Sustainability in Process Innovation: Development of A Green Tanning Process Supported by LCA Methodology

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Abstract

As a response to the growing concerns about a variety of environmental issues expressed by public opinion and political bodies, the leather industry needs to support its market by environmental criteria as a guarantee of quality. For this reason, assessment tools as Life Cycle Assessment (LCA) methodology, which allow a more thorough knowledge of the products to the enterprises and can help to guide the environmental policies, are recommended (e.g. EC Directive on Ecologic Labels).

The LCA methodology, described in details by the ISO 14000 series, allows the assessment of the environmental impacts due to products, processes, or services, by the identification of the input (e.g. energy and material consumption) and output (e.g. waste and pollutant production) streams exchanged by the process with the environment (i.e. from raw materials procurement to waste streams disposal). The application of LCA as tool for integration of sustainability aspects in process design and development is gaining wider acceptance and methodological development.

In this study, the life cycle modeling was used to support the development of a novel tanning process based on the use of a new class of tanning agent produced from renewable resources (e.g. glucose). The experimental activity performed to investigate the technical feasibility of the innovative tanning cycle was supported by the modelling of the process using the LCA methodology in order to assess the environmental performance of the leather production cycle. Therefore, an LCA analysis was performed in order to compare the glucose-tannage process with the traditional one from an environmental point of view.

Keywords: Life Cycle Assessment, tanning process, leather

1. Introduction

As a response to the growing concerns about a variety of environmental issues expressed by public opinion and political bodies, the leather industry needs to support its market by environmental criteria as a guarantee of quality. Since sustainability is a global concept, this inevitably calls for a system-wide analysis. A system perspective is at the core of the Life Cycle Assessment (LCA) approach, which can provide valuable support in the sustainability evaluations, as demonstrated by the numerous environmental policies at European level (e.g. EC Directive on Ecologic Labels), based on the life cycle concept. The LCA methodology, described in details by the ISO 14000 series, allows the assessment of the environmental impacts due to products, processes, or services, by the identification of the input (e.g. energy and material consumption) and output (e.g. waste and pollutant production) streams exchanged by the process with the environment (i.e. from raw materials procurement to waste streams disposal). During the early years of LCA, the methodology was mostly applied to products but recent literature suggests that it also has potential as an analysis and design tool for chemical processes (Burgess and Brennan, 2001; Jacquemin et al., 2012). LCA could be used in several contexts. These include use in process design for comparison and selection of options; in business planning for identifying weak links in a processing chain or in comparing processes with those of business competitor; at the research and development phase of a process, in guiding process evolution (Castiello et al., 2008).

Besides, during the evolution of the methodology, a number of related applications emerged, including its use as basis to communicate the overall environmental performance of the products to stakeholders.

Specific standards are available for LCA-based environmental labels and declarations. The International Standards Organization (ISO) has classified the existing environmental labels into three typologies—types I, II, and III—and has specified the preferential principles and procedures for each one of them (ISO 14021, ISO 14024, and ISO 14025). An Environmental Product Declaration (EPD), also referred to as type III environmental declaration, is a standardized (ISO 14025) and LCA-based tool to communicate the environmental performance of a product (Grahl and Schmincke, 2007). There are a number of requirements for how the LCA should be performed to be used as basis for an EPD. They are concerned on detailed specifications on how to model the product system in the LCA, what to include, what data to use, which environmental indicators to report, etc. These requirements are developed for different product groups by the industry and are referred to as Product Category Rules (PCRs). The aim of the PCRs is to achieve comparability in results between different producers of the same product. And as such, the PCRs are valuable and useful as basis for any type of LCA to be used in external communication of results. Recently, the PCR for the assessment of the environmental performance of "Finished bovine leather" are established.
In this study, the life cycle modeling was used to support the development of an innovative tanning process based on the use of a new class of tanning agent produced from renewable resources (e.g. glucose). From the pilot scale experimental tests, the novel process by using glucose as tanning agent appears a feasible leather processing, from the technical point of view, to produce high quality bovine upper leather. Results have shown that the finished glucose-tanned leather are comparable to the conventional chrome-tanned in terms of mechanical and technical properties.

Life cycle modeling was used to support the development the novel tanning process by assess the environmental performance associated to the whole production cycle. Therefore, the LCA methodology was applied in order to compare the novel process with the traditional one from an environmental point of view. The LCA study was performed in according to the Product Category Rules defined for the EPD system.

2. Methods

This study was performed using a methodological framework based on the International Organization for Standardization (ISO) recommendations (UNI EN ISO 14040 and 14044). According to the ISO 14044, LCA methodology consists of four phases: goal and scope definition, inventory analysis, impact assessment and interpretation. In the goal and scope definition are defined the objectives of the study, the functional unit (i.e. the reference unit to which the inputs and outputs are related), the boundaries of the system (i.e. the extension of the study), and the impact assessment methodologies. The inventory analysis involves data collection for all the activities in the studied system: raw materials (including energy carriers), products, and solid waste and emissions. This step includes calculation of the amount of resource use and pollutant emission of the system in relation to the functional unit. The impact assessment phase assigns the inventory results to impact categories and quantifies the system potential contribution to different environmental impacts.

2.1 Goal definition and functional unit

The main objective of this LCA was to compare the environmental potential impacts of two tanning processes. The traditional chrome-tanned leather was compared to novel leather production based on the use of a new class of tanning agent produced from renewable resources (e.g. glucose). The scope is to include all important activities of the leather processing, i.e. covering raw materials acquisition and materials production.

Based on Product Category Rules of the international EPD System, the functional unit was set equal to the production of 1 m^2 of "finished bovine leather", intended as a finished product of the tanning sector and ready to become an input as a semi finished good for further transformation in various manufacturing sector.

The leather can be used as a semi finished good for different kinds of final products (for example furniture, clothing, footwear etc.). Since the application of finished bovine leather in final consumer products varies substantially, no specific function has been defined for the product. Therefore, the use phase was not included in the analysis and a cradle-to-gate system was considered. Figure 1 shows the phases included in the analysis. According to the PCRs, the system boundaries include the main flow related to the leather processing: agriculture, cattle raising, slaughtering, tanning. As noted above, since no specific function has been defined for finished leather, the use phase and the waste treatment phase are omitted. The construction of facilities, including the machinery, electrical installation etc., were excluded from the system and only the operation stages were taken into account in the analysis.

2.2 Inventory analysis

The environmental load was calculated in relation to the functional unit, and the inventory results are evaluated and distributed into the life cycle stages.

The aggregated data collected for modeling the systems were derived from the experimental tests performed to explore the technical feasibility of the novel tanning cycle. The needed equipment and electricity quantities were calculated in relation to treatment time of the hides in the various stages of the process. Inventory data for the background system (production of chemicals, electricity, lorry transport, etc.) were based on average technology data from the Ecoinvent 2.2. database.

As most industrial processes yield more than one product, it is necessary to allocate the burdens caused by these processes (resource consumption and emission) to all the products. As defined in PCRs, in this study a mass allocation procedure to raw hide of the impact of agriculture, cattle raising and slaughtering was applied. For example, in the slaughtering phase the allocation factor for raw hides is 7% (i.e. only 7% of the environmental burdens produced upstream of the skinning operation are allocated to hides).

2.3 Impact assessment method

The study was carried out by using SimaPro 7.3 software (Pré Consultants). To conduct an LCIA (Life Cycle Impact Assessment), it is necessary to select an impact assessment methodology which regroups the different characterization models for each impact category. These characterization models allow the calculation of characterization factors which express the measured substance's strength relative to a reference substance.

Among the different methods available in the software, the ReCiPe endpoint and midpoint (hierarchist version) methods were used. An endpoint method was used for the impact assessment in order to achieve maximal agreement with the comparative and management-oriented objectives of the study. Endpoint indicators describe the integrated damage of the components from the inventory, in contrast to midpoint indicators which address effects only. For global warming, a typical midpoint indicator would be the effect of radiative forcing (global warming potential), whereas the endpoint approach would assess the human and environmental damage based on radioactive effects. Use of endpoint indicators facilitates the interpretation of the results and allows integration of environmental burdens to a single score indicator (the midpoint characterization factors are multiplied with a damage factor to obtain the endpoint characterization values). ReCiPe uses three main damage categories: human health, ecosystems and resources. Human health includes climate change, ozone depletion, human toxicity, photochemical oxidant formation, particulate matter formation, and ionising radiation (expressed in disability adjusted life years, DALY). Ecosystems includes climate change, terrestrial acidification, freshwater and marine eutrophication, terrestrial, freshwater and marine ecotoxicity, agricultural and urban land occupation, and natural land transformation (expressed in species·yr). Resources include metal depletion and fossil depletion, expressed in $.

3. Results and Discussion

The results of the life cycle assessment of the traditional leather production (chrome-tanned) at endpoint level are reported in Figure 2. Regarding the three damage categories (human health, ecosystems and resources), the graphic highlights the environmental impact of the tannery compared with the others activities related to the leather production (agricultural phase, cattle raising, slaughterhouse are included in the *raw hides* block). The contribution to

Ecosystems damage category is remarkably higher for the activities associated with the calf hides production in relation with the agricultural stage and cattle raising. The agriculture-related emissions are caused mainly by fertilizer use and production. The use of fertilizers causes N_2O emissions, which contribute to Climate change category included in Ecosystems damage category, and nitrate emissions in water, which contribute to Eutrophication and Human Toxicity categories. Also the emission of methane from the cattle raising causes the main impacts and contributes largely to Climate Change and Photochemical oxidant formation categories. This result is especially notable taking into account the fact that only 7% of the impacts generated in these phases have been allocated to leather production.

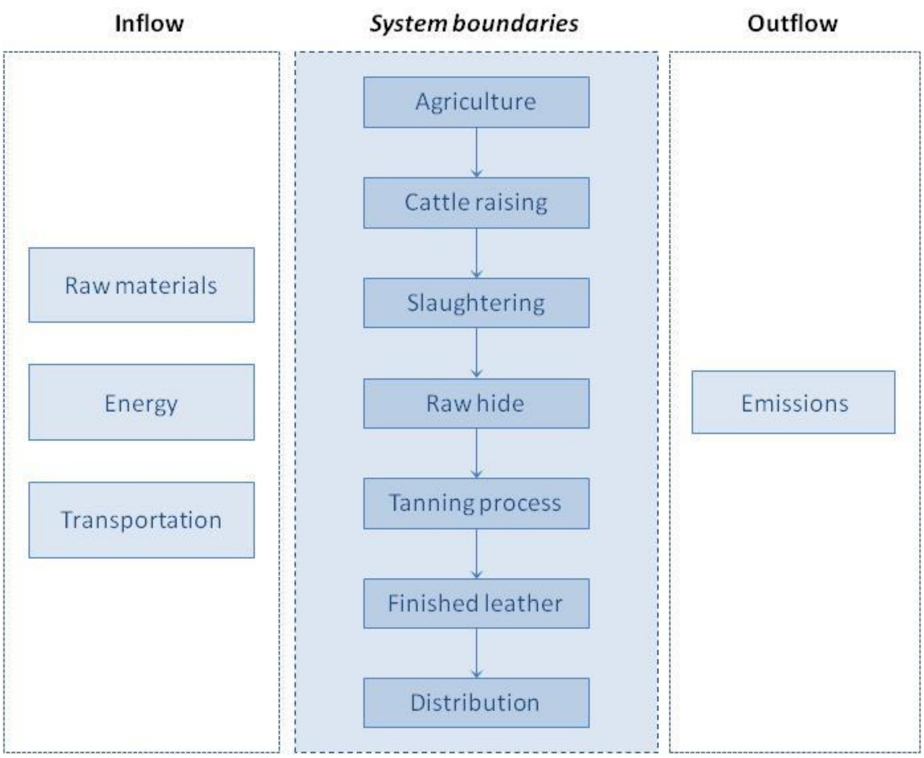

Figure 1. Life cycle flow diagram of the studied system

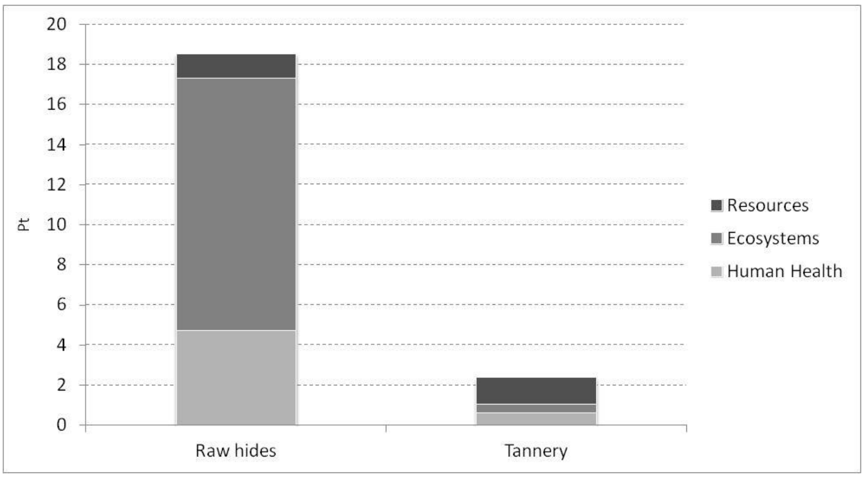

Figure 2. Results of the life cycle assessment of the chrome tanned leather at endpoint level

Figure 3 shows the results of a contribution analysis performed to reveal the most important contributing stages for the chrome-tanning cycle. As it can be seen, the tannage phase accounts for most of the whole environmental impact. This result is related to chromium content of the wastes (solid wastes and wastewaters) and also its manufacturing process. Therefore, the substitution of chromium salts with tanning agents having a lower environmental burdens in relation with its use (pollutants content of the exhaust bath) and its production can remarkable reduces the impacts of the tannery.

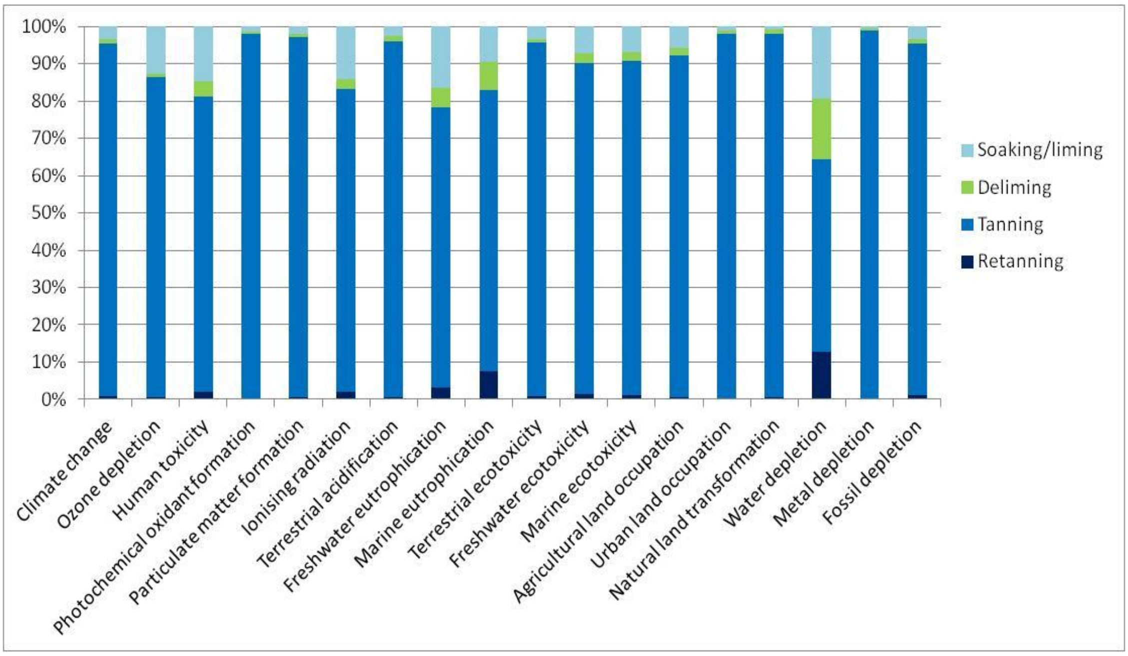

Figure 3. Contribution of subsystems of the chrome-tannage cycle to each impact category

Table 1 lists the parameter values obtained from the life cycle impact assessment of the two tanning processes, which are used to calculate the disadvantage factors reported in Table 2. The disadvantage factors are calculated by dividing the higher value by the lower value, in order to highlight how many times a process causes more environmental burdens compared to the other one (Volkwein et al., 1999).

The results show that the potential environmental loads for traditional tanning process are higher than the burdens associated to glucose-tanned leather production. As noted above (see Figure 3), the main contribution to environmental impact of hides processing is related to use of chromium salts, therefore the use of glucose instead chromium sulphate reduces the loads of the tannery. This result indicates that the environmental advantage in the novel leather cycle outweigh the costs to the environment in the form of greenhouse gas emissions, particle emissions, use of limited resources, etc. in the traditional chrome-tanned leather production, although the cultivation activities and manufacturing process associated to glucose production were considered. These phases contribute mainly to categories included in the Ecosystem category damage. So the potential effect on ecosystem are very similar for the two system production, as shows in Figure 4. On the other hand, it must be taken into account that the potential damage on ecosystems is strongly affected by the agricultural phase.

Table 1. Midpoint results per impact categories

Impact Category	Unit	Traditional leather production	Novel leather production
Climate change	kg CO_2 eq	$1.93 \cdot 10^{2}$	$1.75 \cdot 10^{2}$
Ozone depletion	kg CFC-11 eq	$1.63 \cdot 10^{-5}$	$1.37 \cdot 10^{-5}$
Human toxicity	kg 1.4-DB eq	3.33	1.39
Photochemical oxidant formation	kg NMVOC	$3.26 \cdot 10^{-1}$	$1.89 \cdot 10^{-1}$
Particulate matter formation	kg PM10 eq	$3.45 \cdot 10^{-1}$	$3.07 \cdot 10^{-1}$
Ionising radiation	kg U235 eq	2.72	1.21
Terrestrial acidification	kg SO_2 eq	2.25	2.16
Freshwater eutrophication	kg P eq	$5.63 \cdot 10^{-3}$	$4.05 \cdot 10^{-3}$
Marine eutrophication	kg N eq	2.64	2.63
Terrestrial ecotoxicity	kg 1.4-DB eq	$3.26 \cdot 10^{-3}$	$6.35 \cdot 10^{-4}$
Freshwater ecotoxicity	kg 1.4-DB eq	$8.92 \cdot 10^{-2}$	$2.28 \cdot 10^{-2}$
Marine ecotoxicity	kg 1.4-DB eq	$9.64 \cdot 10^{-2}$	$2.38 \cdot 10^{-2}$
Agricultural land occupation	m2a	$2.25 \cdot 10^{2}$	$2.24 \cdot 10^{2}$
Urban land occupation	m2a	$2.07 \cdot 10^{-1}$	$1.26 \cdot 10^{-2}$
Natural land transformation	m2	$6.61 \cdot 10^{-3}$	$6.38 \cdot 10^{-4}$
Water depletion	m3	$2.59 \cdot 10^{-1}$	$1.59 \cdot 10^{-1}$
Metal depletion	kg Fe eq	5.61	$1.86 \cdot 10^{-1}$
Fossil depletion	kg oil eq	$1.41 \cdot 10^{1}$	7.89

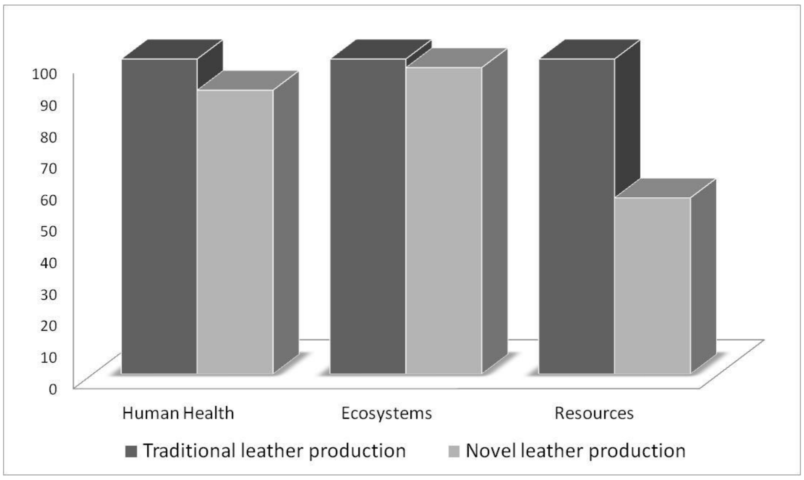

Figure 4. Comparison of the environmental impacts associated with the two tanning process at endpoint level

4. Conclusions

A comparison of the environmental performance of two leather manufacturing processes was carried out. An innovative tanning process based on the use of a new class of tanning agent produced from renewable resources (e.g. glucose) was compared to the traditional chrome-tanned leather production by using the LCA methodology.

From the pilot scale experimental tests, innovative process by using glucose as tanning agent appears a feasible leather processing, from the technical point of view, to produce high quality bovine upper leather. Results have shown that the finished glucose-tanned leather are comparable to the conventional chrome-tanned in terms of mechanical and technical properties. Life cycle modeling was used to support the development the novel tanning process by assess the environmental performance associated to the whole production cycle in view of the application of this new tanning process at industrial scale.

The results of the impact assessment of the chrome tanned leather underline that the main potential impact is associated with the raw hides production in relation with the agricultural stage and cattle raising rather than with the tanning phases. The contribution analysis of the stages reveals that the main contribution to environmental impact of hides processing is related to use of chromium salts.
The use of glucose instead chromium sulphate reduces remarkably the environmental loads of the tannery, as highlighted from the results of the comparative analysis at midpoint and endpoint level.

Then the outcomes obtained indicate that the novel leather production is a promising alternative to the traditional process to overcome the ever increasing environmental constraints.

Table 2. Disadvantage factors per impact categories.

Impact Category	Unit	Traditional leather production	Novel leather production
Climate change	kg CO_2 eq	1,10	1,00
Ozone depletion	kg CFC-11 eq	1,19	1,00
Human toxicity	kg 1.4-DB eq	2,40	1,00
Photochemical oxidant formation	kg NMVOC	1,73	1,00
Particulate matter formation	kg PM10 eq	1,12	1,00
Ionising radiation	kg U235 eq	2,25	1,00
Terrestrial acidification	kg SO_2 eq	1,04	1,00
Freshwater eutrophication	kg P eq	1,39	1,00
Marine eutrophication	kg N eq	1,00	1,00
Terrestrial ecotoxicity	kg 1.4-DB eq	5,13	1,00
Freshwater ecotoxicity	kg 1.4-DB eq	3,91	1,00
Marine ecotoxicity	kg 1.4-DB eq	4,06	1,00
Agricultural land occupation	m2a	1,00	1,00

Urban land occupation	m2a	16,41	1,00
Natural land transformation	m2	10,37	1,00
Water depletion	m3	1,63	1,00
Metal depletion	kg Fe eq	30,20	1,00
Fossil depletion	kg oil eq	1,78	1,00

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