LCA Case Studies

Application of Life Cycle Assessment to Footwear

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Abstract

Life Cycle Assessment (LCA) has been applied in the leather footwear industry. Due to the fact that the goal of the study is to point those steps in the footwear cycle which contribute most to the total environmental impact, only a simplified semi-quantitative methodology is used. Background-data of all the inputs and outputs from the system have been inventoried. Impact assessment has been restricted to classification and characterisation. From the results of this LCA it has been concluded that energy consumption is an important impact generator phase, due to the characteristics of the electricity production in the studied area (Catalonia and the rest of Spain). A remarkable impact is generated in the solid waste management phase, also due to its characteristics in the studied area. Another significant impact source is the cattle raising phase where great values of Global Warming, Acidification and Eutrophication Potentials are estimated. At the tannery, a great value of water eutrophication potential is observed and this phase is also important for its non-renewable resource consumption.

Keywords: LCA, case studies; footwear manufacture, LCA; LCA, footwear manufacture; allocation, LCA; leather; leather footwear; tannery, LCA; tannery, environmental impacts; Spain; Spanish industry

1 Introduction

The footwear industry is very important in Spain, due to the amount of people working in it – both directly and indirectly – and due to its turnover; the main part of this production is exported (about 50-60%) to other EC countries (61.5% of the exportations, in 1990) and USA (25.7%, in 1990) (after Peat Marwick, 1992). The most important sector in this industry is that of medium-high quality leather shoes, which require good marketing techniques to be sold. Recently, this marketing is partially supported by environmental criteria as a guarantee of quality. For this reason, assessment tools like LCA, which allow a more thorough knowledge of the products to the enterprises and can help to guide the environmental policies, are strongly recommended (EC Directive on Ecologic Labels: 880/92/EC). The main phases of footwear life cycle are animal care, slaughterhouses, tannery, footwear confection, domestic use and the waste management. The tannery is the phase that, at first sight, seems to be most problematic, due to its huge amount of waste water generation, and to the substances which contaminate them. This is the starting hypothesis in the present study.

In Spain, this not only involves shoes, but also the tanning of raw hides to produce the prime material: the leather. Catalonia is one of the most important tanning regions in Spain, its production being focussed in Igualada ("big hides": cattle) and Vic ("small hides": mainly sheep and goats).

The work carried out by Perdijk et al. (1994), who investigate on the LCA application to the footwear industry is one of the most significant studies which has been performed. There are more specific works about improvement proposals in different process steps, all of them justified by the economic importance of the sector in Spain. Thus, in this study we try to identify the most problematic phases in the production of a pair of leather woman shoes, from an environmental point of view, in order to determine in which ones an improvement would more efficiently reduce the associated environmental impact. Woman shoes have been chosen because of their relative importance in the Spanish industry.

Life Cycle Assessment has been chosen as the methodology to study the life cycle of the product from an environmental point of view. The goal was to point those steps in the footwear cycle – from animal care for the production of hides to waste management – which most contribute to the total environmental impact, in order to be able to guide further applications of the method and improvements of the process. Both economical and social aspects are excluded from the analysis, as well as risks and human labour.

The phases of the LCA considered here are the goal definition and scoping, the inventory and the impact assessment. The interpretation has been left for further studies. For impact assessment, we have used methods recommended in the Nordic Guidelines (LINDFORS et al., 1995) in some of the categories, and for the ones related with resources we have directly used the emission values, with no characterisation; research is still being performed on this matter. The categories used are:

1. Input related categories
   - Non-Renewable Prime Materials Depletion (NRPMD)
   - Water Consumption (WC)
   - Non-Renewable Energy Sources Depletion (NRESD)
2. Output related categories
   - Global Warming Potential (GWP)
   - Acidification Potential (AP)
   - Eutrophization (Nutrification) Potential (EP)
   - Human Toxicity Potential (HTP)
3. Pro memoria: Flows not followed up to system boundary
   - Inputs not followed to the "cradle": chemicals, insole, shoe patterns...
   - Outputs not followed to the "grave": radioactive wastes, blood, fleshings...

2 Main Decisions made During the Study

During the study, a number of critical decisions and hypotheses have had to be made in order to perform the LCA. We show them below for they could be of major importance in the final results.

2.1 Functional unit

The functional unit chosen had to keep relation with the function of the product studied ("to protect or cover the foot"; after PERDIJK et al., 1994), and therefore it had to be a time unit. We finally took "1000 hours of protection of the feet" as functional unit, for it is the best approximation to "the best functional unit" defined by PERDIJK (1994), which is "one year of standard use". We have calculated this number of hours by estimating the number of hours a lady will wear her shoes during a year. We assume a consumption rate of 3.7 pairs of shoes per year, taking into account that these shoes are worn 14 hours per day, 5 days per week, and 45 weeks per year.

2.2 System boundaries and allocation

When analysing leather production upstream in its life cycle we find some complications, notably:

- different types of leather are used in a shoe, mainly cow leather (for the outsole), bovine leather (for the upper material and/or the insole and stiffener), and goat leather (lining). Every one of these types has its own production system.
- hides (the prime materials for leather) are not the only products for cattle. Other co-products include, of course, edible meat, milk (in the case of dairy cattle), manure (used as fertiliser), bone (also used as fertiliser and to make "bone china"), blood (animal feed), tallow (soap production, oleochemical industry, etc.), ligaments/cartilage, etc...

The first point can be easily solved by extending the system to all the types of cattle raising (cows, beef, and goats), while the second one poses a problem of allocation. POSTLETHWAITE (1995) presents a very interesting discussion about this issue, for the case of tallow production. At this stage we have two extreme options:

1. Consider hides as the only product of cattle raising, for which all the environmental impacts associated with this phase must be attributed to leather production.
2. Hides are an unavoidable waste in the production of meat for which a use has been found, and so they are free of environmental burdens up to the slaughterhouse waste production.

These two extremes may seem to be unrealistic, although the second option could be an acceptable one in the case of dairy cattle (the weight of the hide would be very small compared with the weight of the other co-products, mainly milk), and the first one could be true in the case of furs (e.g.: mink furs) which are not treated in this study. We have opted to allocate burdens using economic criteria. The reason of this election is that the relative economic value of one co-product could be considered as the part of cause this co-product has had in the occurrence of the process; i.e. if the economic value we will obtain is the only reason to slaughter a calf (and there is no reason to think otherwise), then the part of this value directly obtained from the hide's sale is the part of the cause of the slaughter allocable to the hide. We have used a typical value of 7.69% as the relative economic value of hides. This datum has been taken from the Catalan industry, as it is a critical value which will greatly determine the overall impact of the phases upstream the slaughterhouse, and so it must be a foreground datum.

There is also an important decision in relation to boundary setting, as for cattle product life cycles where there are at least four starting points (POSTLETHWAITE, 1995):

- Grass
- Cattle
- Carcass
- Slaughterhouse Waste

If we considered option 2, then the Slaughterhouse waste would be our system boundary, but as we opted for an economic allocation, there is no reason not to bring the boundary to the top, at the Grass production, and this is the boundary we have finally worked with.

We must also note that complementary systems (production of plastics, rubber, chemical products used during the life cycle of the shoe – primarily in the tannery, but also during use –, metallic complements, etc.) have not been inventoried, because their contribution would be of poor relevance in this preliminary study. These systems should be included in future applications, for they could be important in some specific types of shoes (rubber sole shoes, etc.).

2.3 Inventory

The footwear life cycle stages are presented in **Figure 1**.

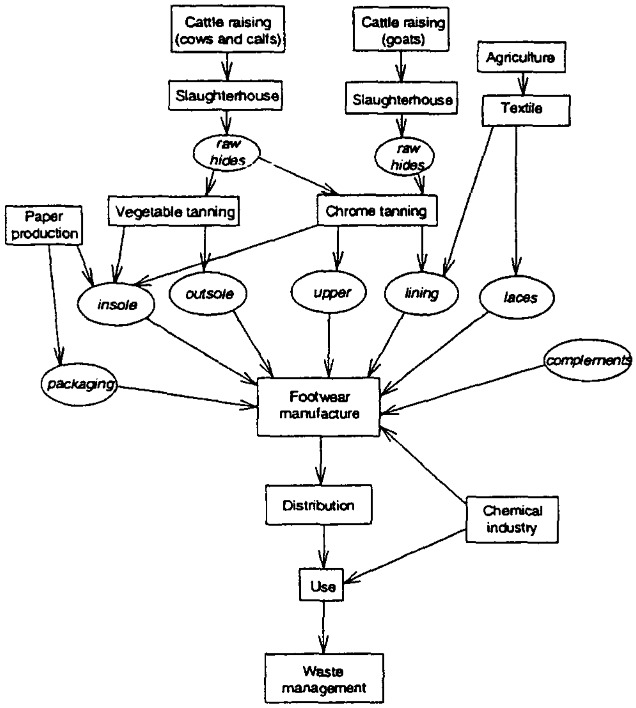

Fig. 1: Life Cycle process tree of footwear

2.3.1 Cattle raising

In this first phase of the life cycle, we have firstly assumed that the inventory profile would be the same in dairy cattle and in beef cattle. This could be an error source because dairy cattle usually live longer, producing a bigger amount of waste and emissions, and need a greater space for living: 2 head of cattle per hectare, while beef cattle present typical densities of 4 head per hectare (COLL BATLLORI, 1993). However, as we stated above, dairy cattle produce many more co-products than beef cattle, so the impact finally allocated to cow hides could be similar to that of calf hides.

On the other hand, data for goat raising was not available, and so we have not included it in the inventory. Nevertheless, this will not pose a very big error, because this kind of cattle raising does not have a large impact on the environment.

2.3.2 Slaughterhouse

We have worked with background data (with the exception of the allocation value, see above), assuming that cattle hides are salted, while goat hides are dried and leave the slaughterhouse with a moisture of 12%.

2.3.3 Tannery

The major difficulty found in this phase of the system is that there are plenty of similar processes doing the same function, and it is necessary to choose an ideal "standard tannery method". Thus, we have assumed some mechanical operations and inputs which may be different in another tannery. Anyway, these details will not vary the final result to a great degree.

Different information sources presented the data for nitrogen emissions in different parameters: N-NH_3, TKN, NH_3, dissolved proteins, etc... We have assumed that all the nitrogen emitted in this phase was in ammonia form, and have therefore converted all the data to N-NH_3.

In the case of salt, we must note that where we have found data corresponding to "Salinity", we have assumed that it is all NaCl, which is justified by the fact that it is the major type of salt used during the process.

2.3.4 Footwear manufacture

As in the later phase, emissions at the work place have not been included; potentially toxic substances emitted during footwear manufacture come mainly from the adhesives used, and include N-hexane, toluene and dichloromethane (concentrations above the TLV have been found for these substances in some factories: CTSS, 1985 and 1990).

2.4 Main scenario traits

2.4.1 Waste management

We have assumed that all the solid wastes produced during the life cycle of 1000 hours of feet protection are comparable with Urban Solid Waste (USW), and consequently follow the typical management for this kind of waste. This typical management in the area of the study is based in landfilling (95%), and incineration (5%) (DOMÈNECH & RIERADEVALL, 1996). We have not considered any management for radioactive waste which we have just quantified.
Apart from the shoes themselves and their packaging, solid wastes treated in this way have been: the buffing dust produced in the tannery, chrome shavings, hair, chrome leather trimmings and lime split and pelt trimmings. The rest of solid waste generated during the life cycle (fleshings, rawhide trimmings, etc...) are supposed to have application in other sectors (mainly animal feed).

2.4.2 Electricity production

The characteristics of electricity production are of major importance in an LCA, for they will broadly affect the environmental impacts assigned to energy-consuming steps. These will be minor if the production of electricity is based on renewable and clean technologies – such as wind power, solar, tidal, etc. –, whereas the impacts assigned can be very big if this production is based on non-renewable resources (as is the case in Spain and Catalonia). The figures of this production are represented in **Table 1**; we have used the Catalan figures in the Slaughterhouse and Tannery stages, and the Spanish ones for the rest of the stages.

2.4.3 Transport

This is another phase where many different hypotheses can be made. We have assumed all the trade was done between factories in Spain, not including importations nor exportations of final or intermediate products; this time, the option finally chosen could be a source of error, as it can represent a big difference to consider only road transports (in Spain or in the EC), or to consider overseas transport (exportations to USA, importation of tanned hides from North Africa, etc...) in ship containers. Again, the manifold possibilities make it difficult to choose a standard.

3 Results

The long lists of emissions and consumptions produced in the inventory phase is presented in **Table 2**. In this table, only the most important substances are given (those which contribute with more than 5% to any impact category), as the full list would otherwise be too large. In the impact assessment, the list has been reduced further to nine impact categories (classification) and then converted into a contribution to these impacts (characterisation). An overview of the relative contribution of the different stages to the different impact categories is presented in **Figure 2** (*p. 208*). Neither normalisation nor valuation have been performed with the data.

storage, and application form) that is done with them, for we are able to modify this management and thus the emissions (BATLLÓ, 1993); the control of ammonia emissions will be a critical point for improvement development. In the GWP, methane (CH_4) and carbon dioxide (CO_2) – mainly originated in rumen digestion and respiration – are also important sources of impact, although we can not modify this emissions unless we change the metabolism of ruminants. Energy-related emissions (SO_x and NO_x) associated to agriculture (mostly to the production of fertilisers) also play a significant role in the AP. A significant contribution to Human Toxicity is also generated at this stage, mainly due to energy related emissions (SO_x, NO_x, and HC).

In the tanning stage, the most important impact categories are those related to water and resource consumption. Nearly 50% of the non-renewable prime materials and 70% of the water (considering the actual data) consumed during the life cycle are used at this stage. Water consumption also implies a huge waste water production, which is mainly contaminated with nitrogenated organic matter, thus contributing to the EP (50% of the EP is produced at this stage). The tannery contribution to HTP is shared between energy-related emissions (mainly SO_x) and process-related emissions. These process-related emissions come from the tanning step, and correspond to chromium (Cr^{3+}) – for the mineral-tanned hides – and to phenols – for the vegetable tanning –, which come from the main tanning agents.

Table 1: Electricity production in Catalonia and the rest of Spain and Europe

Origin	Catalonia (%)[a]	Spain (%)[b]	Europe (%)[c]
Hydroelectric	14.02	18.8	15.2
Thermoelectric	81.26	81.2	84.1
- Nuclear	76.71	36.5	36.2
- Coal	2.81	34.9	28.8
- Fuel-Oil (NG)[d]	1.74	9.8	19.1
Rest	4.72		0.7
- Co-generation	4.35		?
- Incineration	0.37		?

[b] Source: MIE (Energy and Industry Ministry, Spain), 1994
[a] Source: ICAEN (Catalan Institute for Energy), 1993
[c] Source KNOEPFEL, 1994 (1990 UCPTE electricity mix)
[d] nowadays, all the fuel-oil thermoelectric plants have been adapted to work with Natural Gas, and normally work with it because of its lower price

The agricultural part of the life cycle of footwear is mostly important with respect to what we have called "ecological impacts": Global Warming, Acidification, and Eutrophication. This part of the cycle contributes 35-45% to these impact categories. It must be pointed out that this represents only the 7.69% of the real impact of agriculture (because of the allocation factor, see above), which is actually much larger. This exceptional contribution comes from the emissions related with the slurry and excreta production. On the one hand, ammonia (NH_3) coming from this source, is responsible of 36-40% of the Eutrophication and Acidification Potentials generated during the whole life cycle of the functional unit. On the other hand, nitrous oxide (N_2O) produced in the denitrification of the excreta generates more than 50% of the GWP for the cattle raising phase which represents about 25% of the GWP generated during the whole life cycle of footwear. It is important to point out that these slurry and excreta related emissions depend on the kind of management (collection,

With regard to the shoe production part, we must point out that this was the one that seemed to have a lesser environmental impact, and it has turned to be almost the most impacting phase. It is a dominant contributor to the energy-related impacts: NRESD, HTP, and AP. This is due to its important electricity consumption and to the origin of this electricity production. GWP is also important at this stage, due to energy-related CO_2 emissions. An energy-related *pro memoria* impact category is that of Radioactive Waste generation, and it is mainly generated at this stage.

The waste management step is only relevant for the GWP, as it is based in landfilling without energy recovery. If a bigger incineration proportion was used, the HTP and the AP would probably have been more important.

Table 2: Summary of the inventory results of the life cycle of 1000 hours of leather lady footwear

Substance	Unit	Cattle raising	Slaughter-house	Tannery	Footwear manufact.	Waste manag.	Transp.	Total
Known Inputs from Technosphere								
Materials								
NaCl	g	0.00E+00	5.54E+01	8.50E+00	0.00E+00	0.00E+00	0.00E+00	6.39E+01
$Ca(OH)_2$	g	0.00E+00	0.00E+00	1.62E+01	6.18E-01	0.00E+00	0.00E+00	1.68E+01
$Cr_2(SO_4)_3$	g	0.00E+00	0.00E+00	3.96E+00	0.00E+00	0.00E+00	0.00E+00	3.96E+00
Oils and Tannins	g	0.00E+00	0.00E+00	2.71E+01	0.00E+00	0.00E+00	0.00E+00	2.71E+01
Syntans	g	0.00E+00	0.00E+00	1.30E+01	0.00E+00	0.00E+00	0.00E+00	1.30E+01
Waste wood	g	0.00E+00	0.00E+00	0.00E+00	3.02E+01	0.00E+00	0.00E+00	3.02E+01
Energy								
Electricity	MJ	1.85E-02	1.24E-02	3.34E-01	4.44E+00	0.00E+00	0.00E+00	4.80E+00
Fossil Fuel	MJ	3.02E-01	1.26E-02	1.50E+00	2.06E-01	0.00E+00	5.15E-01	2.54E+00
Known Inputs from Nature								
Water	g	n.d	5.42E+02	8.18E+03	3.39E+03	0.00E+00	0.00E+00	1.21E+04
Outputs to Technosphere (Wastes and Products)								
NaCl (solid)	g	0.00E+00	1.14E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E+02
Tanned trimmings	g	0.00E+00	0.00E+00	5.75E+00	1.72E+00	0.00E+00	0.00E+00	7.47E+00
Entrails	g	0.00E+00	3.87E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.87E+01
Fleshings	g	0.00E+00	4.86E+01	2.07E+01	0.00E+00	0.00E+00	0.00E+00	6.93E+01
Salted split	g	0.00E+00	0.00E+00	2.59E+01	0.00E+00	0.00E+00	0.00E+00	2.59E+01
Tanned split	g	0.00E+00	0.00E+00	0.00E+00	2.38E-01	0.00E+00	0.00E+00	2.38E-01
Hair	g	0.00E+00	0.00E+00	1.31E+01	0.00E+00	0.00E+00	0.00E+00	1.31E+01
Shavings	g	0.00E+00	0.00E+00	1.48E+01	0.00E+00	0.00E+00	0.00E+00	1.48E+01
Buffing dust	g	0.00E+00	0.00E+00	6.88E-01	0.00E+00	0.00E+00	0.00E+00	6.88E-01
Packaging	g	0.00E+00	0.00E+00	0.00E+00	7.74E+01	0.00E+00	0.00E+00	7.74E+01
Shoes	g	0.00E+00	0.00E+00	0.00E+00	9.78E+01	0.00E+00	0.00E+00	9.78E+01
Known Emissions to Nature								
Air								
NO_x	g	1.84E-01	7.91E-03	2.50E-01	1.03E-01	1.21E-02	6.72E-01	1.23E+00
SO_x	g	1.87E-01	2.87E-03	3.37E-01	2.18E+00	3.32E-03	7.94E-02	2.79E+00
CO_2	g	1.94E+02	1.99E+00	1.32E+02	6.54E+02	3.94E+01	4.05E+01	1.06E+03
CH_4	g	8.91E+00	3.13E-03	0.00E+00	0.00E+00	1.69E+01	0.00E+00	2.58E+01
N_2O	g	2.98E+00	9.70E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.98E+00
NH_3 (gas)	g	2.31E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.31E+00
Hydrocarbons	g	1.31E-01	7.14E-04	2.71E-02	2.82E-03	3.46E-03	1.07E-01	2.73E-01
Water								
NaCl	g	0.00E+00	7.07E+01	3.18E+01	0.00E+00	1.90E-01	0.00E+00	1.03E+02
Chrome (III)	g	0.00E+00	0.00E+00	3.38E-01	0.00E+00	0.00E+00	0.00E+00	3.38E-01
Suspended solids	g	8.04E-01	1.17E+00	1.34E+01	1.58E-01	6.14E-03	0.00E+00	1.55E+01
COD	g	7.45E-02	2.40E+00	2.57E+01	1.26E+00	3.16E-01	6.03E-04	2.97E+01
N-NH_3 (aq)	g	1.71E-03	1.81E-01	1.59E+00	0.00E+00	1.23E-02	0.00E+00	1.79E+00
Soil								
Nuclear wastes	g	2.44E-02	9.50E-03	2.56E-01	1.59E+00	0.00E+00	0.00E+00	1.88E+00

Finally, we find that the transport phase yields an insignificant contribution to the most impact categories, being noticeable only in those where NO_x are important (AP, EP, HTP), and, of course, in NRESD.

4 Improvement Proposals

- In the tanning phase, further research must be done in the sense of reducing the consumption of tanning agents (chrome, vegetal tannins and syntanes). A complete waste water treatment must also be assured.
- For the shoe manufacture stage, the best advice is to reduce electricity consumption (improving machinery efficiency), and press the electrical companies to base their production on cleaner energies (the big impact of this stage is due to the use of fossil and fissile fuels in electricity production).
- With a view to future studies, it will be important to close the life cycle by including all the inputs and outputs which have not been followed to their boundaries with nature (*Pro Memoria* impact categories). In this sense, research is already being performed, developing this and other studies. Moreover, data quality is being improved, searching for foreground data for all the main flow stages.

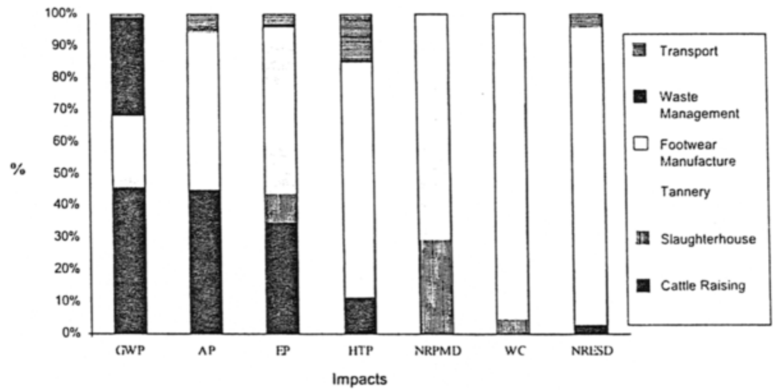

Fig. 2: Environmental profile of footwear: share of the different stages

5 Conclusions

- The agricultural part of the life cycle is an important contributor to the ecological impacts, which means that boundary setting will be of capital importance for the final results. We should keep in mind that only 7.69% of the total impacts of this part have been allotted to the functional unit, and the choice of this allocation factor will be most affecting the final profile: it can range from 0 to 100%, depending on the criteria used (in the preliminary study, economic criteria).
- The scenario main traits, such as the electricity production and the waste management profiles, will be of major importance to the final result. The transports being used will also be relevant.
- Thanks to the LCA, we have been able to detect the important indirect impacts associated to the shoe manufacture stage, which seemed of minor importance before this preliminary study. These indirect impacts are generated mainly during electricity production.
- The phase that seemed to be most problematic – the Tannery – has come to be important mostly to water-related impacts (WC, EP, and HTP because of its water contaminants). It is interesting to point out this perception distortion, which probably arises from the thought of electricity as being a clean form of energy, and from the historical importance of fluvial contamination in the environmental arousal lived in the industrialised countries since the 1960s (in Catalonia and Spain, where water is a scarce resource, this distortion may even be larger).

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