The Analysis of Carbon Footprint of Biodegradability in Leather during Products Manufacture

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Abstract

A carbon footprint is a measure of the impact of human activities on earth and in particular on the environment; more specifically it relates to climate change and to the total amount of greenhouse gases produced, measured in units of carbon dioxide emitted. Effort of individuals in the leather sector in minimizing the carbon footprint is vital to save our planet. The present study evaluates the micro flora that initiates the biodegradation process of various leather products and establishes the degradation pathway of the leather products. The study of the carbon footprint of leather and its products using life cycle impact assessment (LCIA) technique was carried out. The study on the impact of conventional leather and its products in the manufacturing phase without considering their usage and disposal phases (cradle to gate stage) is analyzed initially. This is followed by analysis on carbon footprint of leather products at their usage and disposal phases (cradle to grave stage). The results from both the methods "cradle to gate" and "cradle to grave stage" are compared. The impact of leather and its products and waste generated in terms of their carbon footprint potential is very high if no usage and disposal options were provided. A higher percentage of reuse is preferred to recycling and disposing to landfill. The higher percentage of reuse could significantly scale down the carbon footprint. Once the leather reaches "no longer be reused", they must be forwarded to recycling options, rather than being disposed to landfill. Consumer's perceptions and behaviors in connection with the respective government's policies in promoting & facilitating recycling systems could be critical in reducing the carbon footprint of leather.

Keywords: Leather and Leather Products, Life cycle impact assessment, Cradle to gate, Cradle to grave stage, Carbon Footprint, Reuse and Recycle

1. Introduction

Leather making is several centuries old technology, which attracts people even today of the versatile properties it possesses over other synthetic materials. However, the ironical part of it is that even after their lifetime, these used leathers are dumped or thrown away as municipal wastes, which add to solid waste management concern. The average leather thrown as wastes world-wide is around 0.6 million tons per year. Production, usage and consumption of any leather product pose a threat to carbon footprint. Leather and leather products, a symbol of the throw-away society, exacerbate the seriousness of the human carbon footprint. There are two types of carbon footprints - primary and secondary. Primary footprints, which are under our direct control, are the result of direct emissions of CO_2 from the burning of fossil fuels including domestic energy consumption and transportation. The secondary footprints are related to the indirect CO_2 emissions from the whole life cycle of the products human beings use - those associated with their manufacture and eventual breakdown (Hertwich and Peters,

2009). Hence, the study of entire life cycle phase of different types of leather and leather products from the manufacturing stage to the disposal stage is essential.

Once the product is decided to be disposed of, there may be three possibilities: reuse of the product for the same or for different purposes; recycle the product; dispose it off to landfill. In landfills, treatment of leather solid wastes is carried out by mixing the biodegradable organic wastes with soil under appropriate condition. Human dimensions in consumer behaviour rule the decision of a product's disposal phase and consequently the environmental impact. Apart from human dimensions, governmental policies also assume greater significance in the environmental impact. There are many dimensions of environmental impact caused by leather products; of which global environmental change is one of the prime concerns and this is discussed in detail in this article. Out of all the phases of a product's life cycle, the disposal phase is very critically related to the environmental issues and is solely decided by the consumer's attitude and the governmental policies to facilitate recycling of the product.

All the leather products have an impact on the planet and quantifying the impact is crucial to reduce it. Among many techniques to study the eco-impact of a product, life cycle assessment (LCA) is one of the most widely used and popular ones. LCA examines the product from its initial (cradle stage) to final stage (grave stage), covers its entire life cycle, and also evaluates the product in terms of the environmental impact during its life time. A life cycle assessment (LCA) is an analytical tool which can help to understand the environmental impacts from the acquisition of raw materials to final disposal (SETAC, 1993). In accordance with the definition given by The Society of Environmental Toxicology and Chemistry (SETAC), LCA is an iterative process for evaluating the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment. LCA can also be used to assess the impact of those energy and materials used and released to the environment and can help to identify and evaluate opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution, use, reuse, maintenance, recycling and final disposal (Fava et al., 1991). According to ISO 14040, an LCA study essentially consists of four interconnected steps/phases (ISO 14040, 2006). Leather Products, as an example of unnecessary waste, require LCA to assess the environmental impact in terms of their carbon footprint. Research into the influence of the consumer's attitude and governmental policies on this is minimal. The focus on the gaps and the impact of different types of leather products on the human carbon footprint and also how the consumer and policy dimensions influence it is presented.

Consumer behaviour and governmental policies play an important role in the disposal stage of leather products. Notwithstanding the capability of certain types of footwear and leather products to be recycled and reused, it is in the hands of customers to reuse a leather product until it can be discarded or recycled, i.e. to reuse the leather products many times till they can be disposed of and to keep them in recycling bins provided by the government, rather than dispose to landfill, which is detrimental to the environment as far as eco-impact is concerned. It is the responsibility of government to provide more recycling options and viable policies to set things in place in terms of recycling. Frequent promotion of recycling options by government and the behaviour of the consumer to reuse the footwear till they can be discarded is crucial in reducing the carbon footprint.

To determine the attitude of users of leather products and to understand the disposal scenarios, a questionnaire survey was conducted in Chennai, India among different user groups of leather products. The aim of the survey lies in comprehending how different user groups use and dispose leather products. Usage and disposal behaviors are defined as how many times people reuse different leather products, what percentage of leather products can be recycled/sent to landfill with the existing possibilities of recycling and what percentage of leather products people perceive can be reused/ recycled/sent to landfill. Also this survey intends to comprehend the existing recycling options provided by the government and the willingness of people to support the government's policies further to improve the possibilities of recycling.

This article reports a study of the carbon footprint of various types of leather products (footwear, hand bags and small leather goods) using life cycle impact assessment (LCIA) technique in two stages. The first stage (baseline study), comprises the study of the impact of different types of leather products in the manufacturing phase, without considering their usage and disposal phases (cradle to gate stage). The LCIA was accomplished by the IPCC 2007 method, developed by the Inter Panel on Climate Change in SIMAPRO 7.2. The GWP (Global Warming Potential) values calculated by the IPCC 2007 method for 100 years were considered as a directive to compare the carbon footprint made by the different types of leather products under consideration. The next stage was the study of the carbon footprint of these leather products including their usage and disposal phases (cradle to grave stage) and the results derived were compared with the results derived from the baseline study, which is the major focus of this research work. The values for usage and end-of-life phases were obtained from the survey questionnaire performed amongst different user groups of leather products in Chennai, India. The micro flora that initiates the degradation process of the leather products were identified and used for the biodegradation process. The results establish that the biodegradation of leather products is initiated by fungal species followed by bacterial degradation in both aerobic and anaerobic conditions. The degradation pathway of the leather products was elucidated. Organic composition of these leather products was also established.

2. Materials and Methodology

2.1. Study of Impact of Various Leather Products on Carbon Footprint

This paper revolves around the study of global climate change due to the production, usage and disposal phases of leather products in Chennai, India. The initial step of this study is the collection of secondary data for Life cycle inventory (LCI) for various types of leather products under consideration in this present study. The basic data was converted to the functional unit assumed for India. The data arising from this study included the total energy consumed by a leather product to get it manufactured, where total energy represents process and feedstock energy and the quantity of pollutants emitted to the atmosphere during the manufacturing process. The goal of the study under discussion is to analyse the carbon footprint of these leather products in India with the available data from a secondary source (cradle to gate) in the first step and in the second step, to study the effect of consumer's attitude and policy dimensions in the carbon footprint of these leather products (cradle to grave). The scope of this study includes the comparative investigation of carbon footprint of leather footwear, leather bags and small leather goods in both cradle to gate and grave states from the data sources mentioned in Table 1 for Chennai, India. The cradle to gate assessment

phase of this study considers impacts at each life cycle stage of above leather products under consideration, which includes extraction/processing or growing/harvesting of resources; the process of manufacturing; transport from the manufacturer to the wholesaler/retailer as indicated in the secondary data sources from which the cradle to gate data were referred. For cradle to grave stage, public opinion from Chennai, India on percentage of reuse, recycle and disposal to landfill were considered to build the end-of-life scenarios in addition to the above mentioned areas in cradle to gate stage. To derive the functional unit which suits better for the three territories considered, the consumption statistics of leather products was referred from the literature pertaining to Chennai, India. Among the above leather products under consideration in this present study, statistics were readily available on the consumption of leather footwear. Leather disposed as municipal solid waste in Indian metropolitan cities was considered. The total footwear usage in India is 2 pairs per capita, in which leather concedes above 20% total footwear usage. Apart from this, leather is also used in the form of handbags, wallets, belts and other small goods. According to a study reported in MSW generation in India, 2 million leather handbags and around 6-7 million small leather goods are discarded after usage. The average leather thrown as wastes in Indian cities is around 34190 ton per year. But the efficiency of collecting wastes from cities is only around 10%. Hence on an average, 2750 ton of leather footwear, 667 ton of leather handbags and about 2 ton of small leather goods are discarded as municipal solid wastes. Chennai produces an average of around 157 tons/day of leather wastes. These wastes are disposed in landfill sites. As per currently available literature survey on statistics on leather products consumption, an average Indian, 2 footwear, 1 leather hand bag and 2 small leather goods are consumed and needed to fulfill this study's functional unit.

Table 1: Life Cycle Inventory Data of Footwear, Hand Bags and Small Leather Goods in India

Products	Leather Consumption (Sq.Ft)	Weight/ Product	Products/ year	Green house gas emissions (CO_2-eq.)	Primary energy
Footwear	1	1660 g	2	1.72 Kg	108 MJ
Hand bag	4	1000 g	1	0.86 Kg	28 MJ
Small leather goods	1	152 g	2	824 g	50.6 MJ

The end-of-life values were derived from a survey conducted. Results from the survey were used in Life cycle impact calculations in the usage and disposal states were compared with the life cycle stage without usage and disposal criteria.

2.2. Life Cycle Inventory (LCI) of Leather Products

The energy and pollutants data for the functional unit considered for different leather products under consideration in this present study was taken from the values presented in Table 1.

2.3. Survey Results of Usage and Disposal Behaviour of Leather Products

The major focus of this study is to investigate the influence of human behaviour and governmental policies on the carbon footprint of various types of leather products. A survey

was conducted among students, home makers and employed professionals in various professions of different age groups, who are the users of leather products and who have the knowledge on the usage and disposal behaviour of the same in Chennai, India. This survey was mainly aimed at understanding the consumer's perception of reuse, recycle and disposal to landfill, recycling possibilities with the existing government provisions/policies for recycling, willingness to support recycling systems/policies to reduce the percentage of landfill. The major results extracted from this survey are presented in Table 2. From the survey results, usage and end-of-life scenario values are deduced to the following categories, which can be seen from Table 2.

2.4 Biodegradation of Leather Products

The leathers products were placed in a moist tray at 28-38^{o}C and 65-75% RH for initiating biodegradation process. The fungal and bacterial organisms were identified. Three different batch experiments were carried out using (i) Isolated fungal spores (ii) Isolated bacterial species and (iii) Serial inoculums of fungal spores for 15 days followed by bacterial isolates. The biodegradation of the leather products were analyzed by estimating the amount of hydroxyproline released in the solution after hydrolysis of these leathers by microorganisms. The leather products (~0.5 g) sterilized in UV chamber for about 6 h, was taken in 1000 mL screw capped glass bottles filled with 750 mL of demineralized water and sterilized further for 2 h. The pH of all the experimental solution during the degradation process was maintained at 7. The %biodegradation was measured by estimating the amount of hydroxyproline released in the solution after hydrolysis of collagen on biodegradation of leather by mixed microbial culture.

Table 2: Values for usage and disposal options from survey results in Chennai, India

Percentage	Leather Footwear (%)	Leather Handbags (%)	Small Leather Goods (%)
Recycle	30	33	25
Reuse	39	45	72
Sent to landfill	31	22	3

3. Materials and Methods

3.1. Biodegradation of Leather Products

Biodegradation of the leather products was studied by isolation and identification of micro flora from the biodegradation process of these leather products in closed environmental conditions. The products were allowed to degrade at ambient conditions. Collagen present in finished leathers is a proteinaceous material and hence susceptible to biodegradation, once the tannin linkage is broken. Fungal and bacterial species were isolated and identified during the natural biodegradation of the leather products. The biochemical characterization of the identified fungal and bacterial species was carried out. These isolated bacterial and fungal species were used for the biodegradation process of finished leathers. The predominant fungal isolates were *Penicillium*, *Aspergillus flavus*, *Aspergillus fumigatus*, *Aspergillus niger* and

Mucor and the predominant bacterial isolates were *Bacillus subtilis, Pseudomonas aueroginosa, Staphylococcus aureus, E. coli, Micrococcus roseus, Micrococcus luteus, and Proteus vulgaris.* The %degree of biodegradation for all the leather products was analyzed by estimating the amount of hydroxyproline released in the solution after hydrolysis of the culture bath by various fungal, bacterial and a combination of both species. From the biodegradation profile of leather products, it was found that biodegradation of all the leathers was initiated by fungal species. The hydroxyproline released in solution was high for biodegradation with fungal species compared to biodegradation with bacterial species. Biodegradation of leathers with bacterial species took longer duration than with the fungal species in the initial stages of degradation, but reversed once the leather matrix was completely disintegrated. However, degradation by individual bacterial or fungal species was very low compared to use of both the species. Hence, it can be concluded that biodegradation of leather products is initiated by fungal attack followed by bacterial degradation.

3.2. Life Cycle Assessment Analysis and Results without Usage and Disposal Options

In this section, energy and pollutants data were processed by using one of the commercial LCA software SIMAPRO 7.2. The IPCC 2007 method (IPCC method) for LCIA was employed to assess the carbon footprint, which is expressed in terms of Global Warming Potential of 20 years, 100 and 500 years. LCIA modelling was done in three phases as per the functional unit assumption. Results of these analyses can be seen from Fig. 1 for Chennai, India. For the functional unit assumed, all the three leather products were considered for this study. Leather footwear has very high global warming potential for 20, 100 and 500 years compared to leather bags and small leather goods. Life cycle inventory data presented in Tables 1 and 2 clearly enumerate these results and indicate that small leather goods occupy better position in this comparative analysis. For the functional unit assumed, small leather goods consume lesser energy and fewer amounts of materials and also they emit lesser green house gas emissions in the production phase of leather footwear. According to the first part of this study, leather footwear seem to be very much detrimental to the environment in terms of more amounts of carbon emissions compared to its counterparts as per the secondary data source references. However, this can be further studied with the inclusion of the positive effect of the biodegradable products used, from where the footwear is primarily being made. This part certainly needs to be included in the carbon footprint modelling part.

3.3. Life Cycle Assessment Analysis and Results with Usage and Disposal Options

The results of the survey findings tabulated in Table 2 were employed to investigate the impact of all the leather products on carbon footprint in terms of global warming potential (GWP) and they were compared with the results obtained from without usage and disposal options (baseline study). The GWP results of the same for Chennai, India are described in Fig. 1. For better clarity and ease of comparison, only the results from 100 years are considered for this discussion. The data tabulated in Fig. 1 permit a comparative investigation between, without and with usage and disposal options according to the existing consumer behaviour and government policies in Chennai, India. In all the cases, the carbon footprint values are less than those of the without usage and disposal options. When the comparison is made between the options from all the leather products under discussion here, one can see that for leather footwear, the carbon footprint values is more compared to other products. This is due to the fact that reuse option is most selected by Indians for leather handbags and small leather goods. The influence of reuse option on reducing carbon footprint values is very much

pertinent in all the cases under discussion here. While looking at the results in Table 1 for small leather goods, we can notice that a 8% difference in percentage of reuse results in 2 Kg CO_2 equivalents of global warming potential from leather sector (around 20% of GWP) in Fig. 1 and Fig. 2, which showcases the importance of reuse option. It is a well known fact that the more reuse of leather products, lesser will be the environmental impact. However, the magnitude of importance needs to be revealed, which will portray the real scenario to the consumers of leather products. Even 1% of more reuse of leather products will make a world of difference in terms of environmental impact, which has to be unveiled to public, if one wants them to be educated in terms of environmental improvement. If we expect the public to appreciate the environmental education in terms of their contribution to reduce environmental impact, they should be aware of the real values of environmental impact. Based on the above results and discussions, one important point to be noted here is, if any product is not reused till the end of its life, the concerns about environmental impact are huge. On the other hand if any product is not recycled and sent to landfill more, the eco-impact concerns are more acute than the manufacturing and usage state, which can be understood from the results of this research work. So, usage and disposal of leather products assumes greater significance in minimizing the carbon footprint. If policies of these governments were reconsidered and recycling systems are encouraged and if they are in their appropriate places, percentage of recycling options will be increased and it is beyond anybody's doubt that the impact of global climatic change will come down enormously. Though governmental policies to promote recycling can be seen all around the globe, still they need to be up to the mark; thereby every individual goes for it. The emphasis on interpretation phase of this analysis is not on concluding which one leather product is much better. Actually the conclusion needs to be drawn on how to reduce the impacts caused by carbon footprint by all variety of leather and leather products. One of the possible ways to decipher this is by means of finding ways to reduce, reuse and recycle. In fact, many retail stores have started utilizing this philosophy of reducing, recycling and reusing the leather products. Building up public awareness and motivation to reduce, reuse and recycle all these leather products will definitely help to resolve the environmental problems to a greater magnitude.

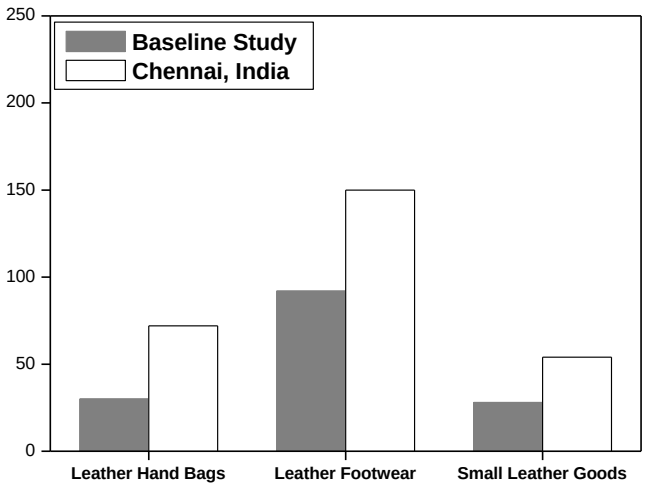

Fig. 1. Carbon Footprint Results of Leather Products without Usage and Disposal Options in India

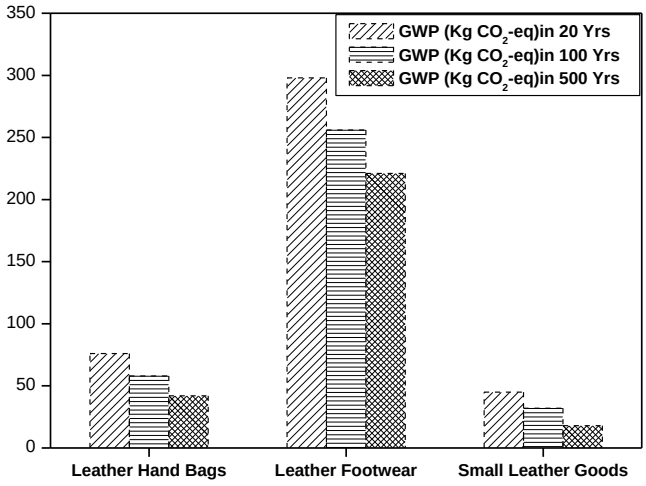

Fig. 2. Carbon Footprint Results of Leather Products with Usage and Disposal Options in India

4. Conclusions

This research article encompasses the study of carbon footprint of different types of leather products in both cradle to gate and cradle to grave stages in Chennai, India. Among different phases of a product's life cycle, disposal phase assumes greater significance as far as the environmental impact on carbon footprint is concerned. The peculiar part of this phase is that end-of-life scenarios are mostly decided by consumer behaviour and governmental policies. In this research paper, an exploratory study was performed to analyse the impact of various leather products on carbon footprint by using secondary data for LCI to manufacturing phase. In this stage, reusable leather footwear seem to be environmental friendly compared to the conventional plastic and other non-biodegradable footwear for the functional unit assumed for this comparative study. As far as the end-of-life phase is concerned, it lies mostly in the hands of the public. Also it is vitally important to use real values rather than assumptions, which can be obtained only from the actual users. Hence the inputs from public opinion were employed to deduce the values for end-of-life scenarios.

In the first stage of LCA modelling without disposal options, according to the LCI data and the software used for this study, which also has certain hypothesis and assumptions, biodegradable leather footwear are found to be better in terms of carbon footprint compared to its counterparts. However, this stage of conclusion depends solely upon the secondary data and the LCA software employed for the study. Public opinion was used to model the usage and disposal values of LCA, where the GWP values of all footwear were less in all cases. It was found in all of the cases under study that the more the option of reuse is chosen, the lower the environmental impact. In one of the cases in this study, it was found that even a 5% increase in reuse option selected, around 20% of carbon footprint will be saved.

Hence, the key here is that consumers must reuse the bags till they can be discarded. Once they decide to discard, the other best option would to be sending the bag to recycling rather than disposing it off to landfill. The production process of the various leather footwear considered in this study is a long chain and the amount of carbon footprint of the same could

be different in today's scenario when compared to the results presented in this study, derived from second-hand data sources. It should also be noted that the number of times each type of footwear can be reused and potential of each type of footwear to be recycled with their consequent environmental implications also would be different from each other. The consumers' behaviour and governmental policies are pivotal in terms of encouraging people to go for reusable bags and promote more recycling systems to scale down the environmental impacts made by any type of leather footwear.

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