Chapter N (please do not write anything in this line. Editors will annotate the chapter number)

**Modelling the leather industry waste from the circular economy perspective. A depth-review.**

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**Abstract.** The tanning industry is a significant economic sector in Italy, but also a source of high environmental impacts. Many studies underlined the issues of each phase of the leather production cycle, looking for more ecofriendly solutions. This research was encouraged by the Sustainable Development Goals set by the 2030 Agenda, in particular goals 12 and 13 which respectively promote responsible consumption and production and the fight against climate change. In support of these goals, the application of circular economy (CE) practices allows both a reduction of the environmental impact and economic savings. The tanning industry indeed produces a huge amount of liquid and solid waste, and the CE model allows both the prevention and the recovery of such waste. This paper provides a review of the potential applications of the CE to the tanning sector through the design of eco-sustainable products and the reuse of waste as secondary raw materials within the same or other production processes. The use of biological, chemical, and thermal techniques allows for a high degree of reducing waste production and recycling of secondary materials with a significant decrease of the environmental pollution.

**Keywords.** Circular economy, leather waste, environmental impact.

* 1. **Introduction**

Currently, corporate sustainability is a requirement for maintaining an industrial economy that achieves a sustainable competitive advantage. The latter has changed its configuration and it consists of not only an economic but also a social and, above all, environmental component. The economic strategy adopted by the market, indeed, is no longer based on the linear model centered on the exploitation of resources until they are exhausted, on mass consumption and on the accumulation of waste. The current and sustainable model proposed is the circular economy model, which mainly provides for the reuse of waste as secondary raw materials.

Tanned leather is characterized by high level manufacturing and a process handed down over time and which is known throughout the world for its value. Hence, the tanning sector has a significant economic importance, representing a strategic segment for the manufacturing sector in Europe, which covers 30% of global turnover. Furthermore, the finished leather chain generates a value creation boost of 125 billion euros in turnover for downstream producers. In Italy, the value of production amounts to 3.5 billion euros with volumes of 97 million m2 of finished leathers. It has to be stressed that a certain amount of waste directly proportional to the volumes of production has generated, with an average of 2.63 kg per m2 of finished leather. Leather manufacturing could be defined as one of the oldest examples of circular economy, as well as being a natural and biodegradable material (SER, 2020). However, in order to produce the finished leather, the raw material requires a series of processes presenting multiple environmental critical issues. Therefore, the benefits of recycling the waste leather deriving from animals destined for slaughter are outweighed by the polluting effects caused by its production process.

Specifically, the various processing stages of the production cycle that transform 1 ton of raw leather into tanned leather generate an average of 15-50 m3 of wastewater, a range of 450-730 kg of solid waste and 500 kg of sludge deriving from wastewater treatment plants (Hu et al., 2011). Particular attention should be paid to the chemicals present in the wastewater and sludge, since 1 ton of raw hides includes about 240 kg of COD, 100 kg of BOD, 150 kg of suspended solids, 170 kg of sodium chloride, 80 kg of sulphate, 10 kg of sulphide and 5 kg of chromate. (Tasca, 2019). Overall, European cow tanneries generate around 4,105 tons of sludge per year and approximately the same amount of other solid residues (Tasca, 2019).

Many researchers studied the stages of the leather production cycle in order to identify the most environmental impacting.

This study provides a depth review of the clean technology innovations for the sustainability of the production tanning process aimed both at reducing the use of necessary resources and the quantity of waste produced, notwithstanding improving the quality. Furthermore, the review investigated researches concerning the technologies aiming to solve the issue of the recycling of waste produced by the tanning industry.

* 1. **Methodology**

Firstly we highlighted the inputs and outputs most required and characterized by the greatest environmental impact. Based on this assumption, we gathered scientific literature concerning the best preventive techniques and tools capable of reducing the environmental impact, besides, solutions to recover production waste by redesigning it from a circular economy perspective.

Multiple publications were selected from different databases: Researchgate, Scopus, Springer and ISI Web of Knowledge were mainly used. The keywords used for the bibliographic research were "leather production" retrieving 36,677 results, reduced to 16,613 results using "sustainable leather"; the other words that guided the research were "leather waste" obtaining 21,166 results reduced to 7,786 by adding the word "recycling". Among all the results obtained, the most suitable ones were chosen in order to produce a critical review.

* 1. **Production’s inputs and outputs**

The tanning production cycle includes various operations starting from drying or salting, followed by the soaking necessary to rehydrate the leather and remove the salt, the calcination useful for the removal of hair and meat residues and for the preparation of the leather for the reception of tanning substances. Following, the deliming removes the lime previously used, whilst the pickling reduces the Ph of the leather, the bating allows to separate the fibers of the leather and the degreasing removes the natural fat, up to the tanning. This operation assumes a predominant role in the process giving to the leather the conditions of resistance and stability of the material through the use of tanning agents such as chromium or vegetable tanning agents. The post-tanning and finishing operations make the material complete with its organoleptic and aesthetic properties and, therefore, free from defects. (Covington, 2009).



 Fig.1 Circular economy’s applications in the leather sector

 Source: personal elaboration of the authors

As can be seen from the Fig.1, a per phase analysis of the inputs and the outputs generated allows both to identify which resources are most consumed, and how much and what waste is produced. The inputs with the highest utilization rate are water and energy. Particularly, considering the system boundary from raw leather (1 ton) to finished leather (200 kg), the inputs are the following: 21.4 m3 of water, 2.313,2 MJ thermal energy and 294.92 kWh electric energy (Notarnicola et al., 2011). It must to be pointed out that the leather tanning phase consumes about 90% of the total energy (Navarro et al., 2020).

Among the production outputs, chromium is the chemical substance that is most polluting. Specifically, chromium (VI) oxidized by chromium (III) in tanning is carcinogenic, allergenic and mutagenic. (Wang et al., 2017). This substance is present in wastewater, sludge, chrome-tanned leather shavings and chrome leather trims, generating harm to the environment and human health. A significant problem for tanning companies, but also for leather products manufacturing companies, is the amount of shavings and scraps that accumulate and contain chemicals. In particular, 1 ton of raw hides generate 225 kg of shavings and 150 kg of trimming (Hu et al., 2011). This overview of the most relevant inputs and outputs makes it possible to identify the critical process points of product process.

* 1. **Clean Technologies**

There are several technologies applied to the production process in order to reduce the environmental impact. The most numerous are dedicated to the change, reduction and/or recycling of the most amounting and impactful inputs and outputs such as water and chromium.

China et al. (2020) proposes improvement techniques in the tanning phase. They provide for the recycling of exhausted chromium liquids through the direct recycling method which is more immediate and economical than the indirect one. The authors also investigated tanning technologies with high chromium exhaustion that make use of auxiliaries or other solvents in addition to water to improve the absorption of chromium and total replacement of chromium salts using alternative tanning agents. Although China et al. (2020) proposes a method that leads to the reduction of the amount of polluting wastewater, Statish et al. (2016) studied a process that would allow the complete replacement of the use of water in leather processing using a supercritical fluid as a solvent, eliminating not only the environmental impact of water waste but also the costs associated with the treatment of wastewater. The same advantages are obtained with the use of switchable solvents, also benefiting from energy savings.

Kanagaraj et al. (2020) includes vegetable tanning among the sustainable tanning systems, highlighting, however, the critical issues linked to the use of 20-40% of vegetable tannin which generates considerable quantities of organic loads, sludge and unpleasant odors. Krishamoorthy et al. (2012) propose a solution with the use of green chemistry that develops an ecological tanning system based on optically active unnatural d-amino acids (d-AA) with aldehyde (Ald) as a chrome-free tanning. This method proves to be more effective since it reduces the environmental impact having completely non-toxic wastewater, without burdens concerning the disposal of solid and liquid waste.

The preventive technologies implemented in the upstream of the production process are not sufficient to solve the environmental issues of the sector. Specifically, there are multiple applications with a view to circular economy capable of transforming by-products into secondary raw materials for the same tanning sector or other industrial sectors. Through chemical transformations they are used in the energy, infrastructural and construction fields. Ding et al. (2022) provide a circular economy application with chromed leather scraps in the building field, specifically the obtaining of hydrogel beads for the preparation of light gypsum; this composition has a lower mechanical resistance and thermal conductibility. This last feature offers opportunities to produce materials useful for thermal and acoustic insulation. Indeed, Marconi et al. (2020) use the scraps of leather for the preparation of thermal insulation panels. However, the use of these waste provides for an increase in the aluminum thickness present in the panel which is responsible for 60% of the environmental impact of the frame.

Battig et al. (2021) exploit, also, the potential of wet white skin waste as functional adjuvants and replacements in flame retarded (EVA) polymeric composites, improving their mechanical properties, with respect to tensile strength and Young modulus, and the fire-fighting performance.

An interesting sector of application of tanning waste is biofuels. These could be used as a source of energy needed during the production process. Priebe et al. 2016 propose the production of biogas or methane fractions through the anaerobic treatment of solid waste, obtaining lower energy consumption and disposal costs, while Kenskin et al. (2020) study the production of biodiesel using waste fat, obtaining a yield of 86.8%; however, on the output parameters of a diesel engine there is no reduction in NOx emissions but only in the fumes.

* 1. **Conclusion**

The review carried out investigated the current multiple technologies aiming to improve the environmental impact of the tanning sector, although most of them require huge investments for companies to adapt the disposal and purification plants. The recovery of leather scraps as raw materials for other sectors, however, allows economic savings on disposal costs as well as encouraging circular economy models. Although the fields of applications are numerous and heterogeneous, there is a lack of industrial symbiosis districts between the tanning industries and the companies that use leather waste. The building of such clusters would further reduce costs for all businesses with a significantly lower environmental impact.

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