Studying type wet blue tannery process for estimating environmental performance using the Life Cycle Analysis methodology: A Case Study in Mexico

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Abstract- In this article the results obtained during a study using the Life Cycle Analysis methodology for the tanning process environmental performance, are reported. This study considered as a total environmental system, the chromium tanning process, and the beamhouse for hide/skin preprocessing. The study uses a functional unit of 1 kg of tanned cowhide produced by the wet blue process. The general procedure incorporated direct indicators including the weight of raw materials, volumetric water and electrical consumption, type of waste generated (recycled, for treatment and/or for disposal), input transportation, and output transportation of tanned leather to local finished. The data was obtained by conducting interviews with local tanneries in Leon, Guanajuato, Mexico. Using these inventory data inputs and outputs of the system, including waste streams, potential impacts on different environmental categories were developed. The team used SimaPro Software and developed models of the ReCiPe Midpoint and Endpoint methods for evaluating environmental impact and damage, respectively. The results show that the beamhouse contributes 0.0352 kg N eq (93.04%) to marine eutrophication and a loss of 1.22 x 10^{11} species.yr (59.53%) on freshwater eutrophication while the chrome tanning stage contributes 1.47 kg Fe eq, and US$0.105 dollar (93.67% of the measured effect) on metal depletion as found from midpoint and endpoint evaluation, respectively. When damage was evaluated, the chrome tanning stage stands out in the depletion of resources contributing 80.43%. In conclusion, it is observed that both the beamhouse and chrome tanning stages present areas of opportunity for improved environmental management.

Index Terms- Tannery, furs, life cycle assessment (LCA), environmental performance measurement, wet blue process.

I. Introduction

The tanning industry in Mexico is one of the ten largest producers of leather in the world, manufacturing about 4% of the leather produced worldwide. The number of tanneries currently registered nationally is 1056, of this total, 540 tanneries, mainly in the city of Leon, are located in the state of Guanajuato. These Guanajuato based tanneries perform about 75% of tanning and leather finishing production in Mexico. The remaining 25% is divided among the cities of Guadalajara, Monterrey, and Mexico City. Of all registered tanneries in Guanajuato about 70% use the mineral (chromium salt) and remaining use the vegetable tanning process [1, 2].

Tanning is the process by which hides (or animal skins) from bovine, swine, sheep, and goats, become leather. In general, the major industrial operations involved the beamhouse used to prepare raw hides for chemical tanning processes, the actual chemical tanning itself, and finishing operations [2-5]. In the beamhouse stage, cleaning of the hide is performed. Here the as-received raw material, which could have been preserved with salt (sodium chloride), called a green salted hide, or one that is received fresh or dried, is first hydrated, then hair and endodermis (made up of proteins and fats) are removed. During the beamhouse operations, the interfibral space is increased and all components of the hide that cannot be converted to leather, such as sodium salts and protein material (hair, sebum/grease, hide trims) are removed. Once conditioned, the hide continues to the tanning step where it is chemically and physically stabilized to retard putrefaction and to make it resistant to changes in temperature and humidity and the effects of normal wear and tear. Currently there are two tanning processes which are commonly employed: i) vegetable tanning or the “wet white” process, where plant products are used and which generates a white/beige leather and ii) chrome tanning (also called "wet blue" process) which uses inorganic salts, specifically salts of chromium, to impart a particular steel-gray colored tanned leather with a bluish tint, giving the wet blue process its name [6,7]. This second technique is most commonly used in the modern tannery, despite having a, potentially, greater environmental impact due to chromium has particular dangers. The chromium ions that are generated in the wet blue process are much more difficult to treat than the waste products of vegetable tanning. Once the leather from either the wet blue or wet white processes has been washed and dried, it passes to the finishing stage. Here it is subjected to a series of treatments to refine certain physicochemical properties needed in the finished leather products. These treatments are intended to provide upgrades and special properties to either side of tanned hide: the so-called flower (grain) side or the opposite, flesh side. Finishing also gives the leather protection against mechanical damage, moisture, dirt, and resistance to effects of further manufacturing of leather articles. Finishing can also be performed to develop special fashion effects. Additionally, leather finishing is done to remove, or increase the intensity of, unequal dying; to cover hide defects in the flower, or to give certain tactile qualities to the tanned product. Of these three stages, the first two, the beamhouse and chrome tanning, the methodologies are regularly standardized within the tanning industry, while the finishing stage poses the most variation as it is a function of final application of the finished leather product.

In the literature, it is well documented that during each stage a considerable amount of waste, both solid and aqueous, is generated. The major amount of waste and contaminated effluent is created during the beamhouse stage, which includes the activities soaking, liming, fleshing, and splitting, with the main purpose of cleaning the hide, to facilitate the tanning step. Specifically, during hide liming, which is performed to remove hair before tanning, 70% to the organic load in the effluent stream is produced, including all residual sulfides, 45% of the chromium free solid wastes (associated with sebum/grease, flesh, hair, and soluble proteins), 35% of total nitrogen, and approximately 50% of aqueous effluent volume [2-5, 8, 9]. The amount of waste generated in the tanning industry depends on the hide thickness and hide care as well as hair type, which in turn depends on the origin of the hides. Thus during LCA, it is important to consider the type of hide being tanned, since the process may vary (mainly in amount of water consumption and the total pollutant load in the effluent). The most common is bovine hide, followed by sheep and goat hides, while most literature reports results only from manufacturers that process bovine hides [2, 3, 5].

The amount and composition of the waste generated depends on different factors including the tanning technique used; the number, type, and sequence of unit operations (as some are optional), chemical dosage and control of the process variations. Additionally, it can be influenced not only by technical factors and operating formulations (infrastructure, environmental experience of the technical staff, etc.), but also by regional and national economic and social factors prevailing in this industrial sector. And finally, perhaps, by a perceived lack of support for providing external resources that facilitate any desired environmental improvement among tanners [2].

The current environmental impact in Mexico has been magnified by long periods in which waste management has been inadequate at a vast majority of tanneries and similar companies. Their solid wastes are accumulated in their plants and then are sent, in mass, to landfills or mixed municipal dumps. Most managers have to pay for third parties certificates to facilitate final disposal, however, since these wastes are highly bio-degradable, disposal in landfills generate strong, and unpleasant odors, and they can release the toxic chemicals they contain, into the soil or groundwater [3, 10]. Some of these solid wastes (flesh, hair, sebum/grease, hide trims and sludges) may be treated to recover valuable components including proteins (either collagen or keratin), chromium, or oils and fats for energy production [2, 3, 5, 11]. In the following section, we highlight some of the, admittedly, limited information about recovery and ways to increase valuation of the waste materials, their treatment and, finally, proper ways to dispose of these solid wastes.

Currently, all wastes from the tannery industry are considered hazardous which forces generators to either collect, confine, and store them on their premises, or transport them for recycling, reuse, or treatment using governmentally authorized companies [2, 11]. Thus governments have put significant pressure on leather producers to develop proper environmental management systems (EMS). These EMS would then direct the proper use and disposal of raw materials and wastes generated at each stage of the overall process. One of the tools commonly used in the EMS is life cycle analysis (LCA), a methodological tool for quantitative analysis to determine the environmental impact of a product, process, or activity [12-15]. It considers all the production phases of the product or process, from extraction of raw materials necessary for manufacture, to the final disposal as waste. However, in some cases, its scope can be reduced to a partial LCA, focused only on specific production phases, or even a single production step. The purpose of LCA in environmental management is the identification and quantification of the inputs and outputs of the process: energy and raw materials used, waste generation (treatment, recycling and disposal) and air, water or soil emissions to the environment [13,14,16]. LCA thus can actively assist in identifying opportunities to improve the environmental performance of products/processes at various stages, providing information for decision making enables the selection of relevant indicators of environmental performance and product marketing [13-15].

According to the methodology described by ISO 14040 and ISO 14044, the LCA process, as an informative tool, can be divided into four main phases: goal and scope of the study, inventory analysis, impact analysis and interpretation of findings. These four phases are not purely sequential, LCA is an iterative informative tool, that allows the user to study operations at increased levels of detail during each successive iteration. The first phase, defining goal and scope, can pinpoint what is to be included in the study (system boundaries, functional unit and the environmental impact categories), in terms of the product system under analysis. The second, inventory analysis, includes data collection and calculation procedures to quantify the inputs (energy, raw- and processing materials) and outputs (products, byproducts/wastes, air and water emissions, and soil discharges). The third stage, impact assessment, is where the organization takes the results of the inventory analysis and classifies them in environmental impact categories. For example, emissions from burning a fuel may include effects on the global warming impact category, as quantified in kilograms of CO_2

equivalent (kg CO_2 eq). The fourth phase, interpretation, is where the results of the impact assessment are turned into recommendations and understandable arguments that facilitate decision making to achieve acceptable EMS [13, 17].

Several studies reported in the literature [18-22] show the advantages of using LCA methodologies across different industrial sectors, either to compare processes and/or products, to develop opportunities for process improvement, through cost control, or by learning about relevant environmental indicators and potential damage. Specifically, in the tanning industry, Brugnoli and Kral (2012) conducted a review of methodologies and recommendations in order to understand the carbon footprint to determine the climate change environmental impact. They suggested a functional unit of 1 m^2 of finished leather (or 1 kg in the case of leather soles) and the system boundaries in the study to start with the animal being killed in a slaughterhouse and including all activities to prepare and tan the hide finishing the study set as the finished leather exited the tannery. Stages involved in the study included slaughterhouses, producers of chemicals, energy and water suppliers, tanneries, wastewater treatment plants and the waste treatment process [17]. The study by Laurenti et al. (2016) compared the chrome tanning and vegetable tanning processes for 12 tanneries in seven countries (including Mexico). These authors employed as their functional unit 1 m^2 of leather (from 1.2 to 1.4 mm thick) and the evaluation compared both processes for total water consumption, energy consumption, and overall carbon footprint, across the various tanneries and processes that were included [7]. A similar study, performed by Zia-Uddin et al. in 2015, compared the environmental burdens in the tanning stage, either with chromium or aluminum use, they also using as their functional unit 1 m^2 of leather [16]. They evaluated several environmental categories and resulting damage in their LCA.

Based on the advantages of LCA, this work presents a case study of the wet blue (chromium) tanning process used on bovine hides processed in Guanajuato, Mexico. The study includes an evaluation of several environmental indicators to identify opportunities to improve the environmental performance of this process in local tanneries.

II. METHODOLOGY

A. Objective and scope of the study

It's the foremost preliminary step for proceeding with any research work writing. While doing this go through a complete thought process of your Journal subject and research for it's viability by following means: The goal was to obtain data on the wet blue tanning process from the tanning industry in Leon, Guanajuato, México. These data would then be used to estimate their environmental performance by preforming a LCA study to assist with the identification of opportunities for process improvement. The functional unit chosen was 1 kg of tanned bovine hide and included the beamhouse stage, the chrome tanning stage, and also considered the transport of raw materials and processing supplies and finally ended with the tanned hide transported to finishers. While the finishing step is important for a better understanding of the totality of a leather tanning, and might be included in the LCA study system, this stage was excluded from our study for the following reasons: i) more than 40% of the tanneries surveyed only carried their process through the tanning step before the leather was sold to others for finishing and, ii) companies that performed all of the process stages exhibited great variability in their methods for finishing the tanned hides, including significant differences in inputs and equipment used, making it difficult to homogenization the data obtained. Figure 1 is a diagram illustrating the system boundaries used in this study. Details of the inputs and outputs for each stage are listed. Notice that the transport of raw materials and supplies are included as well as distribution of the tanned wet blue hides.

B. Drawing up an inventory of inputs and outputs

Information for this study was obtained during 2016 by conducting interviews at 39 tanneries that use the wet blue (chromium) process and were located in León, Guanajuato, Mexico. Questionnaires were sent to all local tanneries to solicit general information about their process activities. Specific questions related to their raw materials, including place of origin of hides and other inputs, number of hides processed, average water and energy consumption, amount and type of waste generated during each stage were included. Additional questions related to their recycling, treating and disposal practices, probable environmental emissions, and, finally, details concerning their sales of finished leather (quantities and shipping methods) were also included. Using this information, the inventory data, inputs and outputs of the process, within the limited system illustrated in figure 1, was prepared. All the variables were adjusted to annual production values and then normalized to the 1 kg functional unit. Any missing information was supplied using well accepted values obtained in the literature [3, 5, 9, 10, 22-27].

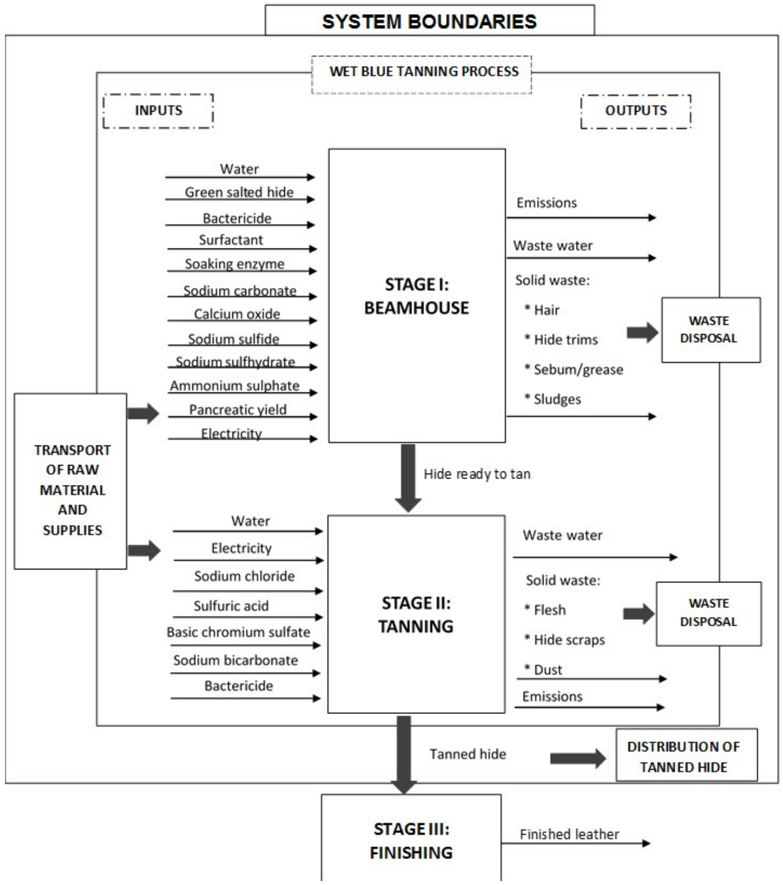

Figure 1. System boundaries for wet blue tanning process

C. Environmental performance evaluation

The environmental performance modeling for the evaluation of wet blue tannery process, including the beamhouse operations, (chrome) tanning, transport of raw material and other inputs, and the distribution of finished wet blue tanned leather (as the system boundaries), was carried out using the Simapro 8 PhD software. The team employed the ReCiPe method in its two modalities: midpoint (H) for the evaluation of environmental impacts and endpoint (H) for the evaluation of damage. The main objective of ReCiPe is to transform the long list of Life Cycle Inventory (LCI) results into a limited number of scores in different indicators (the scores of the indicators express the relative severity on an environmental impact category), to provide information on the environmental performance of each activity in the study. This method was selected because the 18 impact categories classified in it represent a broad set of environmental content. In addition, this evaluation method satisfies the mandatory elements of the international LCA standards, the evaluated impact categories are accepted internationally and, finally, the characterization models used are scientifically and technically valid. This method is considered as a follow-up to the CML 2002 methods (with a focus on the midpoints) and Eco-indicator 99 (EI99) (with focus on the endpoint) and the scores of the indicators in each category are determined in a way similar to the method EI99, in addition to which, the use this software can to combine the modeling of both midpoint and endpoint approaches. These 18 categories were addressed: climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidants formation, particulate matter formation, terrestrial eco-toxicity, freshwater eco-toxicity, marine eco-toxicity, ionizing radiation, agricultural land occupation, urban land occupation, natural soil transformation, water depletion, metal depletion, and fossil depletion at the midpoint. Three categories were explored at the endpoint (or damage) level: human health, diversity of ecosystems and availability of resources [12]. It should be noted that, as with other methodologies, some impact categories are of global interest, including climate change, depletion of the ozone layer, and depletion of resources.

III. RESULTS

One noteworthy issue was that the team encountered a high level of unwillingness to participate in this data gathering effort among the local tanneries who were contacted. As stated above, only 39 tanneries currently operating in León, and using the wet blue tanning process, agreed to answer questionnaires, this represented a response rate of approximately 10.32%. Later, using the information collected in the questionnaires, the input and output inventory data for each process step was prepared. Figure 2a illustrates the types of hides processed at the interviewed tanneries; the most common was bovine (65.6%) followed by swine (16.8%).

Total environmental emissions are important indicators when assessing environmental impacts, this is why it is important to have information on the place of origin of the raw hide inputs; figure 2b shows that only 54.5% the original hides to be processed are of Mexican origin and the rest were imported (45.5%), mainly from the USA (34.9 %). This issue is related to the current market boom and the growing market for finished leather particularly for use by the automotive industry in Central Mexico. To meet this demand, tanneries have to import the hide, since domestic sources are insufficient to meet the current production demand. Using this information on raw material source it is possible to obtain indicators about the transport methods and travel distances involved, leading to a more complete understanding of the total environmental costs of the process.

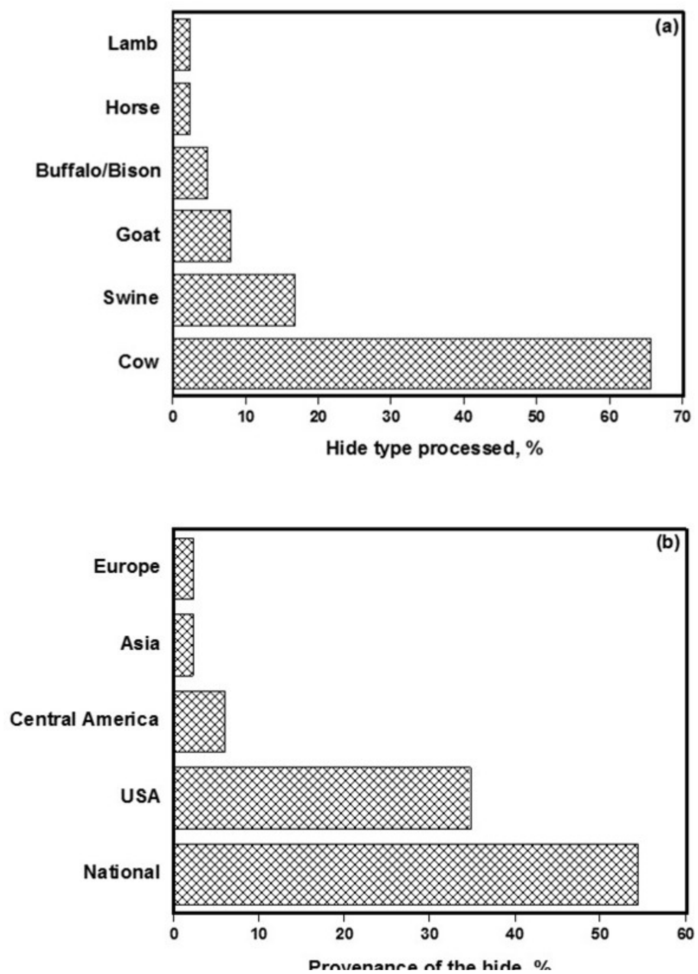

Figure 2. Type of processed hide (a) and their place of origen (b).

The information obtained showed that the majority of sales of finished leather was to the shoe industry (68.6%), followed by leather goods (18.6 %), furniture (7.1%) and finally automotive (5.7%). It is important to note that the finished leather specifications are targeted to the product market and that the team noted significant differences in physicochemical properties and cost as a function of the finished product market.

Tanning processes generate large amounts of solid and aqueous waste. The information collected showed an amount of waste generated annually in the full tanning process (beamhouse, tanning, and finishing stages) of 133,324 ton/year of solid waste. This includes hair, sebum/grease, hide trims, scrapings, leather trims, flesh, sludge, and dust/dirt. The major solid residues were flesh (31,657.5 ton/year) and hide trims (23,036.8 ton/year) (see figure 3). The most commonly recycled sub-product was animal protein, mainly collagen, which was commonly reused to produce food for dogs and cats; the sebum/grease obtained are using in the production of soaps and shampoo by some companies [28] (Bajza and Vrcek, 2001), and the hair waste (approximately 10,700 ton/year), is also a rich source of the protein keratin, which can be utilized by various industrial sectors including companies making cosmetics, foods, composites, or as a fertilizer or energy source, among others potentials[29]. There is little information reported about recovery of this waste product, however, suggesting that it is an opportunity for further exploitation. Here then, by gathering data to conduct a LCA for this industry, the team identified a potential new revenue stream for the industry, exposing one of the most important aspects of the LCA procedure, in general. The sludge that is generated contains an average of 35.0 % organic material and 65.0 % mineral matter [30,31] depending on operating practice. Its recovery, if enhanced, can be used as a resource for energy production, through bio-digesters, or composted to produce a low quality material intended for use on green areas. Similar work was reported by Guo-Tao et al. (2013), who published a study describing the conversion of tannery sewage sludge, in composite, by a high temperature aerobic fermentation process for possible application in agriculture and forestry [32].

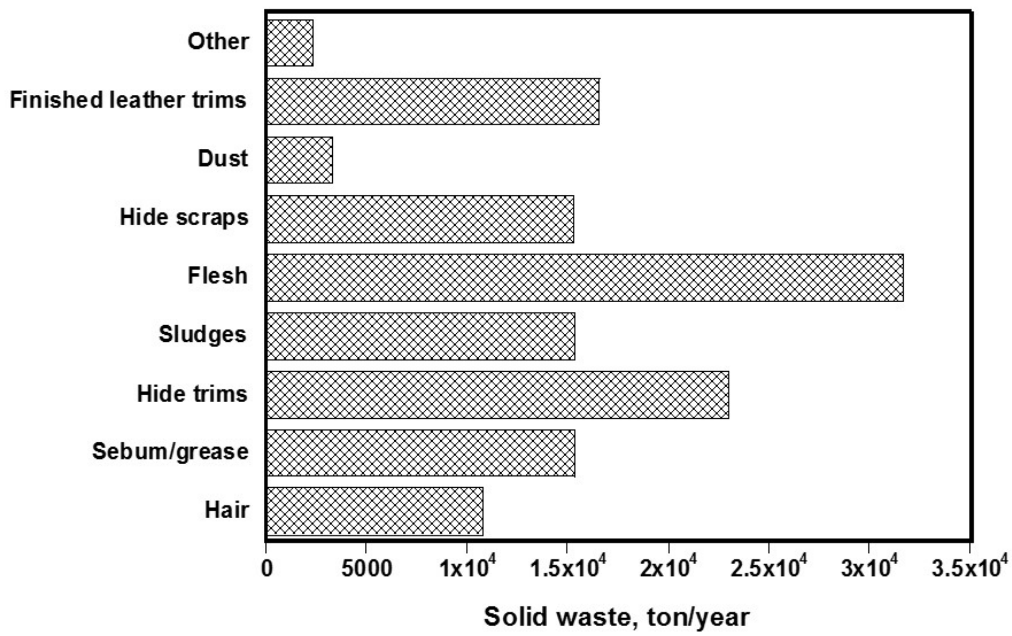

Figure 3. Solid waste generated annually in the process of tannery.

Of these solids wastes: hair, sebum/grease, hide trims and sludge are generally generated in beamhouse stage; the flesh, hide scraps and dust/dirt in the tanning stage; and finished leather trims and others solids during the finishing stage. The total amount of aqueous residue generated, drawing on information from the team collected data, was 3,653,444.2 m^3/year. The beamhouse stage contributes 85.6% (3,127,348.2 m^3/year) and the (chrome) tanning stage 14.4 % (526,956 m^3/year). Most small tanneries produce only slurries during finishing and they typically sent their tanned leathers to other companies having the machinery to give the required finish to the tanned leather, as stated earlier these external finishing operations were outside the scope of this study. Also important to note was that the aqueous waste values reported here are specific to tanning bovine hide [3, 23]; and the effluent parameters for each stage of the tanning process used information supplemented from the literature [5, 24, 25, 30].

Table 1 presents input and output inventory for the wet blue tanning process within the defined system (beamhouse stage, chrome tanning stage, transport of raw materials and supplies, and final leather distribution), using the 1 kg wet blue tanned cowhide functional unit for tanneries in Leon, Guanajuato. All relevant indicators were considered for the evaluation of environmental impacts using the SimaPro software and the ReCiPe method to generate both Midpoint and Endpoint outputs.

Table 1. Inventory of inputs and outputs for wet blue tanning process

Beamhouse					
Inputs	*Quantity*	*Unit*	*Outputs*	*Quantity*	*Unit*
Salted hide	1	kg	Hide ready to tan	0.6128	kg
Water	19.2600	L	Waste water	18.6822	L
Dithiocarbamate-compound (bactericide)	0.0020	kg	Suspended solids	0.3000	kg
Propylene glycol (surfactant)	0.0020	kg	Biological oxygen demand	0.1500	kg
Novozyme celluclast (Enzyme)	0.0100	kg	Total nitrogen	0.0350	kg
Sodium carbonate	0.0050	kg	Sebum/grease	0.0200	kg
Calcium oxide (lime)	0.0400	kg	Chemical oxygen demand	0.4000	kg
Sodium sulfate, anhydrite	0.0200	kg	Sulfide	0.0225	kg
Sodium sulfide	0.0050	kg	Chlorides sulfates	0.3750	kg
Ammonium sulfate	0.0196	kg	Sulfates	0.0500	kg
Sodium chloride	1.0000	kg	Total dissolved solids	0.7500	kg
Electricity	0.0430	kWh	Solid waste	0.3872	kg
Tanning					
Inputs	*Quantity*	*Unit*	*Outputs*	*Quantity*	*Unit*
Hide ready to tan	0.6128	kg	Waste water	3.2400	L
Water	3.2400	L	Suspended solids	0.0250	kg
Sulfuric acid	0.0171	kg	Biological oxygen demand	0.0175	kg
Sodium chloride	0.1142	kg	Total nitrogen	0.0025	kg
Chromium oxide	0.0685	kg	Sebum/grease	0.0050	kg
Sodium bicarbonate	0.0171	kg	Chromium III	0.0125	kg
Dithiocarbamate-compound (bactericide)	0.0011	kg	Chemical oxygen demand	0.0500	kg
Stage	0.0008	pza	Chlorides	0.1500	kg
Electricity	0.0172	kWh	Sulfates	0.1250	kg
			Total dissolved solids	0.3000	kg
			Solid waste	0.3020	kg
			Tanned hide	0.3108	kg
Transport					
Inputs	*Quantity*	*Unit*	*Outputs*	*Quantity*	*Unit*
Transport of supplies (Beamhouse)	0.0135	tkm	Distributión tanned hide	0.0369	tkm
Transport of raw material	0.0949	tkm	Waste disposal (Beamhouse)	0.0046	tkm
Transport of supplies (Tanning)	0.0444	tkm	Waste disposal (Tanning)	0.0052	tkm

The results of the modeling by the ReCiPe Midpoint method, for estimation of environmental impacts in the 18 categories considered, are presented in table 2 and separated by the various stages. As seen here the beamhouse stage affects different categories: marine eutrophication at 0.035 kg N eq representing 93.04 % of the total amount; water consumption 0.025 m^3 (or 69.75% of the total consumption), climate change 0.403 kg CO_2 eq (40.72% of total generated) and human toxicity 0.321 kg 1,4-DB eq (57.47% of total generated). The chrome tanning step has a major impact on depletion of metals 1.47 kg Fe eq (93.67% of total level), occupation of agricultural land 0.122 m^2a (78.29% of total occupied), freshwater ecotoxicity 0.023kg 1,4-DB eq (74.36%) and 0.487 kg CO_2 eq driving climate change (49.27% of the total).

Table 2. Average environmental impacts obtained for the 18 categories evaluated by ReCiPe Midpoint analysis.

Category of impact	Unit	Total	Beamhouse	Tanning	Transport of raw material and supplies	Distribution of tanned hide
Climate change	kg CO_2 eq	$9.89x10^{-1}$	$4.03x10^{-1}$	$4.87x10^{-1}$	$7.97x10^{-2}$	$1.92x10^{-2}$
Ozone depletion	kg CFC^{-11} eq	$7.30x10^{-8}$	$2.56x10^{-8}$	$3.02x10^{-8}$	$1.38x10^{-8}$	$3.34x10^{-9}$
Terrestrial acidification	kg SO_2 eq	$5.86x10^{-3}$	$2.52x10^{-3}$	$2.86x10^{-3}$	$3.96x10^{-4}$	$9.55x10^{-5}$
Freshwater eutrophication	kg P eq	$4.59x10^{-4}$	$2.73x10^{-4}$	$1.75x10^{-4}$	$8.83x10^{-6}$	$2.13x10^{-6}$
Marine eutrophication	kg N eq	$3.78x10^{-2}$	$3.52x10^{-2}$	$2.61x10^{-3}$	$2.09x10^{-5}$	$5.05x10^{-6}$
Human toxicity	kg 1,4-DB eq	$5.58x10^{-1}$	$3.21x10^{-1}$	$2.11x10^{-1}$	$2.14x10^{-2}$	$5.17x10^{-3}$
Photochemical oxidant formation	kg NMVOC	$3.09x10^{-3}$	$1.11x10^{-3}$	$1.30x10^{-3}$	$5.53x10^{-4}$	$1.34x10^{-4}$
Particulate matter formation	kg PM_{10} eq	$2.76x10^{-3}$	$1.22x10^{-3}$	$1.30x10^{-3}$	$1.91x10^{-4}$	$4.61x10^{-5}$
Terrestrial ecotoxicity	kg 1,4-DB eq	$8.71x10^{-5}$	$3.10x10^{-5}$	$2.77x10^{-5}$	$2.28x10^{-5}$	$5.51x10^{-6}$
Freshwater ecotoxicity	kg 1,4-DB eq	$3.03x10^{-2}$	$7.28x10^{-3}$	$2.25x10^{-2}$	$3.98x10^{-4}$	$9.61x10^{-5}$
Marine ecotoxicity	kg 1,4-DB eq	$2.70x10^{-2}$	$7.13x10^{-3}$	$1.92x10^{-2}$	$5.01x10^{-4}$	$1.21x10^{-4}$
Ionising radiation	kBq U^{235} eq	$5.69x10^{-2}$	$2.85x10^{-2}$	$2.14x10^{-2}$	$5.64x10^{-3}$	$1.36x10^{-3}$
Agricultural land occupation	m^2a	$1.56x10^{-1}$	$3.25x10^{-2}$	$1.22x10^{-1}$	$1.09x10^{-3}$	$2.64x10^{-4}$
Urban land occupation	m^2a	$1.62x10^{-2}$	$4.42x10^{-3}$	$8.41x10^{-3}$	$2.69x10^{-3}$	$6.49x10^{-4}$
Natural land transformation	m^2	$1.75x10^{-4}$	$5.98x10^{-5}$	$7.87x10^{-5}$	$2.96x10^{-5}$	$7.16x10^{-6}$
Water depletion	m^3	$3.51x10^{-2}$	$2.45x10^{-2}$	$1.03x10^{-2}$	$2.31x10^{-4}$	$5.58x10^{-5}$
Metal depletion	kg Fe eq	1.57	$9.43x10^{-2}$	1.47	$4.13x10^{-3}$	$9.97x10^{-4}$
Fossil depletion	kg oil eq	$2.45x10^{-1}$	$1.03x10^{-1}$	$1.07x10^{-1}$	$2.80x10^{-2}$	$6.77x10^{-3}$

CO_2 carbon dioxide; *eq*, equivalent; *CFC*, chlorofluorocarbon; SO_2, sulfur dioxide; *P*, phosphorus; N, nitrogen; *DB*, dichlorobenzene; NMVOC, non-methane volatile organic compounds; PM_{10}, particulate matter ≤10μm diameter; U^{235}, uranio-235; *Fe*, iron;

The results of the ReCiPe Endpoint method modeling which assessed potential damage resulting from these two tannery stages are presented in table 3. Here the units of measurement were disability-adjusted life year (*DALY*), species.yr or cost. In environmental impact studies, *DALY* is a unit of measurement, extracted from the public health records, which relates the "years of potential life lost" due to a disability resulting from continuous exposure to a particular chemical substance in an industrial context versus humans not thus exposed; *species.yr*, measures the rate of known species per year that are lost due to exposure to environmental hazards from the activities under study, and cost (reported in US dollars) measures future, additional, costs for resource extraction to maintain the activity at its current level. As can be seen in table 3, the beamhouse stage impacts eutrophication of water suggesting a loss of $1.22x10^{-11}$ species.yr (or 59.53% of the total impact for this indicator), the tanning stage impacts the depletion of metals, a cost factor, by US$0.105 dollar (93.67% of total impact in this indicator), material transport and, finally, tanned hide distribution (both in the category terrestrial ecotoxicity) at $3.44x10^{-12}$ species.yr (26.21% of total) and $8.31x10^{-13}$ species.yr (6.33% of total) respectively.

Table 3. Average environmental impacts obtained for the 18 categories evaluated by ReCiPe Endpoint analysis.

Category of impact	Unit	Total	Beamhouse	Tanning	Transport of raw material and supplies	Distribution of tanned hide
Climate change human health	DALY	$1.38x10^{-6}$	$5.64x10^{-7}$	$6.82x10^{-7}$	$1.12x10^{-7}$	$2.69x10^{-8}$
Ozone depletion	DALY	$1.93x10^{-10}$	$6.94x10^{-11}$	$7.87x10^{-11}$	$3.65x10^{-11}$	$8.82x10^{-12}$
Human toxicity	DALY	$3.90x10^{-7}$	$2.24x10^{-7}$	$1.47x10^{-7}$	$1.50x10^{-8}$	$3.62x10^{-9}$
Photochemical oxidant formation	DALY	$1.21x10^{-10}$	$4.32x10^{-11}$	$5.05x10^{-11}$	$2.16x10^{-11}$	$5.21x10^{-12}$
Particulate matter formation	DALY	$7.17x10^{-7}$	$3.16x10^{-7}$	$3.39x10^{-7}$	$4.96x10^{-8}$	$1.20x10^{-8}$
Ionising radiation	DALY	$9.32x10^{-10}$	$4.67x10^{-10}$	$3.51x10^{-10}$	$9.25x10^{-11}$	$2.23x10^{-11}$
Climate change ecosystems	species.yr	$7.84x10^{-9}$	$3.19x10^{-9}$	$3.86x10^{-9}$	$6.32x10^{-10}$	$1.53x10^{-10}$
Terrestrial acidification	species.yr	$3.40x10^{-11}$	$1.46x10^{-11}$	$1.66x10^{-11}$	$2.30x10^{-12}$	$5.54x10^{-13}$
Freshwater eutrophication	species.yr	$2.04x10^{-11}$	$1.22x10^{-11}$	$7.78x10^{-12}$	$3.93x10^{-13}$	$9.50x10^{-14}$
Terrestrial ecotoxicity	species.yr	$1.31x10^{-11}$	$4.67x10^{-12}$	$4.18x10^{-12}$	$3.44x10^{-12}$	$8.31x10^{-13}$
Freshwater ecotoxicity	species.yr	$2.61x10^{-11}$	$6.25x10^{-12}$	$1.94x10^{-11}$	$3.42x10^{-13}$	$8.25x10^{-14}$
Marine ecotoxicity	species.yr	$4.75x10^{-12}$	$1.26x10^{-12}$	$3.38x10^{-12}$	$8.82x10^{-14}$	$2.13x10^{-14}$
Agricultural land occupation	species.yr	$1.87x10^{-9}$	$3.91x10^{-10}$	$1.46x10^{-9}$	$1.33x10^{-11}$	$3.22x10^{-12}$
Urban land occupation	species.yr	$3.35x10^{-10}$	$9.15x10^{-11}$	$1.74x10^{-10}$	$5.57x10^{-11}$	$1.34x10^{-11}$
Natural land transformation	species.yr	$3.04x10^{-10}$	$1.06x10^{-10}$	$1.34x10^{-10}$	$5.13x10^{-11}$	$1.24x10^{-11}$
Metal depletion	$	$1.12x10^{-1}$	$6.75x10^{-3}$	$1.05x10^{-1}$	$2.95x10^{-4}$	$7.12x10^{-5}$
Fossil depletion	$	$4.05x10^{-2}$	$1.71x10^{-2}$	$1.77x10^{-2}$	$4.63x10^{-3}$	$1.12x10^{-3}$

Figure 4 graphically presents the contribution of each process stage on cumulative environmental indicators focusing on human health, ecosystems effect and resource depletion for the LCA study. As seen, the chrome tanning stage has the greatest impact on the three indicators: 46.89%, 54.42% and 80.43% respectively, while the beamhouse stage contributed 44.33%, 36.56% and 15.56%, respectively. Materials transport had lower impact indicated by values less than 10%, while final distribution of leather had the lowest impact at about 2% in each of the three indicators.

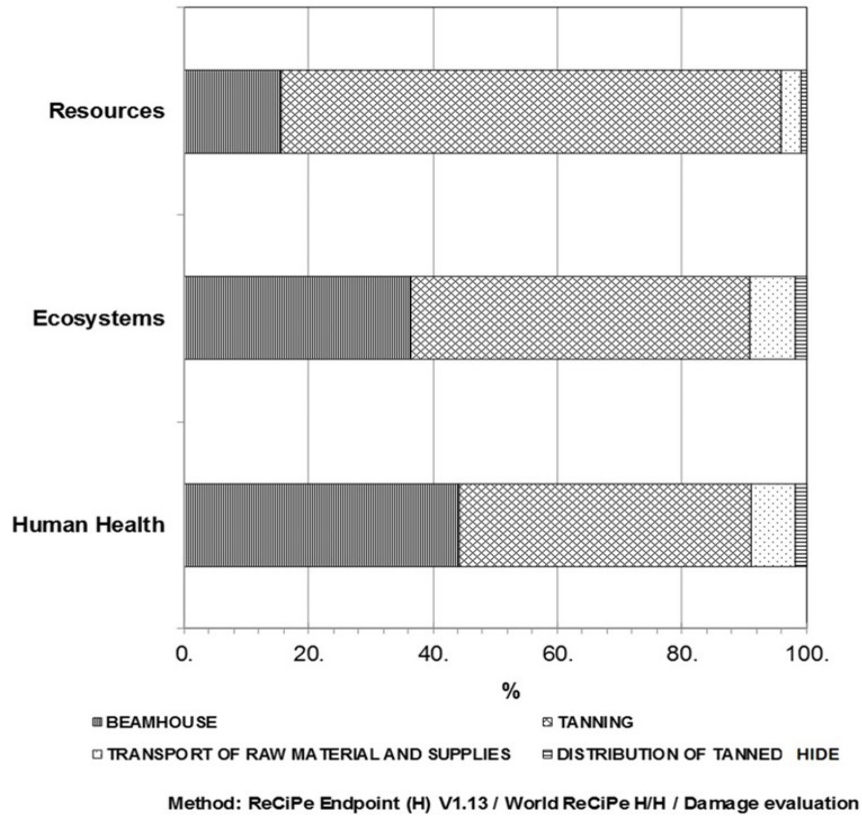

Figure 4. Damage assessment indicators categorized as effects on human health, ecosystems and resource depletion.

A. Significant issues

Significant issues of a product refer to the processes, materials or emissions that generate the greatest potential environmental impact during the life cycle within its defined system limits. Generally, the LCI results of both the beamhouse and chrome tanning stages had significant environmental impacts in several categories. For the beamhouse stage significant impact were in the categories: eutrophication of marine and fresh water, water depletion and human toxicity, caused by the materials used in the processes, particularly the large volume of water. The main effects of chromium tanning stage were with metals depletion through the use of chromium salts, depletion of agricultural land, fresh water eco-toxicity, and urban land occupation. Transportation makes no significant contribution in any of the impact categories when compared to the other process stages. Note that the transportation of solid wastes, mostly an organic waste, was dumped locally into Leon's landfill sites. Finally, no significant contributions were observed for the final leather distribution step either. Typically, distribution of tanned leather was done on (returnable) wooden pallets or in wooden containers, that were carried in freight vans, an average distance of less than 50 km.

B. Study limitations

Limitations to this LCA study are primarily related to the lack of information. Due to the reluctance of most tanners to respond, some of the assumptions that have been made, and the use of international databases to represent the processes studied in the life cycle of wet blue tanning within Leon, Guanajuato could have somewhat skewed the results.

This LCA study focused only on the beamhouse, and chrome tanning stages within a typical local tannery, transport of raw materials and supplies to the tannery, and transportation employed to bring the tanned leather to finishers. It does not evaluate hide finishing activities since little of the relevant data about different types of finishing processes for tanned leather could be obtained from the tanneries studied. The team found that because of the widely varying uses for the wet blue tanned leather, that most of the interviewed tanneries (about 60%) do not perform their own finishing activities.

Materials and manufacturing inputs to provide packaging or containers for raw materials and supplies or for the distribution of the tanned leather to the end user were also not included due to the scope limitations of the study. The team also assumed that the suppliers (not including hides/skins) used by the two internal stages come from an average distance of 124 km and 50 km respectively during material transport analyses.

A general measure of electrical energy consumption was developed from an average energy consumption rating for each machine within each stage and then multiplied by the number of each machine type and average hours of operation they were used during each process stage.

It was assumed that wastewater is discharged directly into municipal sewers. More than 90% of the companies who responded reported do not have wastewater treatment systems within their plants.

The team treated all reported waste materials as bio-solids which were then carried to municipal dumps. All of the survey responders only reported organic waste from the leather processes while no inorganic residues were reported.

During the product distribution stage, it was assumed that all production leather was placed in/on wooden containers/pallets, capable of handling 1.3 ton of leather and transported in freight vans with capacities of 3.5 to 7.5 tons. The tanned leather was carried an average distance was 50 km.

IV. CONCLUSIONS AND RECOMMENDATIONS

Both, the beamhouse as well as the wet blue (chrome) tanning stages have areas of opportunity to provide environmental performance improvements. The LCA suggested that tanneries should study means to optimize their level of inputs and sources of raw materials, improve their recovery of waste by developing recycling activities, including reuse, recovery and reduction. Specific recommendations that were observed include:

- Studying and employing means to reduce the water used (particularly during the beamhouse stage). Tanneries are encouraged to develop techniques to allow water reuse in the process to directly decrease water stress in their area of operation. It is also advisable that they perform effluent treatment processes on site to better prepare their wastewater streams for discharge. These steps should reduce potential eutrophication impacts on fresh- or marine-water bodies caused by the discharge of the untreated reactive and organic pollutants they contain.
- Solid wastes that are generated, including flesh, sebum/grease, hide trims, hair and sludge, could be successfully recycled (valorization). By recycling potentially valuable materials into beneficial uses industrial sustainability in this and other industrial sectors of the Mexico economy will increase.
- Transportation of raw materials and inputs to the production site can be a significant ecotoxin for the earth, especially when considering the impact of imported materials and their extended travel distances. Efforts should be studied to reduce industrial dependence of materials sourced far away from León.
- Finally, as the distribution of wet blue tanned leathers is mostly local, this step was found to have little impact on the environmental categories that were evaluated, but may benefit from the use of reusable plastic or metal pallets or boxes during transport.

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