Tanning leather environmental assessment: a case study in Leon, Mexico

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ABSTRACT

Purpose. The tanning industry generates a significant amount of pollutants throughout its processes, posing risks to the environment, as well as to overall human health. This paper aims to present a case study conducted at two associated tanning companies in Leon, Mexico, in order to identify opportunities for improvement for reducing potential hazards.

Design/methodology/approach. Two main approaches were utilized for the case study: a Life Cycle Assessment (LCA) to identify potential global warming and climate change impacts at the production cycle, and a review of the chemical products used in the tanning process via the Hazard Statement Codes of the Globally Harmonized System of Classification and Labelling of Chemicals (GHS).

Findings. The most significant environmental impacts identified through LCA occurred during the drying and fatliquoring stages. In the global warming-related impacts, both stages measured 8,744.51 kg CO_2eq, while in climate change-related impacts, the result was 10,582.75 kg CO_2eq. In the GHS chemical review, 35 hazardous chemical compounds were identified; they are classified as levels 1 and 2, meaning they possess the highest hazard potential according to the GHS Hazard Statement Codes.

Research limitations/implications. Most of the information used in this study was obtained from the Ecoinvent database and through an external audit of the companies involved; however, there was no field verification of the data.

Originality/value. The assessments of the tanning industry in Mexico are usually challenging to conduct. Thus, the results of this study will increase the pool of available knowledge regarding the potential environmental impacts of the tanning industry in the country that can be used for decision making at strategic levels for companies and government agencies.

Keywords: *Life Cycle Assessment, Globally Harmonized System, Bovine leather, Environmental performance, Mexico*

1. INTRODUCTION

Leathermaking has long been one of the most socially relevant industries. Leather itself is a material obtained from animal skins or hides after undergoing a tanning process that both avoids its degradation and improves its physical characteristics, including flexibility, softness, and durability (Correa Delgado et al. 2011). Leather production can occur either in a handicraft or industrial manner, depending on the equipment and the quantity of hides involved (Moreyra 2015). It involves the use of various tanning agents, mechanical processes, and chemical substances that, besides altering its physical characteristics, also add various aesthetic characteristics to the finished leather (Guinée et al. 2002).

There are three main tanning techniques, classified according to the tanning agent used (Rydin et al. 2013). The most common is the mineral tanning process, which relies on various salts, including chromium, aluminum, and zirconium (Lampard 2000). Another method is synthetic/organic tanning, which consists of mixing natural tanning agents with formaldehyde or oils to facilitate hide penetration (CAAAREM 2007). The third process is vegetable tanning, which uses tannic acids extracted with ether or alcohol from the bark, fruits, or roots of a large variety of trees, including mimosa and oak (Hourdebaigt et al. 2007).

From 2012 to 2014, the worldwide production of bovine light leather, mostly for the manufacturing of bags, coats, shoes, and other products, amounted to 14,298.70 million square feet; while in developing countries were produced 3,493.30 million pairs of footwear using bovine leather during this same period (FAO 2016). Effluents from this industry contain large amounts of sediments, metal compounds, chemicals, and biologically oxidizable materials (Mahmood 2000), resulting in unfavorable conditions for nearby aquatic life and soil productivity (FAO 2003). Although leather tanning is a necessary industry for society, including its production of valuable byproducts such as collagen, its industrial waste, including emissions and electricity consumption, negatively impacts human health (Salinas Vásquez 2014) and represents a severe social problem (Vidaurri Ramírez and Beltrán 2011).

Internally, the tanning industry generates numerous occupational health hazards. Several studies suggest that workers may develop afflictions like dermatitis, ulcers, respiratory diseases, and cancer as a result of exposure to toxic substances such as chromium and chlorinated phenols (Rastogi et al. 2007). In addition, it is estimated that this industry is one of the largest contributors to global warming and climate change. Tanning causes both deforestation and land degradation, as well as the emission of huge amounts of carbon dioxide (CO_2) due to large scale animal breeding as a raw material resource (Koneswaran and Nierenberg 2008). Over time, the requirements imposed on leather processing have increased, not only in terms of quality and process optimization, but also in occupational health, environmental conservation, and sustainability (Buljan and Král 2015).

In Mexico, the tanning industry has a high growth potential, despite the gradual technological development of tanneries (Carrillo González et al. 2017) and the severe environmental impacts generated by them (Blackman 2005). In Guanajuato, the leather-footwear chain has been one of the activities that has generated more added value, with 13.21% of manufacturing by 2014 (Dussel Peters and Cárdenas Castro 2018), creating a large area of opportunity for further development (García Salazar 2008). The municipalities of the state of Guanajuato, including Leon, San Francisco del Rincon, and Purisima del Rincon, collectively control 68.4% of the country's footwear production and 76.4% of its leather tanning and finishing (INEGI 2014).

The State Secretariat for Sustainable Economic Development affirms that, in Guanajuato, various certifications are promoted focusing on sustainable processes and innovations in the leather footwear industry (SDES 2016). However, according to the Municipal Planning Institute and the Council for Municipal Development Planning, while there are approximately 756 tanneries (IMPLAN; COPLADEM 2016) in the region, only about 3% have attended the Ecotannery certification program put forth by the Chamber of Industry of Tannery of the State of Guanajuato

(CICUR 2015). This program is based on the Global Green Protocol British Leather Center (BLC 2017; Ecotannery 2017), which provides services such as Life Cycle Assessment (LCA) and leather waste, sustainability training, chemicals management, and program audits.

Mexico occupies eighth place in the global production of footwear (Jiménez Rodríguez et al. 2016), and Leon is home to two outstanding international events for this sector, the National Association of Suppliers of the Footwear Industry (ANPIC by its Spanish acronym) and the Leather and Shoes Room (SAPICA by its Spanish acronym). The latter is the most important footwear supplies trade fair in Latin America (CICUR 2018). Those events make Leon one of the most important suppliers of leather in the entire country; this city contribute 57.8% of the total value of production (INEGI 2014). As a whole, the sector is 90% comprised of small and medium-sized family businesses (Carrillo González et al. 2017).

The development and growth of the tanning industry are of great importance, but it is necessary to achieve them in a sustainable way. Hence, the LCA has become a fundamental tool with which to identify environmental problems in the sector, as well as to generate both corrective and preventive measures (Drault 2004). There have been several LCA studies in the matter conducted around the world, mostly with the general objective of analyzing the main stages of the bovine leather tanning process, identifying their hot spots, and making recommendations for ecological improvement.

The study by Notarnicola et al. (2011), in which the tanning systems of Italy and Spain were analyzed, identified key problems, specifically: the use of chromium sulfate in the tanning stage, ammonia (NH_3) and methane (CH_4) produced from associated landfills, and the volatile organic compounds (VOC) left over from finishing operations. The Chinese study by Brugnoli and Král' (2012), analyzed the leather industry's background knowledge on LCA and Product Carbon Footprint (PCF) with the objective of producing consistent proposals for convergence and harmonization. A more recent example is a study by Chowdhury et al. (2018) in Bangladesh, where they compared the environmental effects of chrome leather tanning and retanned wet blue, identifying significant potential impacts associated with several production cycle stages, mainly due to the use of chromium trivalent (Cr3+) and hexavalent (Cr6+).

Several international studies have used LCA to estimate the environmental impact of bovine leather production; however, few evaluations of Mexican production conditions exist. An environmental impact analysis was thus conducted on the production of 129.17 tons of leather at two associated companies in Leon, Guanajuato. The aim of this paper is to present a case study conducted at two associated tanning companies in Leon, Mexico, in order to identify opportunities for improvement for reducing potential hazards in their processes.

2. MATERIALS AND METHODS

Two main approaches were used. First, an LCA to identify climate change and potential global warming impacts in the production cycle, as shown in Figure 1. Second, a review of the chemical products used in the tanning process to identify potential hazards through an analysis of the Hazard Statement Codes of the Globally Harmonized System of Classification and Labelling of Chemicals (GHS). The GHS goal is the international homogenization of the information on potential hazards for assuring the safer transport, use, and disposal of chemical products through safety data sheets and holistic labeling (United Nations 2011). The names of the participant companies and their products were omitted due to a confidentiality agreement. The first company, hereafter called Tannery 1, performs the initial phase of the tanning process, while the second company, hereafter called Tannery 2, performs the final phase. The product under study is hereafter called 'Leather type A.'

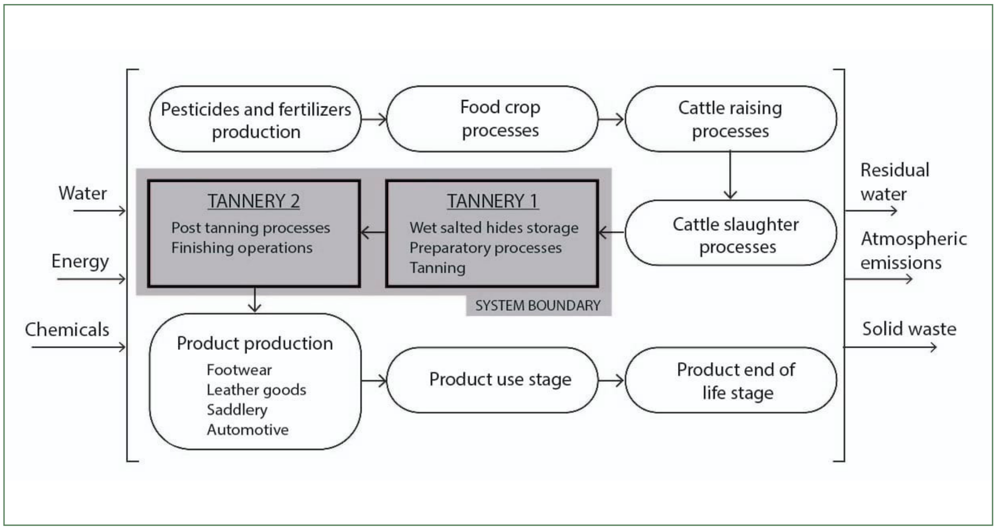

Figure 1. System boundary in the leather production chain.

Categories directly related to global warming and climate change were specifically evaluated using LCA. The method used is based on the European Platform on Life Cycle Assessment (EU-JRC-IES 2010). It is essential to first determine the objective and scope of the study, as well as the declared unit, the allocation, and the impact categories that will be evaluated. An inventory must then be carried out in relation to the system under study in order to evaluate the impact of the life cycle. Thus, the SimaPro® program with the EcoInvent database and the IMPACT2002+ and ReCiPe Midpoint H methodologies were applied for a further interpretation of the results. Finally, since commercial secrets and supplier patents make it difficult to exactly assess the percentage of components in various product formulae, it was decided to evaluate potential chemical impacts through analysis in the context of GHS.

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2.1 CASE DESCRIPTION

The study includes two associated companies in the city of Leon, Guanajuato, at the center of Mexico, during a period from June 2017 to December 2018. Historical information was also collected from previous audits from 2015 onwards for both companies.

The scope of LCA corresponds to the "gate to gate" approach, which implies the analysis of several stages, from the reception of wet salted hides at the first company to the end of production at the second company. Both companies thus work together to complete a tanning process defined by sixteen main stages, as shown in the flow diagram in Table 1. The selected product analyzed, 'Leather type A,' has specific finish and treatment requirements indicated by a client of Tannery 2. It represents the highest percentage of production, covering 14.05% of the main product lines.

Table 1. Tanning process of 'Leather type A'

Company	Stage	Inputs	Processes within the system boundar	Outputs
Tannery 1	01 Wet salted hides	Brined hides and rags	Reception and weighing of the brined hides Inspection Storage	
	02 Desalting	Water, energy, plastic containers, and liquefied petroleum gas	Elimination of traces of salt Weighing for formulation	Wastewater, WWTP sludge, municipal solid waste, plastic containers, inert waste, oils, atmospheric emissions, and residual salt
	03 Soaking	Water, energy, plastic containers, liquefied petroleum gas, and chemical products	Hides rehydration	Wastewater, WWTP sludge, municipal solid waste, plastic containers, inert waste, oils, and atmospheric emissions
	04 Unhairing, fleshing and splitting	Water, energy, plastic containers, liquefied petroleum gas, chemical products, and calcium oxide	Removal of hair and subcutaneous material	Wastewater, WWTP sludge, municipal solid waste, plastic containers, inert waste, oils, atmospheric emissions, and rawhide trimmings
	05 Liming	Water, energy, plastic containers, liquefied petroleum gas, and chemical products	Elimination of interfibrillar proteins and fats	Wastewater, WWTP sludge, municipal solid waste, plastic containers, inert waste, oils, atmospheric emissions, and rawhide trimmings with lime residues
	06 Pickling	Water, energy, plastic containers, liquefied petroleum gas, chemicals, and acid solutions	Lower the pH and add acidic solutions	Wastewater, WWTP sludge, municipal solid waste, plastic containers, inert waste, oils, and atmospheric emissions
	07 Tanning	Water, energy, plastic containers, liquefied petroleum gas, chemicals and chrome solutions	Chromium based mineral tanning	Solid urban waste, plastic containers, inert waste, oils and atmospheric emissions
	08 Basified	Water, energy, plastic containers, liquefied petroleum gas, chemical products to raise the pH	pH elevation and drainage	Wastewater, WWTP sludge, municipal solid waste, plastic containers, inert waste, oils, and atmospheric emissions
	09 Finished Wet Blue	Energy and fuels	Wet Blue	Leather in Wet Blue, and atmospheric emissions

Transport between companies				
Tannery 2	10 Wet blue	Leather in Wet Blue and wooden pallets	Reception and weighing of the Wet Blue leather	Cardboard and classified paper waste, municipal solid waste, atmospheric emissions, and bilge oil
	11 Retanning	Water, energy, plastic and metal containers, liquefied petroleum gas, and chemical products	Leather trimming and retanning	Wastewater, WWTP sludge, cardboard and sorted paper waste, municipal solid waste, mixed solvents, bilge oil, plastic and metal containers, atmospheric emissions, and tanned leather trimmings
	12 Dying	Water, energy, plastic and metal containers, liquefied petroleum gas, and chemical products	Coloring and fixation of dyes	Wastewater, WWTP sludge, cardboard and sorted paper waste, municipal solid waste, mixed solvents, bilge oil, plastic and metal containers, and atmospheric emissions
	13 Fatliquoring	Water, energy, plastic and metal containers, liquefied petroleum gas, and chemical products	Oiled leather	Wastewater, WWTP sludge, cardboard and sorted paper waste, municipal solid waste, mixed solvents, bilge oil, plastic and metal containers, and atmospheric emissions
	14 Drying	Energy, plastic and metal containers, and liquefied petroleum gas	Leather drying	Cardboard and classified paper waste, municipal solid waste, bilge oil, plastic and metal containers, and atmospheric emissions
	15 Finishing	Water, energy, plastic and metal containers, liquefied petroleum gas, and chemical products	Brushed, padded, polished, ironed and varnished	Wastewater, WWTP sludge, cardboard and sorted paper waste, municipal solid waste, bilge oil and residual oils, metal containers, finished leather waste and scraps, unspecified waste, and air emissions
	16 'Leather type A'	Energy, plastic and metal containers, and fuel	Leather type A	Cardboard and classified paper waste, municipal solid waste, bilge oil, and atmospheric emissions

The studied system begins with the chromium tanning of wet salted hides in Tannery 1, resulting in 'Wet Blue' leather, thus named for its pale blue color caused by the chromium (Gálvez Velasco and Ochoa González 2015). This type of tanning maintains the moisture of the hide and prepares it for the next stages of the production cycle.

Around 8,861.11 tons of bovine hides were processed in 12 months. Tanned cattle leather has diverse applications within the industry. Tannery 2 produces leather mainly for footwear and leather goods, such as bags, belts, or leather accessories; however, it also performs some processes for the automotive industry. In total, Tannery 2 produced 919.41 tons of Wet Blue leather.

Finished leather offers a variety of options for customers, some with more flexible aesthetic possibilities and others with greater efficiency in terms of quality and durability. 'Leather type A,' which has specific finishing characteristics for manufacturing footwear and boots, accounted for 129.17 tons of production. Finishing operations determine the final combination of customer aesthetics and performance attributes for each manufactured product.

2.2 SYSTEM BOUNDARIES

LCA embraces the following phases: rawhide storage, beamhouse – where the pre-tanning processes are carried out, tanning, dyeing, and finishing. Further steps in leather processing exist outside those boundaries, including footwear and boots production, as well as the use and disposal of the product. This study did not consider administrative processes, maintenance, and product distribution, as they were not part of identifying and quantifying the environmental burdens associated with 'Leather type A'. The origin of raw materials is difficult to track due to confidentiality issues. According to information provided by the companies, the following percentages reflect the purchase and origin of raw materials: 94.85% from the United States, 1.56% from Mexico, and 3.59% from Canada.

Excel was used for data management together with SimaPro®, which allows the analysis of complex products by deconstructing their materials and processes before selecting from among several databases and methodologies to carry out the analysis. Some of the inputs used in the tanning process of 'Leather type A' were not found in the software libraries; it was necessary to create them in the program. To that end, a bibliographical investigation of materials was carried out to facilitate their assembly in SimaPro® using existing information already present in the database.

2.3 DECLARED UNIT AND ALLOCATION

According to Wittstock et al. (2011), there are two cases in which it is relevant to define a declared unit instead of a functional unit. The first is in the assessment of raw materials, such as cement or gravel. The second concerns materials that can be used for a wide variety of products. Because the product on this study is raw material for manufacture a variety of products, a declared unit of 129.17 tons of tanned 'Leather type A', with an average thickness of 1.816 mm, was defined. The product's main use dwells in the manufacture of footwear and boots, along with weathering and a velvety finish, resistant to water, and boasting a product lifetime of between four and six years, depending on use. This value was determined based on the production records from the tanneries themselves, as shown in Table 2. An attributional system was used because it focuses on support for decision making at the micro level, the consequences of which are therefore of interest (Hauschild et al. 2018).

Table 2. General leather system inventory

Company	Stage	ton	centage of total production per company
Tannery 1	Wet salted hides	10,713.25	100%
	Desalting	3,449.66	32.20%
	Soaking		
	Unhairing, fleshing and splitting		
	Liming		
	Pickling		
	Tanning		
	Basified		
	Finish Wet Blue	905.07	8.45%
Tannery 2	Wet blue	919.41	100%
	Retanning	129.17 *	14.05%
	Dying		
	Fatliquoring		
	Drying		
	Finishing		
	'Leather type A'		

* Declared unit: 129.17 tons, with an average thickness of 1.816 mm.

2.4 IMPACT CATEGORIES

According to Jolliet et al. (2003), the IMPACT 2002+ method links all types of outcomes across several mid-point categories, which are reflected in four major damage categories. It is called "mid-point" because it reflects that this indicator is located between the results of the life cycle inventory and the damage inherent in the impact route (Chowdhury et al. 2018). The categories directly related to global warming and climate change were specifically evaluated, as shown in Figure 2. To broaden the spectrum of evaluation, the study is complemented with the ReCiPe Midpoint H method.

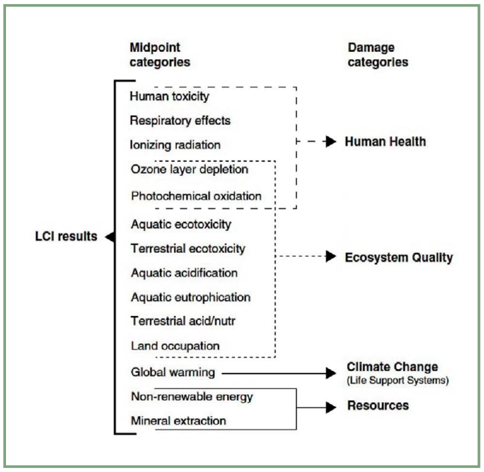

Figure 2. General scheme of the IMPACT 2002+ framework, adopted from Jolliet et al. (2003).

2.5 GLOBALLY HARMONIZED SYSTEM OF CLASSIFICATION AND LABELLING OF CHEMICALS (GHS)

A detailed analysis was carried out based on the GHS to identify the potential hazards posed by each of the chemical compounds in the products. To do this, two reference schemes were used. The first involved the decision logic for acute toxicity from the United Nations (2011); the second concerned safety and hazard information from the National Center for Biotechnology Information at the PubChem chemistry database (Kim et al. 2019). In addition, after reviewing the bibliographic data, a description focused on the most harmful hazard categories was made.

3. RESULTS

3.1 LIFE CYCLE INVENTORY

The information used in this project was obtained from production records and inventories from the companies themselves, as well as from observations and measurements made in the workplace. In addition, the most updated Leather Working Group (LWG) audit protocol was used to validate the data. The LCIA in Table 3 displays the estimations from production, supply, energy, air emissions, effluent flow, waste management, and related transport.

The LWG is a multi-stakeholder group made up of leather manufacturers, suppliers, and technical experts based in offices in Northampton, United Kingdom (LWG 2016). The purpose of the audit protocol is to evaluate the environmental performance of tanneries through various questionnaires, information analyses, and visits. It also provides a list of best environmental practices for tanneries and leather producers. The evaluation parameters relate to the following hierarchy: reduce, reuse, recycle, recover, and waste (LWG 2017).

Table 3. General Inventory of the production of 'Leather Type A'.

Estimation	Unit	Tannery 1	Tannery 2
Energy			
Intern electricity	kWh	348,947.00	1,901.61
Natural gas	MJ	N/A	436,579.00
Petroleum liquid gas	MJ	895,085.00	553,783.00
External electricity WWTP	m^3	33,986.00	34,880.00
Solar energy generated	MJ	N/A	59,033.00
Air emissions			
Nitrogen boiler	ppm	81.78	N/A
Carbon Monoxide boiler	ppm	56.00	28.59 *
Effluent flow			
Water input	m^3	43,925.31	5,949.05
Wastewater output	m^3	41,595.87	5,645.65
Waste management - byproducts			
Salt	kg	586,334.00	N/A
Raw hide fleshing	kg	32.00	N/A
Limed hide fleshing	kg	717.00	N/A
Shaving waste	kg	N/A	26,654.40

Leather wastes	kg	N/A	1,824.95
Finishing trimmings	kg	N/A	1,311.57
Waste management - residual			
Plastic containers (HDPE)	kg	180.96	1,417.74
WWTP sludge **	kg	126,385.00	N/A
Municipal solid waste	kg	215.74	36,899.73
Inert waste with bilge oil	kg	32.20	N/A
Wood pallets	kg	N/A	1,536.23
Cardboard and sorted paper waste	kg	N/A	1,195.94
Dust - unspecified	kg	N/A	1,136.43
Steel containers	kg	N/A	484.87
Bilge oil	kg	N/A	337.20
Oil waste	kg	N/A	33.72
Spent solvent mixture	kg	N/A	157.36

Transport ***		
Weight transported	ton	905.07
Distance between Tanneries	km	23.40
	ton*km	21,178.57

N/A = Not Applicable
* Average with a margin of error ± 3.05
** Contains chromium: 0.0006 kg/m3
*** Distance between Tanneries multiplied by tons transported

The main database used for this study is Ecoinvent, with its attributional modalities, allocation, and unit processes. LCA results show possible environmental impacts, as well as the contribution of each process, allowing for greater transparency in the assessment. The impact assessment results of the corresponding system throughout its life cycle are shown in Figure 3 and Table 4.

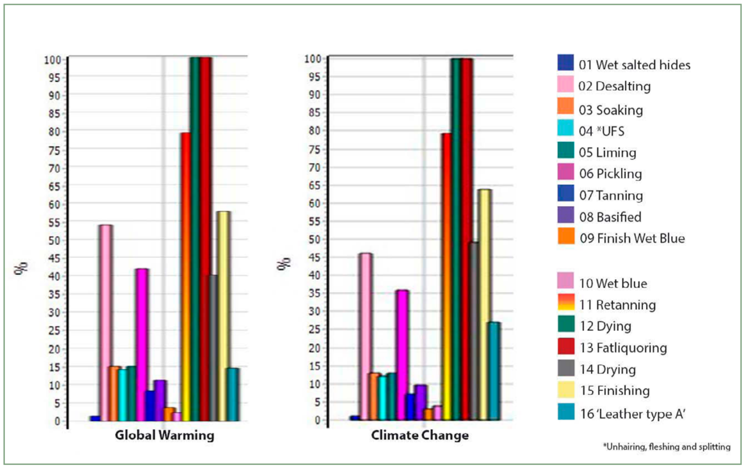

Figure 3. General assessment of potential impacts related to climate change and global warming.

Table 4. Results of the impacts identified in the general assessment.

Methodology	Impact category	Unit	Data of the phase with the greatest impact		Data of the phase with the second largest impact	
IMPACT 2002+	Characterization					
	Global warming	kg CO_2eq	8,744.51	12 Drying	8,744.51	13 Fatliquoring
ReCiPe Midpoint H	Characterization					
	Climate change	kg CO_2eq	10,582.75 10,582.75	14 Drying	10,582.75	13 Fatliquoring

According to the results obtained with the different methodologies, the drying and the fatliquoring stages generate the greatest potential impact. In global warming, both stages recorded 8,744.51 kg CO_2eq; in climate change, they recorded 10,582.75 kg CO_2eq. During the drying stage, the leather passes through the sammying process, which involves removing water from the hides post-tanning and setting them out to dry. The fatliquoring stage consists of a process where oils and fats are used to soften the leather.

3.2 SENSITIVITY ANALYSIS

As stated by Reckmann et al. (2013), in order to estimate the influence of a function on one of its variables, the modification provoked in that function must be calculated while the rest of the parameters remain without change. A sensitivity analysis can then estimate the effect of the selected data on the study result, providing additional information on the choice of reference. It was decided to conduct a sensitivity analysis to estimate the effects of actions that could be taken in companies to improve their environmental performance. Results are shown in Figure 4.

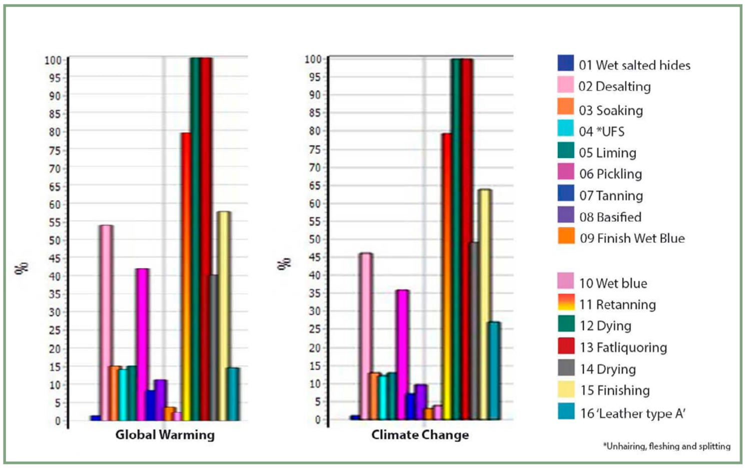

Figure 4. Sensitivity analysis results of potential impacts related to climate change and global warming.

Three main recommendations were generated to improve companies' environmental performance. In Tannery 1, the installation of solar panel heaters would reduce LP gas consumption by 6%, generating 53,705.10 MJ, equivalent to consuming a total of 841,379.88 MJ instead of the current 895,085 MJ. In addition, the installation of a wastewater treatment system, prior to discharge of the effluent, would reduce the generation of WWTP sludge by 42.14%, equivalent to generating 73,122.75 kg instead of the current 126,385 kg. In Tannery 2, applying a comprehensive management plan for the use of materials would minimize the generation of municipal solid waste by 10%, equivalent to generating 36,530.74 kg instead of the current 36, 899.73 kg.

Following these recommendations, according to the sensitivity analysis, would reduce CO_2eq emissions to 48 248.08 kg, down from the current 54,275.19 kg.

3.3 CHEMICAL COMPOUNDS ANALYSIS

Forty-two different chemicals and solvent products are used in the production of 'Leather type A.' During this research, suppliers shared 38 of the 42 safety data sheets that should be available. Of those, 68.4% were incomplete or outdated compared to the Mexican standard NOM-018-STP-2015 related to the use of the GHS (Secretaría de Gobernación 2015). The following tables, 5 and 6, show the analysis of the inventory of chemical products and the toxic description of the most harmful components, respectively.

Table 5. Analysis of inventory of chemical products, indicating with bold font the most harmful Hazard Statements.

STAGE *	NAME **	DESCRIPTION	CAS NUMBER	HAZARD STATEMENT	PICTOGRAM
03 SOAKING	Product S 03-01	Chemical for leather with enzymes	NDA	Classification not possible	
	Product S 03-02	Sodium hydroxide	1310-73-2	H290, H314, H315, H318, and H319	GHS05 and GHS07
	Product S 03-03	Mixture of Highly Ethoxylated Fatty Alcohols	NDA	H302, H315, and H319 ***	GHS07
	Product S 03-04	Magnesium oxide, alcohols, and surfactants	1309-48-4	H315, H317, H319, H335, and H410	GHS07 and GHS09
	Product S 03-05	Degreaser, humectant and emulsifier	68131-39-5	Classification not possible	
	Product S 03-06	NDA	NDA	Classification not possible	
	Product S 03-07	NDA	7681-57-4	H302 and H318	GHS05 and GHS07
04 UNHAIRING, FLESHING AND SPLITTING	Product UFS 04-01	Calcium oxide.	1305-62-0	H314, H318, H317, H410, H370, and H372	GHS05, GHS07, GHS08, and GHS09
		Magnesium oxide	1309-48-4		
		Silica dioxide	7631-86-9		
		Iron (III) oxide	1309-37-1		
		aluminum oxide	1344-28-1		
	Product UFS 04-02	Sodium hydrogen sulfide	207683-19-0	H314, H318, H290, H301, H400, and H335	GHS05, GHS06, GHS07, and GHS09
		Disodium sulfide	27610-45-3		
		Sodium thiosulfate	7772-98-7		
		Carbonic acid, disodium salt	497-19-8		
	Product UFS 04-03	Disodium sulfide	27610-45-3	H314, H318, H290, H301, H400, and H335	GHS05, GHS06, GHS07, and GHS09
		Sodium hydrogen sulfide	207683-19-0		
		Sodium thiosulfate	7772-98-7		
		Carbonic acid, disodium salt	497-19-8		
	Product UFS 04-04	Aminoiminomethanesulfinic acid	1758-73-2	H251, H252, H302, H315, H318, H319, H330, H332, H335, and H373	GHS02, GHS05, GHS06, GHS07, and GHS08
	Product UFS 04-05	NDA	NDA	Classification not possible	

05 LIMING	Product L 05-01	Ammonium sulphate	7783-20-2	H302, H315, H319, H335, and H411	GHS07 and GHS09
	Product L 05-02	Ammonium chloride	12125-02-9	H302, H319, and H360	GHS07 and GHS08
		Boric acid	10043-35-3		
06 PICKLING	Product P 06-01	Formic acid	64-18-6	H226, H302, H314, H318, and H331	GHS02, GHS05, GHS06, and GHS07
	Product P 06-02	Sodium formate	141-53-7	H315, H319 and H335	GHS07
	Product P 06-03	Sodium chlorite	7758-19-2	H290, H271, H272, H301, H310, H311, H314, H318, H330, H400, H410, and H412	GHS03, GHS05, GHS06, GHS07, GHS08, and GHS09
		Sodium hydroxide	1310-73-2		
	Product P 06-04	Sodium chloride	7647-14-5	H319	GHS07
07 TANNING	Product TC 07-01	Chromium hydroxide sulfate	12336-95-7	H315, H317, H319, and H332	GHS07
08 BASIFIED	Product B 08-01	Sodium P-chloro-M-cresol	15733-22-9	H290, H302, H312, H314, H318, H335, H400, and H411 ***	GHS05, GHS07, and GHS09
		Sodium O-phenylphenate	132-27-4		
		Sodium hydroxide	1310-73-2		
	Product B 08-02	Octhilinone	26530-20-1	H302, H311, H314, H317, H318, H331, H400 and H410	GHS05, GHS06, GHS07, and GHS09
	Product B 08-03	Magnesium oxide	1309-48-4	H315, H317, H319, H335, and H410	GHS07 and GHS09
11 RETANNING	Product RL 11-01	Alcohols, C12-14, ethoxylated (Laureth-23)	68439-50-9	H302, H318, H319, H400, H410, and H412	GHS05, GHS07 and GHS09
		Alcohols, C12-14, ethoxylated, sulfates, sodium salts	68891-38-3		
	Product P 06-01	Formic acid	64-18-6	H226, H302, H314, H318, and H331	GHS02, GHS05, GHS06, and GHS07
12 DYING	Product D 12-01	2-Butoxyethanol	111-76-2	H227, H290, H302, H311, H312, H314, H318, H330, H361, H370, H372, H411 and H412.	GHS05, GHS06, GHS07, GHS08, and GHS09
		2-(11-Methyldodecoxy) ethanol; phosphoric acid	73038-25-2		
		Dodecylbenzenesulfonic acid, potassium salt	27177-77-1		
		Deceth-9; 2-(Decyloxy)ethanol	26183-52-8		
		Potassium hydroxide	1310-58-3		
	Product D 12-02	NDA	NDA	Classification not possible	
	Product TC 07-01	Basic chromium (III) sulfate	12336-95-7	H315, H317, H319, and H332	GHS07
	Product D 12-03	Phenolic condensation	102980-04-1	Classification not possible	
		Naphthalene condensation	2624059	Classification not possible	
	Product D 12-04	Sodium thiosulfate	7772-98-7	H315, H319 and H335	GHS07
	Product P 06-02	Sodium formate	141-53-7	H315, H319 and H335	GHS07
	Product D 12-05	Adipic acid	124-04-9	H319.	GHS07.
13 FATLIQUORING	Product F 13-01	Acrylic polymer	NDA	H315, H319 and H335.	GHS07.
	Product F 13-02	Acacia mearnsi, ext., bisulfited	92456-58-1	Classification not possible	
	Product F 13-03	Mimosa Z, Titan yellow	1829-00-1	H226, H319, H315, H317, and H413	GHS02 and GHS07
	Product F 13-04	Aromatic sulfonic acids and formaldehyde	NDA	H226, H319, H315, H317 and H413.	GHS02 and GHS07.
	Product F 13-05	Polycondensate of formaldehyde-naphthalenesulfonic acid as sodium salt	NDA	H318 and H412.	GHS05.
	Product F 13-06	Preparation of synthetic organic dye	NDA	Classification not possible	
	Product F 13-07	Preparation of synthetic organic dye	NDA	Classification not possible	
	Product F 13-08	WMEHWGRJJSAYSJ-UHFFFAOYSA-L	68155-63-5	H412	N/A

15 FINISH	Product FL 15-01	Sodium acrylate	9003-04-7	H315 and H319	GHS07
		Residual Monomer	NDA		
		Water	7732-18-5		
	Product FL 15-02	Lauryl ether sulfate sodium	68585-34-2	H227, H302, H311, H315, H318, H319, H330, H336, H361, H370, and H372	GHS05, GHS06, GHS07, and GHS08
		2-Butoxyethanol	111-76-2		
	Product FL 15-03	2-Butoxyethanol	111-76-2	H227, H290, H302, H311, H314, H318, H330, H336, H361, H370, H372, H411, and H412	GHS05, GHS06, GHS07, GHS08, and GHS09
		2-(11-Methyldodecoxy) ethanol; phosphoric acid	73038-25-2		
		Lauryl ether sulfate sodium	68585-34-2		
		Deceth-9; 2-(Decyloxy)ethanol	26183-52-8		
		Potassium;4-dodecan-3-ylbenzenesulfonate	27177-77-1		
		Potassium hydroxide	1310-58-3		
	Product D 12-02	NDA	NDA	Classification not possible	
	Product FL 15-04	Derivative of fatty amine	NDA	Classification not possible	
	Product FL 15-05	Styromal	25736-61-2	H315, H318, and H335.	GHS05 and GHS07
	Product P 06-01	Formic acid	64-18-6	H226, H302, H314, H318, and H331	GHS02, GHS05, GHS06, and GHS07

NDA = No Data Available
N/A = Not Applicable
* Stages with no use of chemical products:
01 WET SALTED HIDES, 02 DESALTING, 09 FINISH PRODUCT, 10 WET BLUE, 14 DRYING, and 16 FINISHED PRODUCT.
** For confidentiality, the trade names of the products were omitted.
*** Translation of R-phrases to H-statements according to USC (2018).

Table 6. Toxic description of the most harmful components, according to the Signal Word in GHS 'Danger', which indicate the more severe hazards depending at the dose.

CLASS		CATEGORY	HAZARD STATEMENT	
Physical Hazards	Self-heating chemicals	1	H251	Self-heating; may catch fire
	Oxidizing liquids	1	H271	May cause fire or explosion; strong oxidizer
Health Hazards	Acute toxicity -oral	3	H301	Toxic if swallowed
	Acute toxicity - dermal	1 & 2	H310	Fatal in contact with skin
		3	H311	Toxic in contact with skin
	Skin corrosion	1A, 1B, 1C	H314	Causes severe skin burns and eye damage
	Serious eye damage	1	H318	Causes serious eye damage
	Acute toxicity - inhalation	1 & 2	H330	Fatal if inhaled
		3	H331	Toxic if inhaled
	Reproductive toxicity	1A & 1B	H360	May damage fertility or the unborn child
	Specific target organ toxicity single exposure	1	H370	Causes damage to organs
	Specific target organ toxicity repeated or prolonged exposure	1	H372	Causes damage to organs, through prolonged or repeated exposure
Environmental Hazards	Acute toxicity - acute	1	H400	Very toxic to aquatic life
	Aquatic toxicity - chronic	1	H410	Very toxic to aquatic life with long lasting effects

Based on these results, a reduction of chemical product use is strongly recommended. In 33.33% of the products used in the 'Leather type A' tanning process, the use of 35 hazardous chemical compounds was identified and classified into categories 1 and 2, which have the highest potential for harm, according to the GHS. These compounds can cause serious damage to the skin, eye irritation, and acute toxicity by inhalation. In addition, they can be mutagenic or carcinogenic, while generating additional dangers for aquatic environments. These are used mainly in the stages of unhairing, fleshing, splitting, pickling, basifying, and finishing.

4. DISCUSSION

In Mexico, there have been in recent years a rise in improving environmental practices in the tanning industry through cleaner production approaches (Lezama and Graizbord, 2010). However, efforts need to be added through changes in legislation and public policies driven jointly by the Mexican State along with the scientific and business sectors, as well as the consumers themselves (Carrillo Fuentes, 2019). The case study described within this paper on a tanning industry in Mexico focused specifically on two approaches: A climate change impact analysis, through LCA and SimaPro® tools, and a chemical risk assessment, through the GHS framework.

In relation to the climate change impact analysis, the study found that the environmental impacts related to climate change, detected in the LCA of the production of 129.17 tons of 'Leather type A,' in 12 months, represents an estimated 54,275.19 kg CO_2eq. According to data from the United Nations Environment Program (UNEP), this amount is equivalent to fly an average of 246,705 km in economy class; or the use of 19 average sedan cars, with an average of 15,000 km traveled in a year (UNEP, 2008). Consequently, to mitigate this potential release through the absorption of CO_2 during the same period of time involves the corresponding of growing two mature pine trees, *Pinus Pinea*, or 74 mature olive trees, *Olea Euroaea*, which take about 35 years to reach maturity (Figueroa Clemente et al., 2007).

Furthermore, to deepen the environmental impacts identified in this study, a similar case was analyzed as a point of comparison. The research conducted in Bangladesh by Chowdhury et al. (2018) mentions that an average of 0.75 kg of CO_2eq per m^2 of full-chrome tanned leather was generated. For the case of Leon, the declared unit 129.17 tons of leather is equivalent to 129,167.37 m^2, which translates into 0.42 kg of CO_2eq generated for each m^2 produced. Thus, emissions in Mexico case study are 44% lower than those in Bangladesh. Although many factors are surly to be involved, it can be assumed that one of the reasons that could contribute to this discrepancy is because the companies in Mexico are part of the LWG, which requires them to comply with protocols focused on the sustainable production of leather and to be audited by external laboratories every year.

For the second approach, in relation to the review, through the GHS framework, of the health hazards generated by the chemical components, it can be confirmed that 35 of the 51 chemical components of the products, used mainly in the stages of unhairing, fleshing, splitting, pickling, basifying, and finishing, have the potential to cause serious damage to the skin, eye irritation, acute toxicity by inhalation, and be mutagenic or carcinogenic. Therefore, as stated by Sathish et al. (2016), emphasis must be placed on the replacement of these risky products under the context of the principles of green chemistry applied to leather production.

In addition, although the Intergovernmental Forum on Chemical Safety recommended that all countries had implemented the GHS by 2008 (Winder et al. 2005), at least Mexico is still behind. Just recently, the Mexican standard addressing GHS protocols was released in 2015, at came into force in 2018.This may cause irregularities when putting in practice such standard. For example, in this study, more than a third part of the Safety Data Sheets were incomplete and/or outdated. Thus, in agreement with Yen and Chen (2012), the proper use of standard Safety Data Sheets aligned with GHS can be enough to identify the potential hazards and redesign products towards more sustainable systems.

According to the Office of International Affairs of the Environmental Protection Agency of the United States of America (EPA), and the Technological Research Center located in León, Guanajuato (CIATEC by its acronym in Spanish), better management of economic resources can increase the competitiveness of companies of the tanning sector while conducting practices that decrease the environmental impacts (EPA and CIATEC, 2006). For example, carry out the soaking stage with biodegradable bactericides-fungicides, biodegradable surfactants, and/or use enzymes to accelerate the process; perform salt-free pickling, using products based on polysulfonic acid; or tanning the hides through a high depletion process, using dicarboxylic acids.

The tanning industry in Mexico has a high growth potential despite the gradual technological development of the tanneries and the environmental impacts generated by them. Several municipalities in the state of Guanajuato, such as Leon, play a very important role in the country's footwear production, as well as in leather tanning and finishing. Although environmental assessments in Guanajuato are promoted within the industry, this study highlights some limitations. For example, due to the confidentiality agreement and the trade secrets, the chemical products were excluded from de LCA, instead a detailed review was conducted to analyze the potential hazards associated with the chemical components. The LCA utilized the Ecoinvent database, which is made up of data originating in a European context, nevertheless, IMPACT 2002+ and ReCiPe Midpoint H methodologies were applied to minimize, as much as possible, the differences between continents.

5. CONCLUSION

The results of this study reveal the growing need to encourage the use of cleaner production systems, the use of LCA as a standard evaluation tool to achieve environmental goals, and the implementation of a program focused on updating supplier safety sheets in accordance with current regulations. Although this study reflects a particular case and cannot be generalized, the data can even so be used as a baseline for other studies that aim to evaluate the environmental impacts of products and processes derived from leather, or other byproducts derived from beef production. This study will contribute to the stock of knowledge regarding the environmental impacts of the tanning industry, particularly in Mexico. Information presented here can be useful for industry professionals, academics or scientists interested in exploring the subject further.

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