-B generated 38,611 products with sales of 1,969,910.0 PEN (508,692.05 USD) [15].

The company MFH KNITS is dedicated to the weaving and manufacture of garments. This company generates waste in two areas: weaving (threads and panels) and cutting making (pieces and fallen cloths). The company used to store the fallen cloths while the other waste was sold at 0.28 USD/kg; currently the company takes advantage of the scraps to make blankets by garneteado, carding, spinning, and weaving; garneting is done in a Garnett machine, which crushes the scraps into fiber. In 2020 the company generated 1,011 blankets, the cost of each was 25.3 USD with a sale price of 34.6 USD and a profit of 9,409 USD for all [11]; the budget for producing a blanket is shown in Table VIII.

TABLE VIII
BUDGET TO PRODUCE A BLANKET FROM SCRAPS [11]

Cost of scraps		Cost for Garnett Service		Cost of regenerated yarn	
Cost of scraps	0.28 USD/kg	Garnett Service Cost	1.85 USD/kg	Spinning cost	4.78 USD/kg
Classification cost	0.80 USD/kg	Cost of the Garnett (Merma)	2.55 USD/kg	Cost of encroachment	0.10 USD/kg
Freight cost	0.83 USD/kg			Cost of spinning service	2.80 USD/kg
Total	1.91 USD/kg		4.40 USD/kg		7.68 USD/kg

Table VIII shows the costs to produce a blanket, although this adds up to 13.99 USD/kg in Carpio's Thesis [11] it is mentioned that the cost of electricity consumption of the Garnett machine and labor were considered.

C. Tanneries

This section will present some alternative solutions for the proper management of waste from the tannery industry.

Plastic Packaging Waste

In the case of empty containers of the chemical substances mentioned above, the containers must be washed three times, being optional to send them to an authorized collection center for chipping and subsequent transfer to a landfill or recycling. For the specific case of plastic containers containing sulfuric acid, they can be referred to a safety filler. These recyclable containers of chemical products can be returned to the supplier maintaining 100% return strategies.

Chromium Chips

Both hydrolyzed collagen and chromium can be recovered through the application of alternatives that allow the extraction or separation of these for subsequent use in different production processes, which allows to achieve the economic valorization of waste and the mitigation of environmental impacts. Tanned leather shavings (TLS) represent one of the wastes that is generated in greater quantity within the production process of the tanning sector. For this reason, it is important to evaluate alternatives for the recovery or use of this waste, and from there, contribute the reduction of pollution originated by the inadequate disposal of waste. A study carried out focus on the treatment of TLS as an alternative for the use and valorization of the material through the extraction of hydrolyzed collagen from the alkaline-enzymatic hydrolysis method, with the purpose of obtaining products to be used in different fields [3].

The chromium obtained in the hydrolysis process can be reintroduced to the tanning or retanning process, while the hydrolyzed collagen can be reintroduced into the greasing (finishing) process. This valorization alternative is profitable according to the results of Álvarez and Zegarra, who estimated 824 soles as costs for the hydrolysis of 100 kg of VCC and revenues of 2 617 – avoided costs [4].

Table IX shows the input costs required for alkaline-enzymatic hydrolysis with 100 kg of leather shavings.

TABLE IX
INPUT COSTS FOR ALKALINE-ENZYMATIC HYDROLYSIS [4]

Inputs	Used (kg)	Unit price (PEN)	Total (PEN)
Microbial enzyme	0.40	87.50 (22.60 USD)	35.00 (9.04 USD)
NaOH	19.74	40.00 (10.33 USD)	789.60 (203.90 USD)
Lime	0.20	0.70 (0.18 USD)	0.14 (0.036 USD)
		Total	824,74 (212.97 USD)

Table X shows the gain generated by the products (chromium and collagen hydrolysate), resulting from alkaline-enzymatic hydrolysis with 100 kg of leather shavings. Likewise, it is estimated that the gain when performing the alkaline-enzymatic hydrolysis process with the microbial enzyme for 100 kg of shavings would be 1793.04 PEN (463.02 USD), whose result is obtained by subtracting the total value of Table X (2,617.78 PEN (675.99 USD)) with that of Table IX (824.74 PEN (212.97 USD)).

TABLE X
PRICE OF PRODUCTS FOR ALKALINE-ENZYMATIC HYDROLYSIS

Products	Commercial Price PEN/kg	Obtained	Total (PEN)
Chromium	4.60 (1.19 USD)	26.56	122.18 (31.55 USD)
Collagen Hydrolysate	10.00 (2.58 USD)	249.56	2,495.60 (644.44 USD)
	Total		Total

Residues of Skin, Fats, Hairs, and Feces

The "Instituto Tecnológico Agroalimentario de España" describes the process of dry discontinuous melting, which consists of storing, chopping, boiling fats, and pressing them until a pathogen-free flour is obtained. For pelambre residue, according to Numpaque and Viteri [42], the best option is biological treatment or composting, since this type of waste does not represent a danger to the environment. And finally for skins, according to the World Intellectual Patent Organization [12], the WO2012056080A1 procedure will be followed, which serves to obtain artificial casings. These treatments are usually carried out by large tanneries or groups of industries, however, for small and medium-sized enterprises (SMEs) it is not profitable to carry out these treatments due to their high costs and the space they occupy, so, for these companies, biological treatment or composting in reactors or batteries represents a more appropriate alternative to their reality [31].

As for the uses given to the products obtained: flours are used as meat dressing; the artificial casing serves as a wrapping for sausages, etc. [1]; compost could be used as fertilizer in agriculture, gardening, nurseries, etc. Regarding the input to make the compost are effective microorganisms (EM), lime, sawdust, and organic remains, the latter has no cost since it comes from the production process. Table XI shows baseline costs because sawdust was included because it is an appropriate additive for soil improvement, according to a study by Llerena [32].

Table XI shows us the minimum quantities of kilograms of inputs necessary for composting, in addition to unit prices.

TABLE XI
PRICES FOR COMPOSTING

Inputs	Unit	Quantity	Unit price (PEN)	Total price (PEN)
Sawdust	kg	1	3.16 (0.82 USD)	3.16 (0.82 USD)
Tannery waste	kg	2	2.70 (0.7 USD)	5.40 (1.39 USD)
Efficient microorganisms	litres	1	19.75 (5.10 USD)	19.75 (5.10 USD)
Water	litres	18	0.025 (0.0065 USD)	0.45 (0.12 USD)
		Total		28.76

D. Case Studies: Companies San Gabriel, Indutex and Sur Color Star

According to the register provided by the Directorate of Environmental Affairs of the Ministry of Production (DGAAMI) [39], most of those administered are operating with management instruments approved outside the current regulations; however, this does not exempt them from liability for environmental impacts that may be generated from solid waste management.

Table XII presents that knowing the legal requirements is essential, since it generates benefits for the company.

TABLE XII
MAIN BENEFITS FOR COMPANIES WHEN OPERATING UNDER CURRENT REGULATIONS

Avoid penalties	Avoid environmental fines imposed by the OEFA.
Prevent environmental damage	The legislation regulates actions to avoid impacts on the environment.
Anticipating new legislative requirements	A rule that implies relevant changes for companies gives adaptation deadlines, the sooner they are known, the more time to adapt.
Public image enhancement	Environmentally friendly companies have better social recognition.

V. CONCLUSION

A. Haute Couture

In the textile industry, hazardous waste is generated such as oiled rags contaminated by chemicals, needles, blades, and through wastewater, acids, bleaches, solvents, among others. The improper disposal of these waste, as well as the dumping of ethoxylated nonylphenols, ethoxylated alkyphenols, phthalates, etc., into rivers, causes negative effects on human health, affecting the respiratory system, altering the endocrine system, and even causing cancer. Another way of exposure is through the trophic chain since being present in the ecosystems, it impacts the fauna and flora. Consequently, the low biodegradability of these chemicals affects living organisms, through biomagnification and bioaccumulation.

B. Alpaca Fiber

Camel manure has a lower energy potential compared to cattle and horses, but this difference is not significant. Therefore, the use of alpaca excrement for the production of biogas and biol is viable. A Chinese-type biodigester could be an alternative for the management of waste generated in this industry, due to its affordable value for the place where the industries are located. Biogas production is not limited to the use of livestock manure, the residual fiber, generated during the early stages of alpaca fiber processing, can also be used. The correct segregation of waste yarn, weaving panels, cloths, scraps, and thread allows to reduce costs in storage, transport and final disposal; also, efficiently take advantage of materials to make other type products: shawls, blankets, blankets, cartridge cases, necklaces, key chains, purses, slippers, stuffed animals and bracelets; which could mean other income to the company.

C. Tannery

The application of biological processes for the treatment of waste with chromium is limited because chromium and sulfide are inhibitory compounds. So, it is necessary to eliminate the waste through the implementation of physicochemical treatments, and thus an optimal use can be given. The quality of compost can be increased with the use of the waste generated in the process of the tannery industry, and it can be used as fertilizer and improver of agricultural soils from the improved method, with the addition of efficient microorganisms, compared to the traditional method, without adding the aforementioned.

D. Case Studies: Textile Companies San Gabriel, Indutex and Sur Color Star

To 2021, the current regulatory framework is D.L. No. 1278, Law on Integral Management of Solid Waste, published in 2016; however, companies continue to develop their solid waste management instruments (Solid Waste Management Plan) within the framework of the guidelines established by a repealed law. Likewise, the article 5 of the current regulatory is looking for reducing the risk of pollution generated by the various productive activities, as well as to avoid monetary sanctions for regulatory non-compliance.

VI. RECOMMENDATIONS

A. Haute Couture

The production of garments and products of the textile industry of large brands covers various processes, which are mostly not located in one place. Due to this, inadequate management of this hazardous waste can be found in countries where the regulations are not clear or there is no internal control, considering that the problem of waste in this industry is increasing, regulations should be implemented based on guidelines from specialized agencies on solid waste

During the production stages of the garments, a variety of hazardous chemicals are used that allow to grant specific characteristics and serve to improve the quality of the garments. However, there are substitute products that would improve environmental conditions, in addition to prioritizing the minimization of these or the replacement by less dangerous alternatives. The good environmental practices of transnational corporations must be applied in countries such as Peru that do not yet have a specific regulatory framework, generating added value to the client for the acquisition of the garment.

B. Alpaca Fiber

It is necessary that the D.S. N° 016-2012-AG be updated, regulating the opportunity of treatment and use of waste aligning it with the D.L. N° 1278, Law of Integral Management of Solid Waste. It is necessary to strengthen the actual regulations in Peru regarding the management of agricultural waste and promote initiatives for the design, construction, and implementation of biogas treatment plants from agricultural waste.

A National Agroenergy Plan and/or a Training Program in the construction and operation of biogas plants must be elaborated. Likewise, it is necessary to disseminate the technology of biodigesters as a system for the treatment of organic waste in industrial transformation processes and basic sanitation, generate a culture of production, commercialization, and use of biol as an ecological fertilizer that increases crop yields and displaces the use of chemical fertilizers. Peru needs to develop processes for the use of solid waste that is generated in the alpaca fiber industry, from the implementation and improvements in processing infrastructures, to training for the use of these.

The "Ministerio del Ambiente" (MINAM) and "Ministerio de la Producción" (PRODUCE) must carry out training projects and economic valuation of textile waste; in addition to this, they must work together with companies to design guidelines for the integral management of textile waste, emphasizing the generation and segregation with the aim of making possible the use of waste as raw material for the development of new products.

C. Tannery

The "Ministerio de Desarrollo Agrario y Riego" (MIDAGRI) must elaborate a legal device for the treatment of waste produced in the tannery industry, where it expresses the quality standards of the parameters issued. In addition, it is necessary to update the standard D.S. N° 003-2002-PRODUCE of the levels of waste discharge in the tannery industry and in it must contemplate the residue of feces, because it is a hazardous waste due to its potential to be pathogenic. The approach of the legal device should consider the Extended Producer Responsibility to manage the products and packaging that provide these markets, to include the recovery and administration of these materials, promoting strategies with buyers for an adequate return of chemical containers and these can be reused.

It is necessary to update the terms of reference of the Environmental Impact Studies and other environmental management instruments of the industry subsector (tannery), in such a way that the implementation of the Solid Waste Minimization and Management Plan of the companies is monitored. National research should be carried out to evaluate alternatives for the treatment of hazardous waste for small tannery companies, as well as to promote incentives and technical support so that they can incorporate environmental criteria into their industrial process without compromising their profitability.

D. Case Studies: Textile Companies San Gabriel, Indutex and Sur Color Star

The companies analyzed can propose to be part of the Clean Production Agreements, for which the "Ministerio del Ambiente" (MINAM) has the Directive for the signing of Clean Production Agreements on Solid Waste, according to D.S. N° 02-2019-MINAM/DM [19], which was approved with Ministerial Resolution N° 130-2020-MINAM. Through this agreement, companies must comply with selecting raw materials and inputs with less negative environmental impact, incorporate recycled material into their production processes, implement eco-design, train their staff in solid waste management and good eco-efficiency practices aimed at minimizing the generation of solid waste.

Additionally, it is important to specify that the production, manufacturing, and textile sectors must develop a solid waste management instrument, in accordance with the current regulatory and monitor its implementation by reporting the progress obtained to the competent sector.

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