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# Measuring the environmental footprint of leather processing technologies

*Rafael Laurenti, Michael Redwood, Rita Puig, and Björn Frostell*

**Abstract**

The selection of materials and manufacturing processes determines most of the environmental impact that a product will have during its life cycle. In directing consumption towards products with the least impact on the environment, measuring and comparing material alternatives with site-specific data is a fundamental prerequisite. Within the apparel and footwear industry, some famous brands have recently been basing their advertising on the claim that vegetable-tanned leather is more environmentally friendly than chromium-tanned leather. However, there is a lack of scientific research assessing and comparing vegetable- and chromium-tanned leather in a wider context than the toxicity of chromium. To fill this gap, this study measured and compared the carbon, water and energy footprint of vegetable and chromium leather processing technology and intermediate processing stages in 12 selected tanneries in seven different countries world-wide. Each tannery proved to be very individual and therefore attempting to perform this type of analysis without simply producing meaningless generalities is a challenge for companies, researchers and regulators. The variability in results demonstrates that secondary data for the tanning phase should be utilised with caution in a decision-making context. The use of primary data would be advisable for life cycle studies (LCA) studies of leather goods. No significant differences were found in the footprint of vegetable and chromium leather processes, but these are only indicative findings and need confirmation in further studies. An important area needing investigation is then how a fair comparison can be made between renewable natural materials and nonrenewable materials used in both leather-processing technologies.

**Keywords:** chromium tanned, environmental footprint, industrial ecology, leather processing, tanning, vegetable-tanned

## 1. Introduction

In 2014, over 6.6 million tons of bovine hides and skins were produced in the world (FAO, 2015). As a co-product of the meat industry (Redwood, 2013), hides and skins are transformed into a high added value material, leather, by various mechanical and chemical processes. This final material is then used in many important consumer sectors, such as footwear, clothing, fashion accessories, furniture and the automotive industry.

Although leather production is perceived as a polluting industry, using harmful chemicals and concentrating jobs in poorer parts of the world, in the recent years leather making companies have achieved great environmental improvements. Several drivers such as advances in technology, legislation, standards, corporate social responsibility and consumer demands have created the right conditions to accelerate this transformation (Redwood, 2013). In recent advertising, vegetable-tanned leather has been marketed by some footwear and apparel companies as a more environmentally friendly product than chromium-tanned leather[1] (Achabou and Dekhili, 2013). These promotions involve environmental claims, particularly that the use of chromium is highly toxic to humans and the environment. Terms such as 'chrome-free', 'metal-free', 'no heavy metals', 'organic', 'biodegradable', 'bio-' and 'natural' have been frequently used without proper definition or any consideration of the wider context, such as related changes in energy and water usage (Redwood, 2013).

In this transition, companies interested in improving their decision making face the challenge of measuring and comparing the environmental performance of different types of leather and of their leather suppliers. A suitable tool for such work, life cycle assessment (LCA), has been extensively utilised to evaluate the potential environmental impacts of other products over their full life cycle, including resource extraction, production, use, transport and end-of-life stages (ISO, 2006). Peer-reviewed studies have been published on the potential environmental impacts of the leather industry in Spain (Milà et al., 1998; Milà et al., 2002), Chile (Rivela et al., 2004), India (Joseph and Nithya, 2009), Italy and Spain (Notarnicola et al., 2011) and Taiwan (Chen et al., 2014), but these studies have focused on chromium-tanned leather. Therefore limited or inconsistent information about differences in the environmental performance of chromium and vegetable-tanned leather is available to researchers and to the general public.

The aim of this study was thus to survey key environmental footprint metrics of two different leather tanning technologies and intermediate leather processing stages in order to improve understanding of their environmental impact among tanners, their customers and regulators. Water and energy (electricity and fuels) usage and derived greenhouse gas (GHG) emissions of selected tanneries globally were the scope and basis for the footprint analysis.

The water and energy metrics were accounted for in a gate-to-gate perspective, i.e. resource appropriation and emissions from upstream processes (agriculture, animal farming and slaughterhouse) in the supply chain, whereas impacts related to the relevant downstream processes (i.e. wastewater treatment) were not included (except for GHG emissions from production of the fuels and electricity used in the tanneries).

## 2. Method and concepts

### 2.1 Leather processing

The manufacture of leather utilises between 20 to 40 process steps that vary according to the end use of the leather and the preferences of the tanner (Sundar et al., 2013). Nevertheless, there are a number of standard elements in the process that are common to all producers. This standardisation permits classification of tanneries in order to allow data about their production to be compared (LWG, 2014). Furthermore, not all of the process steps in the leather making value chain may be performed by a single tannery or within one site. Some intermediate products (tanned hide and crust hide) are stable and transfer between tanners can be carried out at one of these stages (Black et al., 2013). Consequently, tanners can be classified by their position in the leather making value chain.

[1]The difference between these two processes is explained in section 2.1

This study adopted the classification utilised by the Leather Working Group[2] (LWG), which classifies tanners into six types:

a) Raw hide to tanned hide
b) Raw hide to crust leather
c) Raw hide to finished leather
d) Tanned hide to finished leather
e) Crust leather to finished leather
f) Tanned hide to crust leather

Using this classification allows the leather making process to be divided into three main stages: raw hide to tanned hide, tanned hide to crust leather, and crust leather to finished leather. These three stages and the process steps in the production of leather are shown schematically in Figure 1. There is considerable variation between tanneries, depending on the type of leather produced.

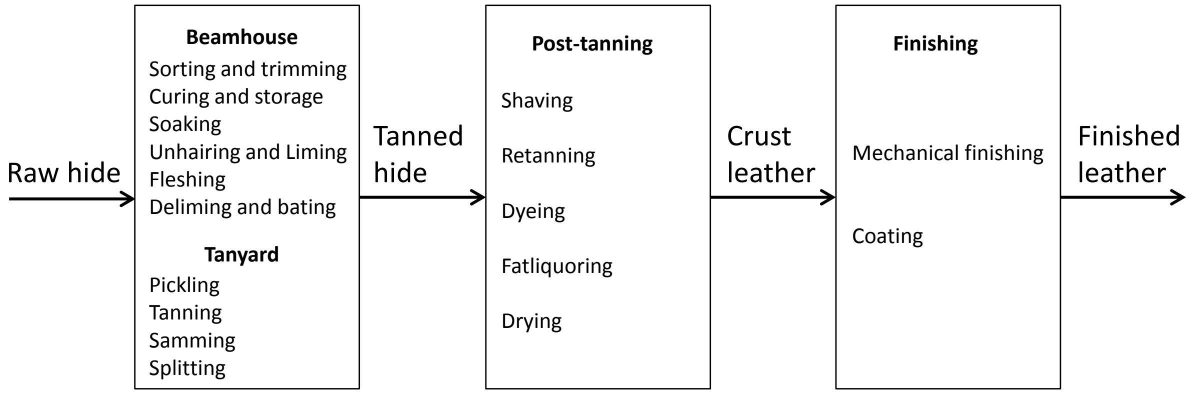


**Figure 1 – The three main stages of leather making and process steps. Raw hides are raw material; tanned hides and crust hides are intermediate products; and finished leather is the final product. Sources LWG (2014) and Black et al. (2013).**

The processes from the raw hide to the tanned hide stage take place in the beamhouse and in the tanyard. The processes occurring in the beamhouse include curing and storage, sorting and trimming, soaking, dehairing and liming, fleshing, deliming and bating (Black et al., 2013); those in the tanyard include pickling, tanning, samming and splitting. The processes taking place in the beamhouse serve to restore moisture to the hide, to eliminate salts, excess tissue, muscles or fat adhering to the hide, and to give softness and flexibility to the hide (Dixit et al., 2015; Deng et al., 2015). In the tanyard, hides are tanned, depending upon the end application of the leather, by vegetable tannins (obtained from wood, bark, leaves, roots, etc.), mineral tannage agents (aluminium, chromium, zirconium) or other methods. Chromium III is currently the most frequently used agent for tanning (Guillén et al., 2012). This process step is concerned with stabilising the collagen to create a flexible structure that dries out without putrefying and becomes suitable for a wide variety of end applications (Krishnamoorthy et al., 2013).

Post-tanning operations involve softening the leather with oils and adding extra tanning agents in order to improve the feel and handling properties of the leather, by filling the looser and softer parts to uniform physical properties. These operations are also useful in producing consistent colouring, lubricating the leather to achieve product-specific characteristics and adding certain properties such as water repellence, oleophobicity, etc.

[2]A global multi-stakeholder group responsible for developing and maintaining an auditing protocol that assesses the environmental compliance and performance capabilities of tanners. The group also seeks to improve the tanning industry by creating alignment on environmental priorities and providing best practice guidelines for continual improvement.

Finally, the dry finishing operations have the overall objective of enhancing the appearance of the leather and providing the performance characteristics expected of the finished leather with respect to colour, gloss, flexibility, adhesion, rub fastness, as well as other properties such as light and perspiration fastness, etc.

Operations carried out in the beamhouse, the tanyard and the post-tanning areas are performed in water. After post-tanning, the leather is dried and subsequent operations (finishing) are dry processes. Modern wet processing uses mechanical agitation of the hides and the liquids. In most tanneries rotating vessels (drums) are used (Black et al., 2013).

### 2.2 Study goal and scope

*Goal*

The goal of this footprint study was to obtain data on energy, water and GHG emissions (expressed as $CO_2$ equivalents), as key indicators of environmental pressure, across the main process steps of leather making, with the focus on providing product information to intermediate and final consumers. Therefore the product footprint (cradle-to-gate) of leather was not calculated as part of the study.

The target groups for the data produced were final consumers of leather goods, tannery companies, their intermediate consumers, apparel and accessory companies and regulatory and labelling bodies. Researchers in the fields of environmental footprinting, LCA and leather technology could be also interested in the results.

The target population was leather making companies committed to the environmental aspects of their business and that have been able to ensure substantial improvements in process efficiency and in pollution prevention and control for the tanning of hides and skins. These tanneries should be operating according to best available techniques (BAT) (Black et al., 2013).

*Functional unit*

The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related (ISO, 2013). This study adopted one square metre (1 $m^2$) of leather of 1.2-1.4 mm thickness as the functional unit. Although this choice differs from that in some previous scientific publications, in which the functional unit is the mass of raw hides processed (Joseph and Nithya, 2009; Rivela et al., 2004), it is consistent with the goal of the study in respect to supplying product information to intermediate and final consumers, and also with many recent reference documents, norms and labels aimed at declaring product information to consumers. Furthermore, having the functional unit as one square metre of processed area of hide/leather allowed consistent use of measures across the process steps of leather making.

*System boundaries*

Figure 2 illustrates the system boundaries of the footprint study. The system boundaries represent the unit processes, inputs and outputs that were included in footprint calculation. Upstream processes such as agriculture, animal farming, slaughtering, chemical production and water extraction and delivery were not included in these calculations. The inputs water and energy were included in the accounting. GHG emissions included were those due to both the production of electricity/fuel consumed and the fuel combustion in the leather making process. They were expressed as $CO_2$ equivalents and based on LCA using the single impact category of global warming potential[3]. Downstream processes not included were solid waste and wastewater treatment,

[3]CML2001 - Apr. 2013, Global Warming Potential, excluding biogenic carbon (GWP 100 years)

leather goods manufacturing, use phase and end of life[4]. This setting of system boundaries is consistent with the goal of the footprint study.

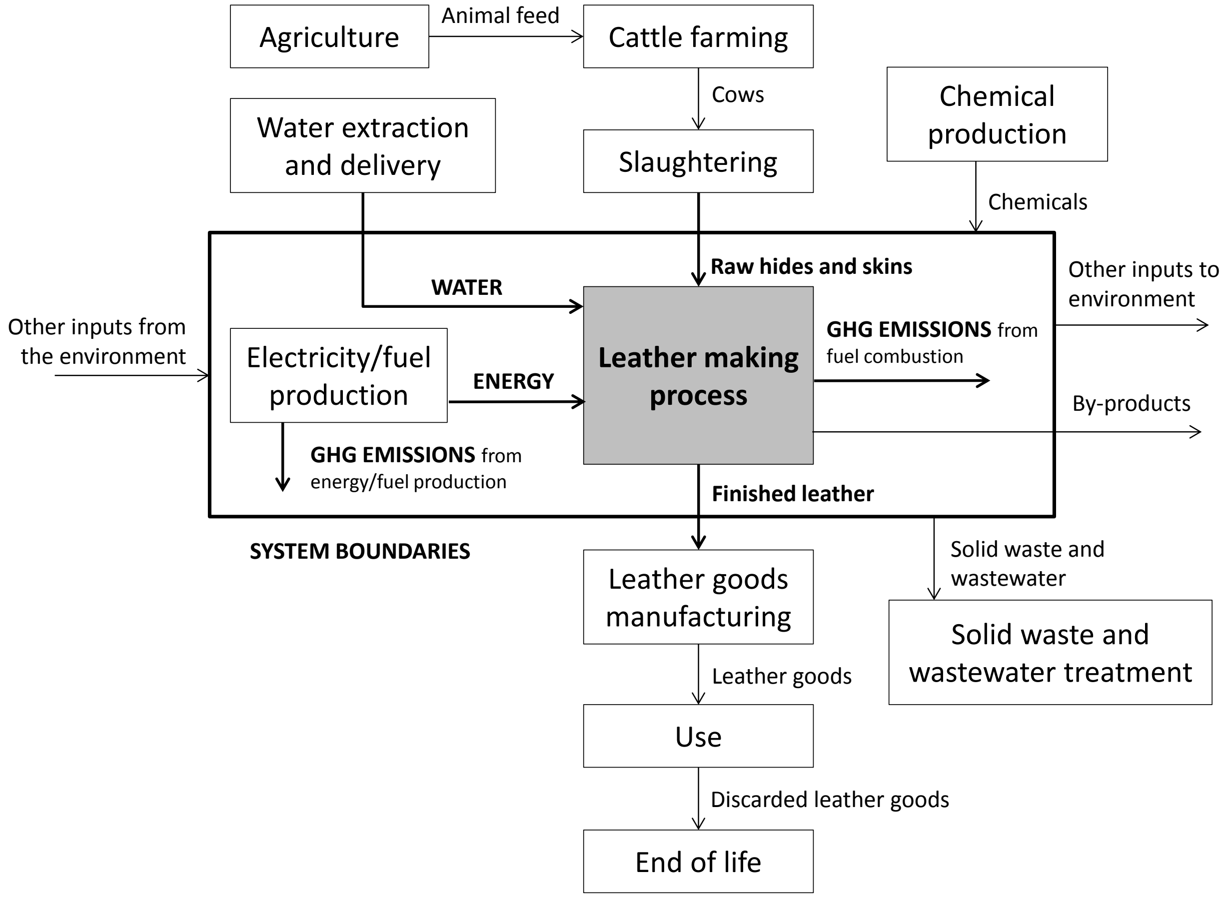


**Figure 2 – System boundaries of the footprint study, life cycle stages, main processes and material flows in the leather production system.**

## 2.3 Collection of data

The data collection phase and call to participate in the survey took place in 2014. About 200 tanneries certified by the LWG were invited by personalised individual e-mails to participate in the investigation. Invitations were also published in specialist online magazine and newsletters[5] and social network websites[6]. There were no costs to the participating tanneries. Potential participants were informed that information such as tannery names would remain confidential. Acceptance was rewarded with early privileged access to the project results.

An Excel-based data questionnaire was developed based on the LWG auditing protocol (LWG, 2014), assessed by five leather experts and validated in three trials. The validated data collection form was then sent to the tanneries that accepted the invitation to participate. The questions asked referred to their water, electricity[7] and thermal energy[8] usage for processing a given hide/leather input quantity (raw hide, tanned hide or crust hide) in a certain period of time of tannery operation[9]. Participants were also asked to specify the source of thermal energy (natural gas, fuel

[4]These downstream processes should be included to calculate the total environmental footprint of leather.

[5]ILM International Leather Maker (www.internationalleathermaker.com), *LeatherNaturally!* (www.leathernaturally.org)

[6]Linkedin groups

[7]For operating machinery and vessels, to produce compressed air and for lighting.

[8]For drying leather in different process phases, to heat water to temperatures needed for chemical processes, and to control the temperature of the working environment.

[9]Data given refer to the year 2014.

oil, LGP liquefied petroleum gas, wood and biomass other than wood). They were asked to record separately electricity use for on-site wastewater treatment plant and certified clean energy. The Excel-based data collection form can be found in the supporting information for this manuscript.

## 3. Results

Twelve tanneries (coded A-L) in seven countries completed and returned the data collection form with details of their performance. Table 1 presents the tannery codes, country, respective category and type of tanning technology used. Tanneries A, B and C process raw hides to finished leather, with C dealing with exotic hides; D and E also process raw hides to finished leather, but they use vegetable tanning agents rather than chromium; F processes raw hides to crust hides using vegetable tanning agents; G processes raw hides to tanned hides; H, I, J and K take tanned hides to finished leather; and L processes crust hides to finished leather.

**Table 1 - Participant tannery codes, category and tanning technology. *Tannery C processes exotic hides.**

| ***Code*** | ***Country*** | ***Category*** | ***Tanning technology*** |
|---|---|---|---|
| A | Spain | Raw hide to finished leather | Chromium |
| B | Taiwan | Raw hide to finished leather | Chromium |
| C* | Australia | Raw hide to finished leather | Chromium |
| D | Argentina | Raw hide to finished leather | Vegetable |
| E | Spain | Raw hide to finished leather | Vegetable |
| F | Brazil | Raw hide to crust leather | Vegetable |
| G | Brazil | Raw hide to tanned hide | Chromium |
| H | China | Tanned hide to finished leather | Chromium |
| I | Mexico | Tanned hide to finished leather | Chromium |
| J | Mexico | Tanned hide to finished leather | Chromium |
| K | Brazil | Tanned hide to finished leather | Chromium |
| L | Brazil | Crust leather to finished leather | Chromium |

The water, energy and carbon footprint of the participating tanneries per square metre of hide/leather processed are given in Figure 3. Detailed numerical results are presented in supporting information provided with this manuscript. Comparisons should only be made within categories and bearing in mind that the tanneries are located in different countries and use different energy sources. The composition of the energy sources (natural gas, LPG, oil, wood, solar, hot water and biomass other than wood) of each tannery and the respective relative contribution to $CO_2$ eq. emissions are shown in Figure 4. The $CO_2$ eq. emission factors for country electricity supply mixes and energy types can be found in the supporting information.

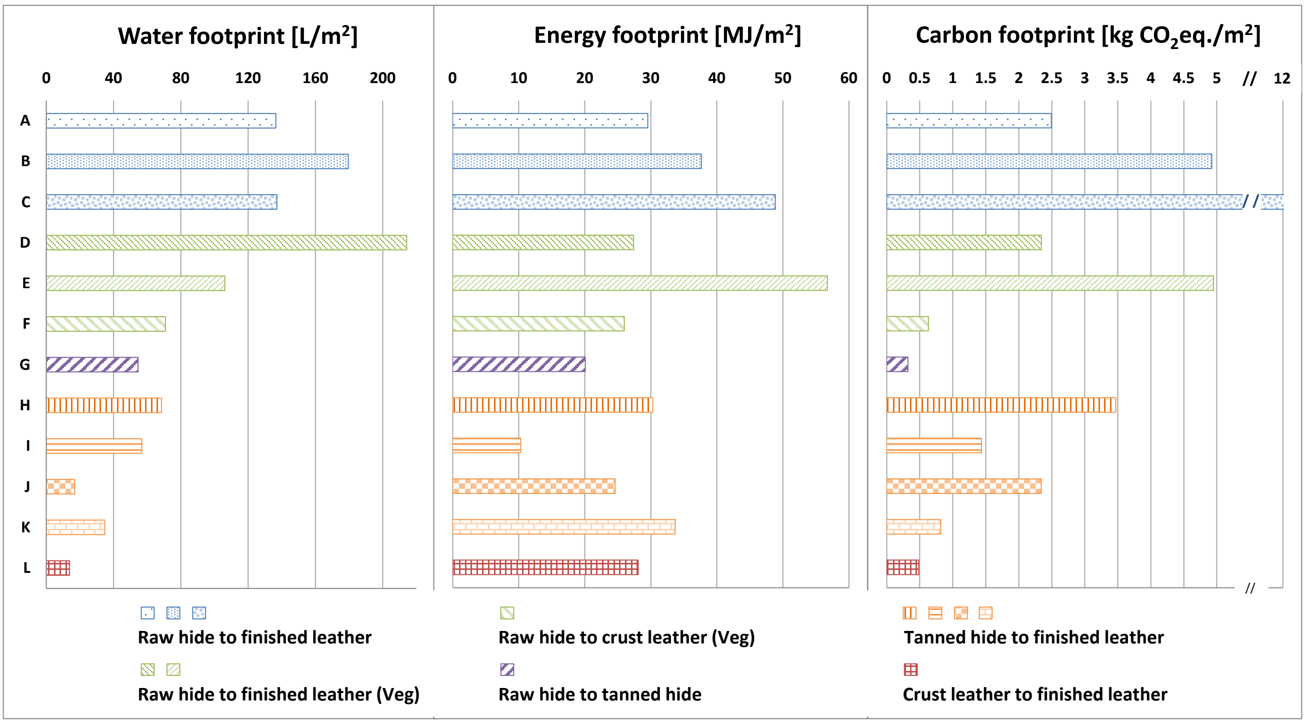


**Figure 3 – Water, energy and carbon footprint of the 12 participating tanneries (A-L). Values are expressed per square metre of hide/leather processed.**

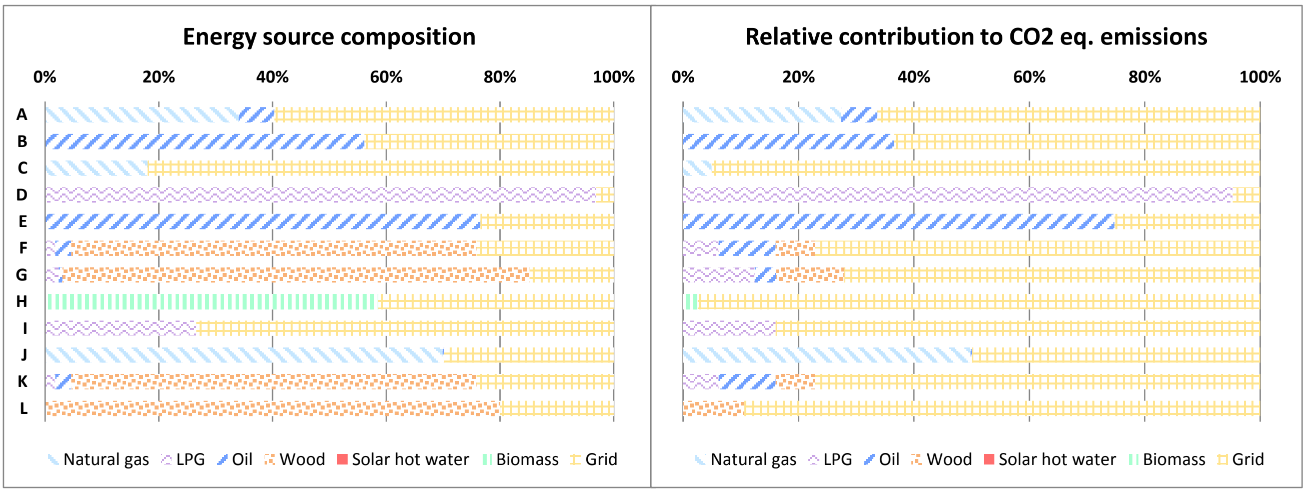


**Figure 4 – Percentage of energy consumption by type of energy source in the 12 participating tanneries (A-L) and respective relative contribution to CO2 eq. emissions.**

For the category 'raw hide to finished leather', tannery A, in Spain, consumes 136 litres of water and 30 MJ of energy to produce one square metre of finished leather from raw hide. This 30 MJ of energy use emits 2.5 kg of $CO_2$ eq. to the atmosphere. Tannery B, in Taiwan, uses slightly higher inputs of water and energy, but emits almost twice as many kg of $CO_2$ eq. because the Taiwanese grid mix has a higher $CO_2$ eq. emission factor. Tannery C, in Australia, processes exotic hides and, although it consumes an equal amount of water per metre square leather produced to tannery A, it scores markedly higher on carbon footprint (12 kg $CO_2$ eq./$m^2$). This is due partly to its high energy demand (49 MJ/$m^2$), but mainly to the high emission factor of the Australian electricity grid mix.

Among the tanneries that use vegetable tanning, tannery D, in Argentina, has the highest water footprint (214 L/$m^2$) and the lowest energy footprint (27 MJ/$m^2$) within the category 'raw hide to finished leather'. In contrast, the lowest water footprint (106 L/$m^2$) and the highest energy footprint (57 MJ/$m^2$) are also for a plant with vegetable tanning, tannery E, in Spain. The carbon footprint of these tanneries follows the same pattern as their energy footprint, i.e. there is no decoupling between energy consumption and carbon emissions. Tannery F, in Brazil, which processes raw hide to crust leather[10], uses about 30% less water per square metre of raw hide processed than tannery E and has a similar energy footprint to tannery D. Yet the Brazilian tannery has decoupled its energy footprint from its carbon footprint (0.632 kg of $CO_2$ eq./$m^2$) by having wood, a low emitting energy source, as its main energy source (around 80%; Figure 4). Evidently, the low emissions factor of the Brazilian supply mix also contributes to this decoupling.

Tannery G, from Brazil, is the only participating tannery in the category 'raw hide to tanned hide'. It has a water and energy footprint of 54 L/$m^2$ and 20 MJ/$m^2$, respectively. Tannery G also uses wood as its principal energy source and has managed to decouple energy use from $CO_2$ eq. emissions.

There are four participating tanneries in the category 'tanned hide to finished leather', H in China, I and J in Mexico, and K in Brazil. Tannery J has a remarkably low water footprint (17 L/$m^2$). Tannery I which is also in Mexico, has the lowest energy footprint (25 MJ/$m^2$). However the Brazilian tannery K has the smallest carbon footprint (0.819 kg $CO_2$ eq./$m^2$). From Figure 4, can be seen that tanneries H, I and J have not managed to decouple their carbon footprint from their energy footprint. A notable example is the Chinese tannery H; although almost 60% of its energy consumption comes from biomass, approximately 95% of its carbon footprint comes from the electricity grid mix.

Finally, tannery L, in Brazil, consumes 14 litres of water and 28 MJ to transform one square metre of crust hide into finished leather. Its carbon footprint (0.488 kg of $CO_2$ eq./$m^2$) is decoupled from its energy footprint.

## 4. Discussion

### Comparison of the tanneries

The results presented above show that although data collection was based on a standard procedure (LWG auditing protocol) and performed on elite companies within very narrow system boundaries, the environmental performance of the tanneries studied differed by a considerable margin. Given the many raw material types, end uses and approaches there are to making leather and the numerous points during processing at which a halt can be called and the leather sold on to someone else (pickle, wet blue, wet white, wet brown, crust), getting an "average" or even indicative measure may be difficult. Yet, this variability in results does not mean that the findings are invalid. These variations and the difficulty in trying to compare diverse processes explain why the benchmarking tanneries set up a measure which they mostly use to monitor their own improvement, rather than trying to use it for comparison with other tanneries or materials.

The participating Brazilian tanneries (F, G, K and L) have succeeded in decoupling their carbon footprint from their energy usage by using biomass as the main source of thermal energy and by having, as a country, an electricity grid mix with a high proportion of renewable primary energy.

The results presented above are inconclusive as regards the most preferable leather processing technology (vegetable or chromium tanning) regarding water and energy usage. This stresses the need for further investigations on a larger sample of tanneries that use vegetable tanning. Site specificities that can greatly influence water and energy usage, for instance tanning process type (drum tanned or pit tanned) and the existence of an onsite wastewater treatment plant, should be specified. These would increase understanding about the wide variations in the footprint metrics

[10]Crust leather has been tanned, dyed and dried, but not finished. These operations usually consume around 90% and 50% of the total water and energy usage, respectively (Reference: IPPC and LWG reference protocol).

helping with developing usable metrics for leather product footprint studies and best practices for tanneries that seek out resource efficiency opportunities.

Related to the previous comparison, in order to determine which processing technology is better from an environmental point of view, many other impact categories should be evaluated (e.g. eutrophication, acid rain, human toxicity, aquatic ecotoxicity, etc.) in addition to carbon footprint.

**Comparisons in the wider context of decision making**

In this particular debate, the wider context is also very significant. This study adopted a narrow view of system boundaries, but footwear and apparel companies often take a life cycle view. Therefore, utilisation of secondary data for comparisons in a life cycle perspective in the context of decision making should be applied with caution.

Secondary data about leather tanning and farm management are commonly adopted as background data in life cycle studies of leather products. Although this is a widely accepted practice, secondary data can omit acute fluctuations in these sensitive values. There is already wide variation in water and energy consumption (and related carbon footprint) among different tanneries without including chemical production and waste and wastewater treatment, so the variations that could be found when taking a wider life cycle approach are likely to be very great. Therefore, obtaining specific primary data for leather production in LCA studies of leather products is recommended.

As also indicated by the results above, feeding regime (e.g. grain- or grass-fed) is known to have a substantial impact on the carbon footprint of cattle rearing, due in part because of the time to reach a desired slaughter weight (Desjardins et al., 2012). In addition, methane emissions from cattle rearing strongly influence the total carbon footprint of leather products. It is thus necessary to have foreground data for different scenarios and origins of the leather to obtain a more accurate evaluation of the carbon footprint of leather.

Furthermore, if vegetable-tanned leather is being compared with chromium-tanned leather, the fact that vegetable tannins can come from renewable trees, whereas chrome is mined and used once in leather, must not be overlooked. This aspect of how a fair comparison can be made between renewable natural materials and materials that come from fossil fuels or, like chromium, from one-time use of a mined resource is an important issue needing consideration. Many more impact categories should be evaluated in such a comparison.

## 5. Conclusion

This study surveyed the water and energy resource usage and derived GHG emissions of leather processing technologies in 12 tanneries in seven different countries. Wide variations in the data were obtained. This demonstrates the difficulty of trying to compare diverse processes and the limits of system boundaries. Other main conclusions of the study are:

- Wide variations exist in the data on the environmental performance of different tanneries and these need to be understood to help with developing usable metrics for leather product footprint studies and best practices.
- The variability in results demonstrates that secondary data for the tanning phase should be used with caution in a decision-making context. The use of primary data on specific leather would be advisable for LCA studies of leather goods.
- The performance of vegetable and chromium tanning appears to be very similar. However, this study had the major limitation of very few available data (especially on vegetable tanning), so this finding is only indicative and would need confirmation with further investigations.

- When comparing chromium with vegetable leather, it is important to note that vegetable tannins should come from trees, a renewable source, whereas chrome is mined and used once in leather. This aspect of how a fair comparison can be made between renewable natural materials and materials that come from fossil fuels or from one-time use of a mined resource is a major area needing consideration. More impact categories need to be evaluated for such comparisons (e.g., toxicity).

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