CARBON FOOTPRINT OF CRUST LEATHER PRODUCED IN BANGLADESH

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CARBON FOOTPRINT OF CRUST LEATHER PRODUCED IN BANGLADESH

A thesis
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It is hereby declared that this thesis has been performed by the author under the supervision of Dr. Tanvir Ahmed, Assistant Professor of the department of civil engineering, BUET. Neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

31 January, 2015

Zia Uddin Md. Chowdhury

DEDICATED

TO

MY BELOVED FAMILY MEMBERS

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LIST OF ABBREVIATIONS

Glossary and Abbreviations

CF	Carbon Footprint
CF-PCR	Carbon footprint product category rules
CO_{2e}	Carbon dioxide equivalent
DIS	Draft International Standard
FAO	Food and Agriculture Organization
GHG	Green House Gasses
GWP	Global Warming Potential
IEA	International Energy Agency
ILCD	International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
IPP	Integrated Pollution Prevention
IPP	Integrated Product Policy
ISO	International Standard Organization
LCA	Life Cycle Analysis or Assessment
LCI	Life Cycle Inventory Analysis
LCIA	Life Cycle Impact Assessment
PCF	Product Carbon Footprint
PCR	Product Category Rules
UNEP	United Nations Environment Program
UNIDO	United Nations Industrial Development Organizations
WBCSD	World Business Council for Sustainable Development

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ABSTRACT

The increased awareness of the importance of environmental protection and assessment of the GHGS emission, and the possible impacts associated with products both manufactured and consumed, has led to the development of life cycle assessment (LCA) methods to better understand and address impacts which assists in identifying opportunities to improve the environmental performance of products at various points in their life cycle. A representative leather tannery industry in Bangladesh has been studied from an environmental point of view. Life Cycle Analysis (LCA) methodology from cradle to gate has been used for the quantification and evaluation of the impacts of two representative leather articles namely full-chrome and chrome retanned crust leather production systems as a basis to analyze, compare and propose further improvement actions. The functional unit chosen is 1 square meter crust leather. The effects of the resource use and emissions generated are grouped and quantified into a limited number of midpoint impact categories (human toxicity, respiratory inorganics, respiratory organics, ionizing radiation, ozone layer depletion, aquatic ecotoxicity, terrestrial ecotoxicity, aquatic acidification, aquatic eutrophication, terrestrial acidification/nitrification, land occupation, global warming, nonrenewable energy consumption, mineral extraction) and these are finally grouped into four endpoint damage categories (human health, ecosystem quality, climate change, and resources). To characterize and assess the effects of the environmental burdens identified in the inventory, impact assessment was conducted based on impact 2002+methodology. In doing so, life cycle inventory data were linked to the midpoint categories. In few cases, like electricity, transportation, packaging energy from generator and diesel combusted in boiler processes have been taken as proxy processes. The obvious advantage of using proxies is that they facilitate the impact estimation when a full assessment would be too costly. The use of proxy data sets is the quickest and easiest solution for bridging data gaps. The results indicate that significant environmental impacts were caused during the tanning as well as the transportation for raw material, imported chemicals and delivery of crust leather; electricity production and packaging materials required in the life cycle. Damages to human health, ecosystem quality are mainly produced by the chrome tanning, acid wash, Rechroming and neutralization processes. Transport and electricity also contributed moderately. The control and reduction of chromium and ammonia emissions are the critical points to be considered to improve the environmental performance of the process. Technologies available for improved management of chromium tanning were proposed. The carbon footprint of the two systems found to be 0.721 and 0.731 Kg CO_2 eq per m^2 of full-chrome and chrome retanned crust leather respectively. Environmental hotspots found for production processes

were tanning, rechroming, neutralization, deliming-bating and acidwash. Supply chain hotspots are transport for raw hides and chemicals, electricity. Slaughtering, the cradle considered for carbon footprint analysis of leather contributed minor amount to the impact categories. Production processes mainly contributed to non-carcinogens, aquatic ecotoxicity, aquatic acidification and aquatic eutrophication midpoint categories which finally contributed much to damage categories human health and ecosystem quality. Supply chain processes mainly contributed to midpoint categories global warming, carcinogens, ionizing radiation, ozone layer depletion, terrestrial ecotoxicity, terrestrial acidification/nutrification, respiratory organics, respiratory inorganics, land occupation, mineral extraction and non-renewable energy which finally contributed much to damage categories climate change, resources and human health. Full-chrome crust leather has 5 times higher impact on aquatic ecotoxicity, 4.53 times higher on non-carcinogens and 2.53 times higher on ecosystem quality. In addition, aquatic acidification of full-chrome system is greater than chrome retanned system but chrome retanned crust leather has marginally higher value of aquatic eutrophication. Comparing all impact categories, full-chrome crust leather had higher environmental burden than chrome retanned crust leather.

CHAPTER 1 INTRODUCTION

1.1 Introduction

Tanning is the process of transforming the animal skin (a natural renewable resource) to leather (Rivela et al. 2004). Leather is an intermediate industrial product with numerous applications in downstream sectors. It can be cut and assembled into shoes, clothing, leather goods, furniture and many other items of daily use. The raw material in the production of leather is a byproduct of the meat industry. Tanners recover the hides and skins from slaughterhouses and transform them into a stable material that can be used in the manufacture of a wide range of products (Joseph & Nithya 2009). In 2011, over 6.7 million tons of raw hides and skins of the Bovine, Sheep and Goats have been produced (FAO, 2012).The increasing requirement of leather and its related products led to a global output that has risen by about 55% over the past 30 yr. (Ram et al. 1999). Its major expansion has taken place in developing and new industrialized countries rather than in other developed economies where solid waste and wastewater treatments are not state of the art (Raghava Rao et al. 2003). In the recent years there has been a large shift of leather industries from industrialized to developing countries like Bangladesh, India prompted by stringent environmental regulations in the former (Joseph & Nithya 2009).The leather tanning process is composed of several batch stages associated with the consumption of large amounts of freshwater as well as the generation of liquid and solid wastes. Although tanning can be performed according to different procedures, most of the leather is obtained with chromium salts as the tanning agent. The wastewaters are characterized by significant organic load and remarkably high concentrations of inorganic compounds such as chromium, chloride, ammonia, sulfide, and sulfate (Tünay 1995) (Ates et al. 1997). Leather processing produces chromium-bearing solid wastes in variable proportions (Rivela et al. 2004). This poses a challenge to the future sustainability of the leather industry with a growing number and layers of non-tariff barriers, including environmental considerations and eco-criteria emanating from major export markets. It is often suggested that the developing countries can take advantage of the increasing environmental concerns in developed countries by undertaking the production and export of environmentally friendly goods (Joseph & Nithya 2009).

The increasing consciousness for a cleaner environment demands immediate measures to control the pollution proceeding from tanneries (Ram et al. 1999). The main actions to reduce water consumption and solid waste generation are based on the efficient usage of raw materials and energy, optimal chemical utilization, recovery and recycling of waste, and substitution of harmful substances (Raghava Rao et al. 2003) (Kabdaçh et al. 1999) (Tünay et al. 1999). A useful tool to evaluate the environmental burdens associated with a product, process or activity is life cycle analysis or assessment (LCA). The objectives of this environmental management tool are the identification and quantification of the input and output flows of the process: energy and materials used and wastes released into the environment (Consoli et al. 1993). LCA techniques have emerged in the last 30 years and are now well established as an effective tool to measure the impact of a product or process on the environment in an effort to reduce the environmental burdens (Jiménez-González & Overcash 2000).The application of LCA in process selection, design, and optimization is gaining wider acceptance and methodological development (Clift 1997) (Clift 1998) (Azapagic 1999). Leather-related products such as footwear have been evaluated under LCA perspective (Milà et al. 1998) (Canals et al. 2002). The tanning process turned out to be the most problematic stage, although a more profound study is necessary to quantify the associated impacts (Rivela et al. 2004). In this work, LCA has been chosen as the methodology to study the environmental performance of the tanning process in a developing country such as Bangladesh. The life cycle assessment framework consists of four phases. They are: goal definition and scoping, inventory analysis, impact assessment and improvement analysis. The researcher has to define the intended use of the results and users of the result. The definition of the scope of the LCA sets the borders of the assessment – what is included in the system and what detailed assessment methods are to be used (Azapagic 1999). The second step (inventory analysis) includes inventory of the inputs such as raw materials and energy and the outputs such as wastes and emissions that occur during the life cycle. The third step (impact assessment) is integration of inventory elements into an assessment of environmental performance which requires the emissions and material used to be transformed into estimates of environmental impacts. The results of this stage of LCA are termed as ‘ecoprofile’(Joseph & Nithya 2009). The final step is interpretation of the results of impact assessment and suggestions for improvements (Allen & Shonnard 2002).The leather industry in Bangladesh is considered as one with considerable growth and investment potential, ranked fifth in the export earning sector and covers 0.5% of the world’s leather trade which is worth US$75 billion (Paul et al. 2013). Different production stages of a leather article generates highly polluting solid and liquid wastes and a recent study found that significant environmental burden is associated with the tanning and finishing of leather as well as the electricity production and transportation required in the life cycle (Joseph & Nithya 2009). The 113 tanneries in Bangladesh produce 180 million square feet of hides and skins per year, most of them do not have effluent treatment plants and they generate about 20,000 m^3 tannery effluent and 232 tones solid waste per day (Paul et al. 2013). In 2003, the Government of

Bangladesh announced that the tanneries located in Hazaribag will be shifted to a purpose-built and modern cluster in Savar, on the banks of the river Dhaleswari, 10 kilometers from Hazaribag. The key highlight of the Savar cluster was to be the Common Effluent Treatment Plant (CETP), conforming to international environmental standards. The Bangladesh Small and Cottage Industries Corporation (BSCIC) is the implementing agency for the project. It will support 195 tanneries with an employment potential of 100,000 people. However, relocation and moving to designated modern tannery cite with existing outdated old machineries from the existing Hazaribag cite is a big challenge, and a matter of big investments for the tannery owners. The sooner it takes place the better (EU 2013). The European Community established an Eco label scheme, which is intended to promote the design, production, marketing, and use of products and services with reduced environmental impact (EU 2000). These ecological criteria are described based on life cycle considerations. Eco label can promote the use of cleaner technologies in any sector that has been traditionally considered very polluting as that of leather industry. Leather products are on the list of priority products selected for Eco labeling (Rivela et al. 2004). With ISO -14001 certificates becoming one of the requirements for products which are to be exported to the European market and with the promotion of eco-label scheme by the European market, the leather industry in Bangladesh needs to take an active approach to these issues so that it can portray leather manufacture and its products as a sustainable (VDL 2013). Considering these, quantifying the use of resources such as fossil fuel, other forms of energy, water and chemicals and the release of wastewater, air emissions and solid waste during different operations of producing leather in Bangladesh has become important. Carbon footprints are now being measured for nearly all products in the world (Jeffrey 2008). The measure most commonly used is calculated in CO_2 equivalents (CO_2eq) where other greenhouse gases are counted in terms of CO_2 (Redwood 2013). This whole scientific area is very complex and it is exceptionally difficult to be sure that a material is being treated correctly (Redwood 2013). 'Carbon footprint' calculation, which can be defined as the total set of Green House Gas (GHG) emissions caused directly and indirectly by an individual, organization, event or product, expressed in carbon dioxide equivalents, has recently become a useful tool to evaluate the environmental burden associated with a product, process or activity[1]. With climate change high up on the political and corporate agenda, carbon footprint calculations are in strong demand. This thesis is an attempt to understand the material and energy flows of Bangladeshi leather by applying a life cycle analysis approach so as to get an

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[1] www.carbontrust.com

idea about the environmental burdens of leather (Joseph & Nithya 2009). The center of interest were the quantification and evaluation of the impacts of the tanning processes being studied in the tannery as a basis to propose improvement actions (Rivela et al. 2004).

1.2 Method

Data will be inventoried and assembled according to life cycle assessment (LCA) methods principle and requirements of ISO-14040/44, 14067 standards and focuses on cradle to-gate approach. Impact assessment method is chosen to be IMPACT 2002+.

1.2.1 Objectives with specific aims and possible outcome

Specific objectives of the thesis are:

- To determine the environmental burden of most representative leather articles full-chrome and chrome retanned crust leather from cradle to gate in an export-oriented tannery in Bangladesh
- To identify and compare the hot spots of different impact categories over the life cycle of these crust leather articles
- To identify the scope of improvements for the tanneries in terms of their environmental standing

The possible outcomes of the thesis are:

- The introduction of the life cycle thinking into the organization processes and also opportunities for others
- Identification and utilization of potential energy savings and reductions in different impact categories. This will lead to more sustainable, ecological and economical production
- Providing scope for improvements of the leather product and production process to be competitive in regional, national and international markets
- Providing information to internal and external stakeholders using life cycle assessment (LCA) tool to demonstrate commitment to environmental mitigation.

1.2.2 Outline of Methodology

Life cycle assessment (LCA) is globally recognized as the leading method to measure product sustainability, as it can evaluate a wide range of metrics and provide a deeper understanding of impacts, from cradle to grave. For this thesis, the LCA approach is based on ISO-14040/44, 14067 standards and focuses on cradle to-gate approach.

Each of these steps is described as follows:

- **Defining goal and scope**

The functional unit and system boundary of the crust leathers will be defined. Therefore all the emissions will be calculated in relation to the production of corresponding functional unit of crust leathers. The illustration of the brief system boundary is given below in figure 1-1.

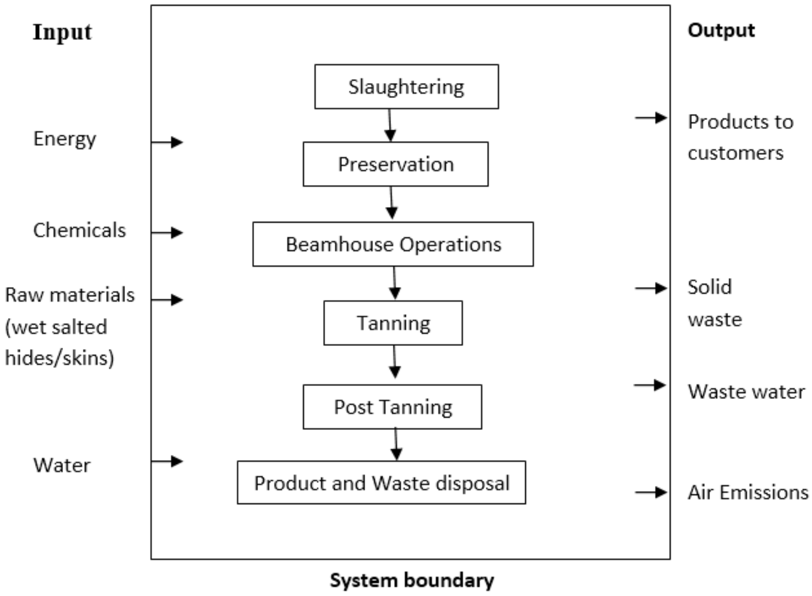

Figure 1-1: Brief system boundary of leather

- **Life cycle inventory (i.e. data collection) and data analysis**

The energy carriers and raw materials used and the emissions are identified and quantified at each process, then illustrated in the process flow chart and were related to some functional basis. An analysis of the physical and chemical characterization of wastewater discharges of the crust leathers at different stages of the production processes will be performed. Data collection will also include annual wet-salted raw hides/skins consumption, input chemicals consumption, water and steam consumption, tannery solid waste generation, electricity, fuel oil consumption for generator and steam boiler. Transportation data (miles travelled annually) will also be required for raw materials, chemicals supply and final products for calculating the corresponding emissions.

- **Impact assessment**

The effects of the resource use and emissions generated will be grouped and quantified into a limited number of environmental indicators such as Greenhouse gas emission, human toxicity, eco-toxicity, acidification potential etc. using SimaPro 8.0.3 LCA software which may then be weighted for importance.

- **Interpretation**

The results will be reported in the most informative way possible and the need and opportunities to reduce the impact of the product and service on the environment systematically evaluated.

- **Preparing action plan for the suggested improvement options**

The need and opportunities to reduce the impact of the product and service on the environment will be systematically evaluated. Action plan for the suggested improvement options like cleaner production options and others will be devised.

1.3 Organization of the thesis

This study shows how life cycle assessment method has been implemented for CF of crust leather produced in Bangladesh. Chapter 2 introduces a brief review of leather processing including a short description regarding the basic structure, some pros and cons of life cycle assessment. In addition, this chapter describes a general overview of CF components with a view to identify potential commonalities for harmonization purposes. The last section in Chapter 2 is focusing on the software used followed by reviewing previous studies regarding CF of leather. Chapter 3 describes the detail methodology. Chapter 4 gives a summary of total data collection. The last section in Chapter 4 describes the results and discussion in accordance. Chapter 5 deals with the results obtained from SimaPro where IMPACT 2002+ impact assessment method were used to analyze and compare two systems and the results were interpreted. Chapter 6 is focused on the scope for improvements options. Chapter 7 is on conclusion where overall findings, limitation and directions for future work have been discussed. Last but not the least, Appendix A contains a summary of SimaPro software and different tables of results extracted form software followed by Appendix B which contains information regarding impact assessment method IMPACT 2002+.in addition, Appendix C explained in short how different midpoint and endpoint categories have been modelled.

2.1 Introduction

This chapter describes a brief review of leather processing including its input and output concept. In addition, a short description regarding the basics, structure some pros and cons of life cycle assessment has been discussed. Several different standards are available today, to footprint product and companies activities. This chapter also briefly describes the main approaches and characteristics of each of them, in order to provide a general overview and to identify potential commonalities for harmonization purposes.

2.2 Brief review of leather processing

Leather making is a traditional industry, after all it has been in existence since time immemorial, certainly over 5000 years, because the industry was established at the time of the Hammurabi Code (1975-1950 BC), when Article 274 laid down the wages for tanners and curriers (Reed 1972).Leather is made from (usually) the hides and skins of animals-large animals such as cattle have hides, small animals such as sheep have skins. The skin of any animal is largely composed of the protein collagen, so it is the chemistry of this fibrous protein and the properties it confers to the skin with which the tanner is most concerned (Covington & Covington 2009). Animal skin consists of epidermis, a layer of fatty tissue called areolar and inner corium. The semi-soluble protein, called ‘collagen’ present in corium is converted into highly durable leather through tanning operations.

The treatment of hides and skins in a tannery can be split into following four main categories:

- Preservation of hides and skins storage
- Beam house operations
- Tanning operations
- Post-tanning and finishing operation

Furthermore, tanneries employ abatement techniques for the treatment of wastewater, solid waste and air emissions generated during these processes. Operations carried out in the beam house, tanyard, and post-tanning areas are often referred to as wet processes, as they are performed in processing vessels such as drums. After post-tanning, the leather is subjected to dry finishing operations. Processes employed in each of the above categories change depending on the raw materials used and the final desired products. Hence the environmental impacts vary from tannery to tannery (ILandFS Ecosmart Limited 2010).

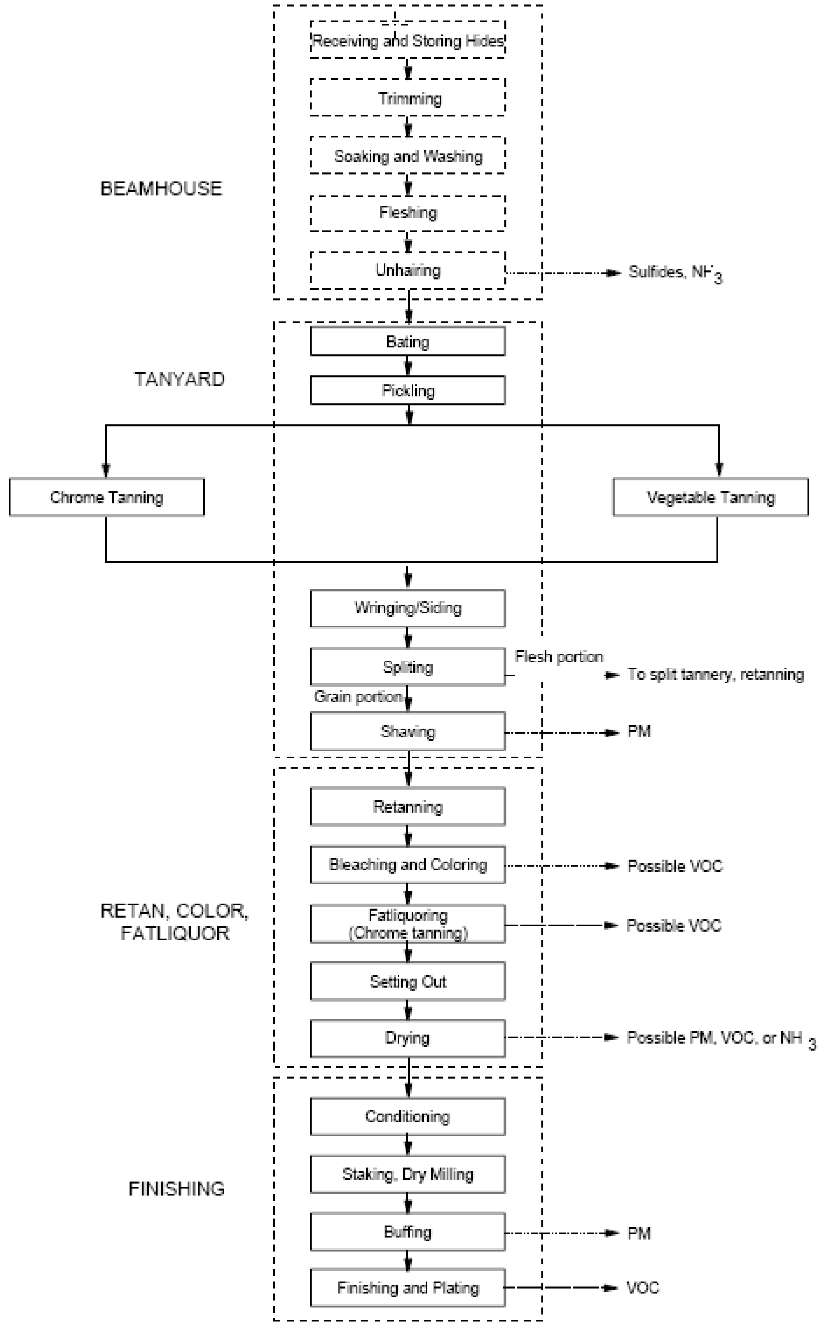

Figure 2-1: Illustration of a typical leather processing activity[2]

2.2.1 Process of tanning

The process of converting raw hides and skins into leather is called tanning. The operations falling in pre-tanning, tanning and post-tanning operations are depicted in the figure 2-1.

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[2] http://oecotextiles.files.wordpress.com/2012/05/tanning_process_description.png

2.2.1.1 Pre-tanning operations

- **Raw hides/skins**

Usually, the hides/skins consist 65% of the water and 30-35% proteins and fat. Because of the high amount of moisture in the hides/skin, there will be bacterial degradation. In order to prevent this bacterial activity, the moisture content should be brought down to less than 30%. This dehydration is usually done by applying common salt (i.e., Sodium Chloride) to the hides/ skins to the tune of 30-45% by weight.

- **Sorting**

Sorting may be carried out in the slaughterhouse, by dealers, and/or in the tannery. On receipt, hides and skins may be sorted into several grades by size, weight, or quality. Hides are also sorted by sex. Materials unsuitable for the particular type of leather manufactured may be sold to other tanners.

- **Trimming**

Trimming is generally carried out during the sorting process. Some of the edges (legs, tails, face, udders, etc.) of the raw hides and skins can be cut off. This process step may be carried out in the slaughterhouse, but it can also be carried out in tanneries. It produces a waste which is subject to control under the animal by-products regulation.

- **Curing and storage**

Curing is a process that prevents the degradation of hides and skins from the time they are flayed in the slaughterhouse until the processes in the Beamhouse are started. Curing is carried out at the slaughterhouse, at the hide dealer's premises, at the hide market, or at the tannery. In certain cases, it might be necessary to repeat the step at the tannery, e.g. if chilled hides are salted for longer storage or if the initial salting was not sufficient to dry the hides. The methods for curing for long-term preservation (up to six months) are: salting, brining, drying and salt drying. Long-term preservation methods are used when hides and skins are traded, particularly for inter-continental trading. For example, much of the raw material for the leather industry in Italy is imported in salted or dried form. Methods for short-term preservation (2 – 5 days) are cooling, using crushed ice or refrigerated storage, and biocides. These methods are used where direct deliveries are made from relatively local sources.

- **Soaking**

Soaking is carried out to allow hides and skins to reabsorb any water which may have been lost after flaying, in the curing process, or during transport. Soaking also cleans the hides and skins (removal of dung, blood, dirt, etc.) and removes interfibrillary material. The soaking methods used depend on the state of the hides. The process is mostly carried out in two steps: a dirt soak to remove the salt and dirt, and a main soak. The duration of soaking can range from several hours to a few days. Putrefying bacteria can thrive during soaking and biocides may be added to curtail their activity. Depending on the type of raw materials being soaked, other additives may be used, such as surfactants and enzyme preparations.

- **Unhairing and liming**

The aim of unhairing and liming is to remove the hair, epidermis, and to some degree, the interfibrillary proteins, and to prepare the hide or skin for the removal of adhering flesh and fat by the fleshing process. Hair removal is performed by chemical and mechanical means. The keratinous material (hair, hair roots, epidermis) and fat are traditionally eliminated from the pelts mainly with sulfides (NaHS or Na_2S) and lime. Alternatives to inorganic sulfides include organic sulfur compounds such as thioles or sodium thioglycolate in combination with strong alkali. Enzymatic preparations are sometimes added to improve the performance of the process.

- **Fleshing**

Fleshing is a mechanical scraping off of the excessive organic material from the hide (connective tissue, fat, etc.). The pelts are carried through rollers and across rotating spiral blades by the fleshing machine .Fleshing can be carried out prior to soaking, after soaking, after liming or after pickling. The process of fleshing is called green fleshing if the removal is done prior to liming and unhairing. If fleshing is performed after liming and unhairing, it is called lime fleshing.

- **Splitting**

The aim of the splitting operation is to produce hides or skins of a set thickness. They are split horizontally into a grain layer and, if the hide is thick enough, a flesh layer. Splitting is carried out on splitting machines, fitted with a band knife. Splitting can be done in the limed condition or in the tanned condition.

- **Deliming**

After the liming process, the lime or other alkali in the skin is no longer required, and, in most cases, it has a detrimental effect on subsequent tannage. The deliming process involves a gradual lowering of the pH (by means of washing in fresh water or by weak acidic solutions or by salts such as ammonium chloride or sulfate or boric acid), an increase in temperature and the removal of residual chemicals and degraded skin components. The extent of deliming to be achieved depends on the type of final leather; a thorough deliming results in a softer leather, whilst partial deliming gives a firmer leather. At this stage, the hides and skins are ready for vegetable tanning but, for chrome tanning, the delimed hides and skins have to be further processed by Bating and pickling. Delimed skins must be taken to the next process immediately, as once the alkali has been removed, putrefying bacteria can thrive.

- **Bating**

The unhairing process leaves the surface of the skin or hide clean, however, some hair roots and pigments are still not removed during unhairing, which is not desirable for certain types of leather. The removal of these hair roots and pigments is achieved by the bating process. Bating uses commercially available proteolytic enzymes.

2.2.1.2 Tanyard operations

The operations carried out in that part of the plant known as the tanyard are often carried out in the same processing vessels, with changes of float and chemicals. In chromium tanning, the vessels are usually drums.

- **Pickling**

Pickling is carried out to reduce the pH of the pelt prior to mineral tanning and some organic tannages (e.g. chrome tanning, glutaraldehyde tanning, and vegetable tanning), thereby sterilizing the skin, ending the bating action, and improving the penetration of the subsequent tanning material. The choice of the exact pickling parameters depends on the subsequent tanning step. Pickling involves treating the bated stock with a solution of sulfuric acid and common salt. The process not only serves to prepare the stock for subsequent tanning, but also if necessary in the preservation of the stock for quite long periods. The pH of the medium is kept at around 3.5.Tanning can be carried out in the pickle liquor, where both operations are undertaken at the same location.

- **Tanning**

In the tanning process, the collagen fiber is stabilized by the tanning agents, such that the hide is no longer susceptible to putrefaction or rotting. In this process, the collagen fibers are stabilized by the cross-linking action of the tanning agents. After tanning, the hides or skins are not subject to putrefaction, their dimensional stability, resistance to mechanical action, and heat resistance increase. There is a wide variety of tanning methods and materials and the choice depends chiefly on the properties required in the finished leather, the cost of the materials, the plant available, and the type of raw material.

The majority of tanning agents fall into one of the following groups:

- Mineral tannages
- Vegetable tannins
- Syntans
- Aldehydes
- Oil tannage.

The most commonly used tanning agent is basic chromium sulfate ($Cr (OH) SO_4$). A high proportion (80 – 90 %) of all the leather produced today is tanned using chromium (III) salts.

- **Draining, horsing, sammying, and setting**

After tanning, the leathers are drained, rinsed and either horsed up (piled onto a 'horse') to 'age' (allow further fixation of the tan and setting out of the fibers to occur), or unloaded in boxes and subsequently 'sammed' (squeezed between rollers) to reduce the moisture content, prior to further mechanical action, such as splitting and shaving. The setting-out operation can be carried out to stretch out the leather. Machines exist which combine the sammying and setting action. After sammying and the setting out, hides and skins can be sorted into different grades after which they are processed further or sold on the market.

- **Shaving**

The shaving process is carried out to reduce and/or even out the thickness throughout the hide or skin. The hides and skins are put through a machine with a rapidly revolving cylinder cutting fine, thin fragments from the flesh side. Shaving can be carried out on tanned or crusted leather. The small pieces of leather which are shaved off are called shavings.

2.2.1.3 Post-tanning operations (wet finishing)

Post-tanning or wet finishing involves neutralization and washing, followed by retanning, dyeing and fatliquoring, mostly done in a single processing vessel. At this stage of the process, specialist operations may also be carried out to add certain properties to the leather such as water repellence or resistance, flame retarding, abrasion and anti-electrostatics.

- **Neutralization**

Neutralization is the process by which the tanned hides are brought to a pH level suitable for the process steps of retanning, dyeing and fatliquoring.

- **Bleaching**

Vegetable tanned skins and leathers with wool or hair may need to be bleached in order to remove stains, or to reduce the coloring in the hair, wool, or leather prior to retanning and dyeing.

- **Retanning**

The retanning process can be carried out with the following objectives:

  - to improve the feel and handle of the leathers
  - to fill the looser and softer parts of the leather in order to produce leathers of more uniform physical properties and with more economical cutting value to the customer
  - to assist in the production of corrected grain leathers
  - to improve the resistance to alkali and perspiration
  - to improve the 'wetting back property (susceptibility to rehydration) of the hides which will help the dyeing process.

A wide variety of chemicals can be used for the retannage of leather. They can generally be divided into the following categories: vegetable tanning extracts, syntans, aldehydes, mineral tanning agents and resins.

- **Dyeing**

The dyeing process is carried out to produce consistent coloring over the whole surface of each hide and skin, and for exact matching between hides in a commercial pack. Typical dyestuffs are water-based acid dyes. Basic and reactive dyes are less commonly used by the leather industry.

- **Fatliquoring**

Leathers must be lubricated to achieve product-specific characteristics and to re-establish the fat content lost in the previous procedures. The oils used may be of animal or vegetable origin, or may be synthetics based on mineral oils.

- **Drying**

The objective of drying is to dry the leather whilst optimizing the quality and area yield. There is a wide range of drying techniques and some may be used in combination. Each technique has a specific influence on the characteristics of the leather. Drying techniques include sammying, setting, hang drying, vacuum drying, toggle drying and paste drying. Generally sammying and setting are used to reduce the moisture content mechanically before another drying technique is used to dry the leather further. After drying, the leather may be referred to as crust. Crust is a tradable intermediate product.

2.2.1.4 Dry finishing operations

The overall objective of finishing is to enhance the appearance of the leather and to provide the performance characteristics expected of the finished leather with respect to color, gloss, handle, flex, adhesion, rub fastness as well as other properties as required for the end use, including extensibility, break, light and perspiration fastness, water vapor permeability, and water resistance. Generally, finishing operations can be divided into mechanical finishing processes and coating.

- **Mechanical finishing processes**

A wide range of mechanical finishing processes may be carried out to improve the appearance and the feel of the leather. The following list of operations includes commonly used mechanical finishing processes conditioning (optimizing the moisture content in leather for subsequent operations); staking (softening and stretching of leather); buffing/dedusting (abrading of the leather surface and removing the resulting dust from the leather surface); dry milling (mechanical softening); polishing; plating (flattening); embossing a pattern into the leather surface. These operations may be carried out before or after applying a coat, or between the applications of coatings. The list is not exhaustive and many other processes exist for special leathers such as sole leathers, wool-on skins, and special effects leathers.

- **Applying a surface coat**

The purpose of applying a surface coat is:

- to provide protection from contaminants (water, oil, soiling)
- to provide color
- to provide modifications to handle and gloss performance
- to provide attractive fashion or fancy effects
- to meet other customer requirements

There is a wide range of application methods, each of which has its advantages and disadvantages. A combination of methods can be used to achieve the desired effect on the finished product. In principle, the following types of application methods can be distinguished:

- padding or brushing the finishing mix onto the leather surface;
- spray coating;
- curtain coating, which is passing the leather through a curtain of finishing material;
- roller coating, which is the application of finishing mix by a roller;
- transfer coating, which is the transfer of a film/foil onto leather previously treated with an adhesive(JRC 2013).

2.2.2 Input vs. output in the tannery process

This part gives information as to the typical emission and consumption levels of tanneries. Due to the wide versatility of tanneries, both in terms of the type of hides and skins used and the range of products manufactured, these levels will generally be indicative only. The environmental impacts from tanneries originate from liquid, solid, and gaseous waste streams and they arise from the consumption of raw materials such as raw hides, energy, chemicals and water. Furthermore, the nature of some of the processes and the materials consumed in those processes has the potential to contaminate soil and groundwater. The main releases of waste water originate from wet processing in the beamhouse, the tanyard, and the post-tanning operations. The potential releases to air are gaseous emissions from wet processing and effluent treatment; particulate matter from dry-finishing and solvent vapors from the degreasing of sheepskins and from coating. The main solid outputs from leather making arise from fleshing, splitting, and shaving. Some of these solid outputs may be sold as raw materials to other industry sectors. A further solid output is the sludge from effluent treatment (where carried out on site).Figure 2-2 provides a rough overview of the input and output flows in a tannery running a conventional process (Joint Research Centre 2013).

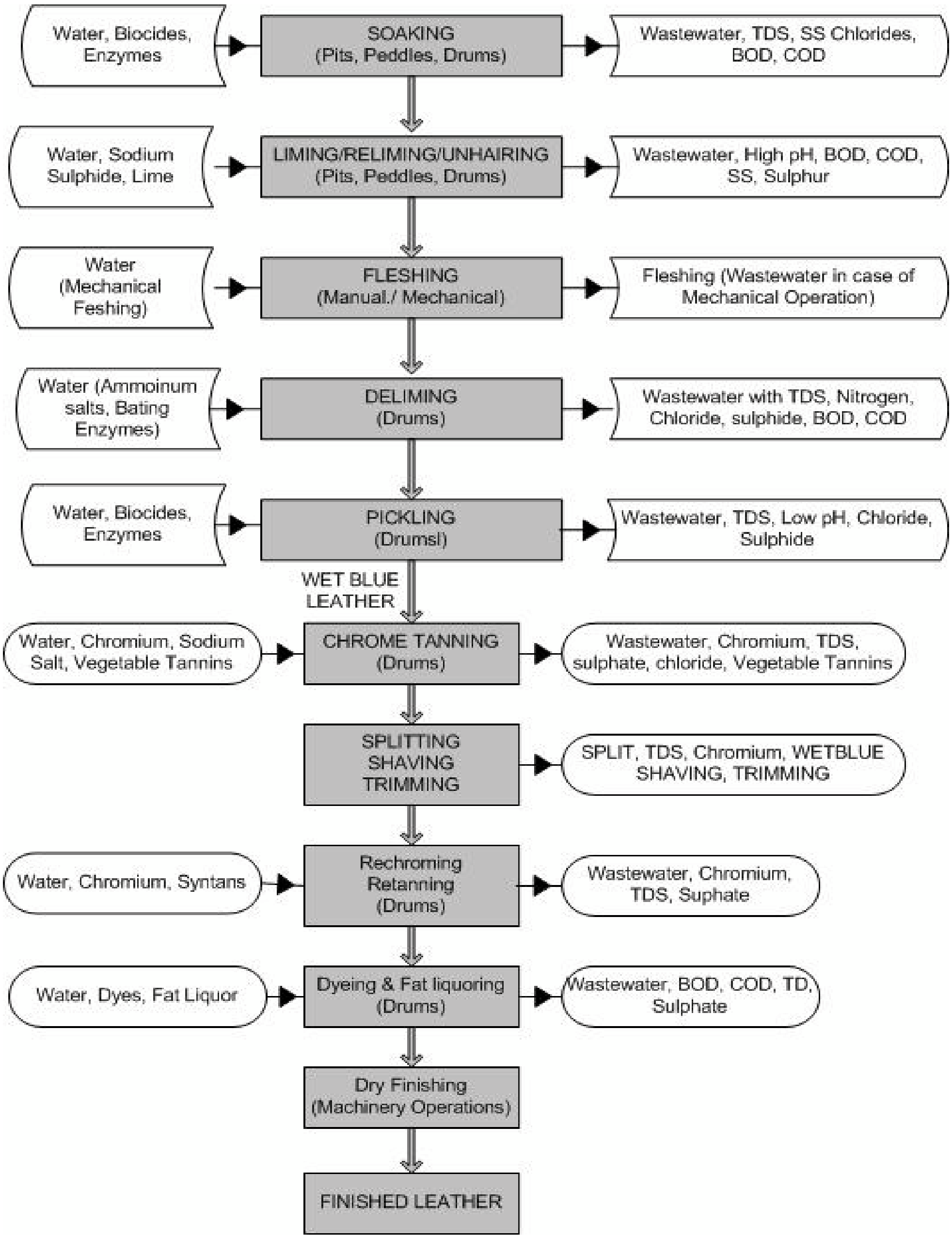

Figure 2-2: input vs. output in tanneries. Source: IL and FS Ecosmart Limited, 2010

2.2.3 Waste emission in tannery processes

- **Wastewater generation**

Water plays a vital role in tannery operations. Ground water is usually used in existing tanneries in Bangladesh. Volume of wastewater (effluent) and its characteristics vary from tannery to tannery. They may also vary within the same tannery from time to time (ILandFS Ecosmart Limited 2010). Tanneries generate effluents that are typically high in organic and inorganic pollutants. Since tanneries employ a sequence of batch processes, and use a wide range of raw materials, their effluent is complex in nature, with variations in characteristics from time to time, process to process and tannery to tannery (Joint Research Centre 2013). The wastewater from beam house process viz. soaking, liming, deliming, etc., are highly alkaline, containing decomposing organic matter, hair, lime, sulfide and organic nitrogen with high BOD and COD. The wastewater from tanyard process viz. pickling, chrome tanning are acidic and colored. Effluent from vegetable tanning contains high organic matter. The chrome tanning wastes contain high amounts of chromium mostly in the trivalent form (ILandFS Ecosmart Limited 2010).

- **Air emission**

Compared to emissions to water, air emissions occur generally in relatively small quantities. Traditionally tanneries have been associated with odor rather than any other air emissions, although the emissions of organic solvents have been a major problem. Modern tanneries should not have significant odor emission problems. Whether a tannery has the following air emissions depends on the type of processes employed:

  - particulate matter
  - organic solvents
  - hydrogen sulfide
  - ammonia
  - odor

Emissions to air have effects beyond the tannery site, but also affect the workplace and possibly the health of the tannery workforce. Apart from odors, particular mention should be made of organic solvent emissions, aerosols, and solid particulates (buffing dust and powdery chemicals). The ventilation required for the health and safety of the workforce will limit the effectiveness of containment provided by the buildings (Joint Research Centre 2013).

- **Solid waste**

In tannery from the process stages various types of solid wastes are generated. The Solid waste generated includes salt from raw skins / hides desalting; raw skins / hides trimmings; hair from the liming / dehairing process, which may contain lime and sulfides; and fleshing from raw skins / hides. Other solid waste from tannery industry includes wet-blue shavings and Splittings containing chromium; wet-blue trimming containing chromium, crust trimmings containing chromium, syntans, dyes; and buffing dust, which also contains chromium, syntans, and dye (ILandFS Ecosmart Limited 2010).

2.3Life cycle assessment

2.3.1 Principle

As environmental awareness increases, industries and businesses are assessing how their activities affect the environment. Society has become concerned about the issues of natural resource depletion and environmental degradation. Many businesses have responded to this awareness by providing "greener" products and using "greener" processes. The environmental performance of products and processes has become a key issue, which is why some companies are investigating ways to minimize their effects on the environment. Many companies have found it advantageous to explore ways of moving beyond compliance using pollution prevention strategies and environmental management systems to improve their environmental performance. One such tool is LCA. This concept considers the entire life cycle of a product. Life cycle assessment is a "cradle-to-grave" approach for assessing industrial systems. "cradle-to-grave" begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product and process selection. The term "life cycle" refers to the major activities in the course of the product's life-span from its manufacture, use, and maintenance, to its final disposal, including the raw material acquisition required to manufacture the product. The following figure 2-3 illustrates the possible life cycle stages that can be considered in an LCA and the typical inputs/outputs measured (SAIC 2006).

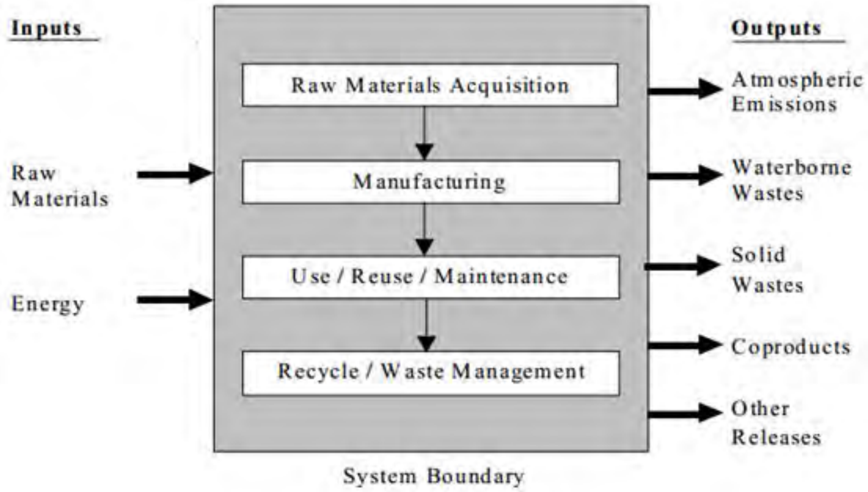

Figure 2-3: Life cycle stages. Adapted from EPA, 1993

Specifically, LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- Compiling an inventory of relevant energy and material inputs and environmental releases
- Evaluating the potential environmental impacts associated with identified inputs and releases
- Interpreting the results to help decision-makers make a more informed decision.

The LCA process is a systematic, phased approach and consists of four components: goal definition and scoping, inventory analysis, impact assessment, and interpretation as illustrated in the following figure 2-4:

- Goal definition and scoping- define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment.
- Inventory analysis – identify and quantify energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, waste water discharges).
- Impact assessment- assess the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.
- Interpretation- evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results (SAIC 2006).

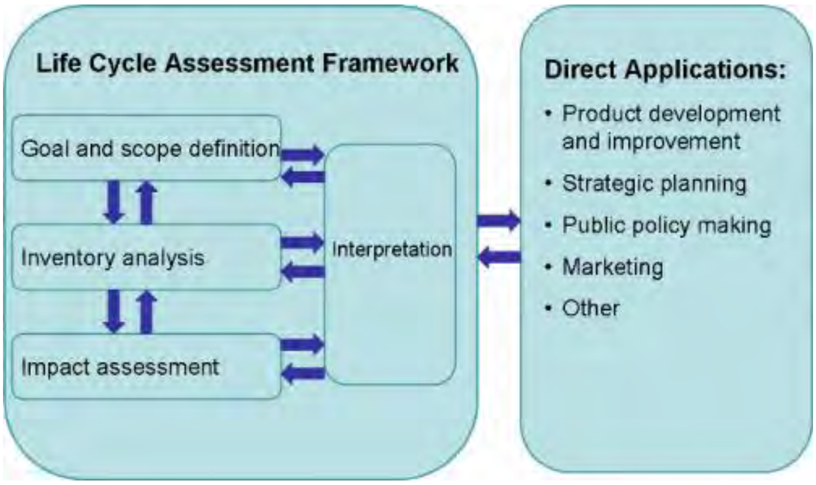

Figure 2-4: Life cycle Assessment Framework. Source: website of beaconpathway[3]

Life cycle assessment is unique because it encompasses all processes and environmental releases beginning with the extraction of raw materials and the production of energy used to create the product through the use and final disposition of the product. When deciding between two or more alternatives, LCA can help decision-makers compare all major environmental impacts caused by products, processes, or services.

2.3.2 Benefits of conducting an LCA

An LCA can help decision-makers select the product or process that results in the least impact to the environment. This information can be used with other factors, such as cost and performance data to select a product or process. LCA data identifies the transfer of environmental impacts from one media to another (e.g., eliminating air emissions by creating a waste water effluent instead) and/or from one life cycle stage to another (e.g., from use and reuse of the product to the raw material acquisition phase). If an LCA were not performed, the transfer might not be recognized and properly included in the analysis because it is outside of the typical scope or focus of product selection processes. This ability to track and document shifts in environmental impacts can help decision makers and managers fully characterize the environmental trade-offs associated with product or process alternatives.

By performing an LCA, analysts can:

- Develop a systematic evaluation of the environmental consequences associated with a given product.

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[3] http://www.beaconpathway.co.nz/further-research/article/life_cycle_assessment

- Analyze the environmental trade-offs associated with one or more specific products/processes to help gain stakeholder (state, community, etc.) acceptance for a planned action.
- Quantify environmental releases to air, water, and land in relation to each life cycle stage and/or major contributing process.
- Assist in identifying significant shifts in environmental impacts between life cycle stages and environmental media.
- Assess the human and ecological effects of material consumption and environmental releases to the local community, region, and world.
- Compare the health and ecological impacts between two or more rival products/processes or identify the impacts of a specific product or process.
- Identify impacts to one or more specific environmental areas of concern.

2.3.3 Limitations of conducting an LCA

Performing an LCA can be resource and time intensive. Depending upon how thorough an LCA the user wishes to conduct, gathering the data can be problematic, and the availability of data can greatly impact the accuracy of the final results. Therefore, it is important to weigh the availability of data, the time necessary to conduct the study, and the financial resources required against the projected benefits of the LCA. LCA will not determine which product or process is the most cost effective or works the best. Therefore, the information developed in an LCA study should be used as one component of a more comprehensive decision process assessing the trade-offs with cost and performance, e.g., life cycle management. There are a number of ways to conduct life cycle impact assessment. While the methods are typically scientifically-based, the complexity of environmental systems has led to the development of alternative impact models. As mentioned earlier, an LCA can help identify potential environmental tradeoffs. However, converting the impact results to a single score requires the use of value judgments, which must be applied by the commissioner of the study or the modeler. This can be done in different ways such as through the use of an expert panel, but it cannot be done based solely on natural science (SAIC 2006).

2.3.4 Standards for LCA-ISO standards

The leading standards for LCA are:

- ISO 14040: Principles and framework

- ISO 14044: Requirements and guidelines

- **ISO 14040:2006 environmental management -- life cycle assessment -- principles and framework**

ISO 14040:2006 describes the principles and framework for life cycle assessment including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements. ISO 14040:2006 covers life cycle assessment (LCA) studies and life cycle inventory (LCI) studies. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA.

- **ISO 14044: Environmental management - life cycle assessment – requirements**

ISO 14044:2006 specifies requirements and provides guidelines for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements. ISO 14044:2006 covers life cycle assessment (LCA) studies and life cycle inventory (LCI) studies (UNIDO 2012a). The ISO standards are defined in a rather vague language, which makes it difficult to assess whether an LCA has been made according to the standard. Unlike the 14000 standard, it is not possible to get an official accreditation stating that an LCA, LCA methodology, or LCA software has been made according to the ISO standard. Therefore, no software developer can claim that LCAs made with a certain software tool automatically conform to the ISO standards. For example, ISO 14044 does not allow weighting across impact categories for public comparisons between products. However, weighting is explicitly allowed for other applications, and thus SimaPro does support weighting. This means that it is one’s responsibility to use weighting in a proper way. A similar example can be made for issues such as allocation rules, system boundaries etc. The most important consequence of aiming to adhere to an ISO standard is the need for careful documentation of the goal and scope and interpretation issues. As an LCA practitioner, one can perform other’s LCA in a number of different ways. A second consequence of adhering to the standards is that one might need to include a peer review by independent experts. It is completely up to practitioner to conform to these standards or to (deliberately) deviate. If one deviate, it is clear he cannot claim that his LCA has been made according to the international standards, and it will be more difficult to convince others of the reliability of that results (PRé 2013).

2.4 ISO DIS 14067-carbon footprint of product

The International Standard addresses the single impact category of climate change and does not assess other potential social, economic and environmental impacts arising from the provision of products. Product carbon footprints assessed in conformity with the International Standard do not provide an indicator of the overall environmental impact of products. The Standard was prepared by technical committee ISO/TC 207, environmental management, subcommittee SC 7, greenhouse gas management and related activities (UNIDO 2012a).

2.5 ISO 14025 - environmental labels and declarations - Type III environmental declarations - principles and procedures

ISO 14025:2006 establishes the principles and specifies the procedures for developing Type III environmental declaration programs and Type III environmental declarations. Type III environmental declarations as described in ISO 14025:2006 are primarily intended for use in business-to-business communication, but their use in business-to-consumer communication under certain conditions is not precluded. It specifically establishes the use of the ISO 14040 series of standards in the development of Type III environmental declaration programs and Type III environmental declarations.

2.6 Ecological Footprint

The ecological footprint (EF) standard is developed by global footprint network. The EF provides measure of the extent to which human activities exceed bio capacity. Specifically, the EF integrates the area required for the production of crops, forest products and animal products, the area required to sequester atmospheric CO_2 emissions dominantly caused by fossil fuel combustion, and the equivalent area estimated to be required by nuclear energy demand.

2.7 Product and supply chain standards greenhouse gas protocol (WRI/ WBCSD)

The world resources institute (WRI) and the world business council on sustainable development (WBCSD) started to develop their product and supply value chain GHG accounting and reporting standard in September 2008. The GHG protocol corporate standard provides standards and guidance for companies and other types of organizations preparing a

GHG emissions inventory. It covers the accounting and reporting of the six greenhouse gases covered by the Kyoto protocol—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The corporate value chain and product life cycle accounting and reporting standards were published in October of 2011. These new standards include requirements and guidelines on both product life cycle accounting and calculation and reporting of corporate. The Product Standard builds upon the ISO 14040 series of standards.

2.8 ILCD - International reference life cycle data system

In response to commitments in the IPP communication of the European commission, the international reference life cycle data system (ILCD) has been established for ensuring consistent and reproducible life cycle data and robust impact assessments. This system consists primarily of the ILCD handbook and the ILCD data network. The handbook is a series of technical guidance documents. It is developed through peer review and consultation and is in line with the ISO 14040 and 14044, while it provides further specified guidance for more quality-assurance than the broader ISO framework can offer. The ILCD handbook provides detailed provisions for product and corporate analysis .To facilitate this development, links have been established with national LCA database projects in all parts of the world, and with the world business council for sustainable development (WBCSD) and the United Nations environment program (UNEP).

2.9 Single issue standards

In addition to the LCA approach which includes multiple environmental issues, single issue LCA approaches have been developed lately, including carbon footprinting and water footprinting. These approaches also take a life cycle perspective but focus on one impact category only. In response to societies' needs for transparency in the greenhouse gas (GHG) emissions of products, several carbon footprinting standards have been developed or are still under development. There are two main standards: GHG Protocol and the draft ISO 14067. The draft ISO 14046 on the quantification of water footprints for products, processes, and organizations is under development since 2009. This standard takes a life cycle approach but focuses solely on water use.

2.9.1 Product category rules (PCR)

ISO 14040/44 is the basis for many other standards. ISO 14025, for example, is based on ISO 14040/44 and introduces two concepts: Product Category Rules (PCR) and environmental product declarations (EPD). PCRs are specific guidelines for the calculation of the environmental impact of products within the same product category. A product category is a group of products with similar characteristics. PCRs contain strict requirements that leave less room for interpretation than a general LCA. A PCR can specify, for example, the functional unit that should be used, or the databases that should be used, or the impact categories that should be included in the study. By following the requirements in the PCR, a company can develop an EPD, which is a concise document containing relevant environmental information about a product. PCRs require a program operator. Program operators can be a group of companies, an industrial sector, trade organization, or a public authority. Examples of program operators are environdec (located in Sweden, with an international focus), Plastics Europe (the Association of plastics manufacturers in Europe), Institut Bauen und Umwelt (Germany), EPD-norge (Norway) and JEMAI (Japan).

2.9.2 Environmental product declarations (EPD)

The development of environmental product declarations (EPDs) has become a major application of an LCA. In some countries and sectors, hundreds of thousands of products now have such a declaration. The declaration generally consists of a series of impact category indicator results. Today, three types of environmental communication are available: Type I, II, and III. Type III is the actual environmental product declaration (EPD), for which an ISO standard (14025) provides guidelines. These guidelines are not specific enough to make EPDs. Instead the standard describes a procedure to make more specific product category rules. Without such rules one cannot produce an EPD. Once a PCR is found, the LCA is performed according to the specification in the EPD. One will find that these rules are usually quite straightforward, and allow for rather simple procedures. Also the impact assessment method is relatively simple. In general, the impact categories are limited to:

- Non-renewable resources (with and without energy content)
- Renewable resources (with and without energy content)
- Global warming (CO_2 equivalents)
- Acidification (kmol H^+)
- Ozone layer depletion (kg CFC11 equivalents)
- Photochemical oxidant formation (kg ethane-equivalents)

- Eutrophication (kg O_2)

These impact categories are defined in a similar way as the CML 1992 method, but there are some differences (PRé 2013).

2.10 LCA and carbon footprint

Concern over climate change has stimulated interest in estimating the total amount of greenhouse gasses (GHG) produced during the different stages in the life cycle of goods and services - i.e. their production, processing, transportation, sale, use and disposal. The outcome of these calculations are often referred to as Product Carbon Footprints (PCFs), where carbon footprint is the total amount of GHGs produced for a given activity and product is any good or service that is marketed. PCFs are thus distinct from GHG assessments performed at the level of projects, corporations, supply chains, municipalities, nations or individuals. It is part of a general effort to demonstrate commitment to climate change mitigation to consumers and stakeholders (UNIDO 2012a).

2.11 Methodological considerations for CF of leather

There is no single methodology on life cycle assessment of products and of company performances that is universally agreed upon and therefore no agreement is currently reached internationally on PCF calculation methods. Different definitions of the boundary of the LCA, in terms of which life cycle stages, emission sources and GHGs area considered, will produce very different results. There is a lack of comprehensive data for LCA, data reliability is questionable, and several databases with different data specifications (e.g. in terms of reference units) are often needed to perform an LCA. Carbon footprints are rarely accompanied by detailed methodological accounts. They are therefore difficult to assess by third parties or to compare with the footprints of like products. The inherent complexity and lack of exactness of carbon footprint analyses contrasts with the need to communicate the results in a simple, clear and unambiguous way to other businesses along the value chain and, ultimately, to consumers. The rapid proliferation of private PCF schemes raises two issues:

- The application of multiple schemes in the marketplace may lead to confusion about what information is relevant and useful and thereby diminish confidence in such information.
- As such schemes proliferate, one may become the de facto standard and thereby create a market access barrier for products using other carbon-foot printing schemes.

It is therefore clear the importance of harmonizing all the standards schemes and practical experience on the market today to get a unique and direct methodology recognizable by the consumers. From a methodological point of view, the Leather PCFs calculations will be based on a modular framework, allowing to quantify the:

- impacts of all the relevant phases of the upstream modules in the supply chain
- impacts related to the tanning process
- Impacts related to the relevant downstream processes (i.e. water purification).

2.12 Leather specific review of ISO DIS 14067 requirements

In ISO DIS 14067, the methodology for CFP quantification is based on specific requirements:

- Functional unit
- System boundary
- System boundary options
- Quantification
- Cut-off criteria
- Data and data quality
- Time boundary for data
- Use stage and use profile
- End-of-life stage
- Life cycle inventory analysis for the CFP
- Refining the system boundary
- Allocation
- Communication

2.12.1 Functional unit-ISO DIS 14067 requirements and recommendation

A CFP study shall clearly specify the functions of the product system being studied. The functional unit shall be consistent with the goal and scope of the CFP study. The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. Therefore the functional unit shall be clearly defined and measurable (UNIDO 2012b).

In general terms, the functional unit shall correspond to the basic unit that the tannery uses for trading the finished leather it produces. For a wider application, due to the fact that worldwide finished leather trade is mostly done on the basis of the surface area, the proposal is to use, as functional unit, 1 m^2 of finished leather. A reference should be added on standards used for measuring the surface of leather (i.e. ‘‘ISO 11646 Leather -- Measurement of area”, UNI

11380:2010 “Guidelines for surface measurement of leather through electronic devices”). In particular case of Sole Leather, production shall be considered, due to the fact that the products are sold by weight. In this case, even with limited applications, the functional unit proposed is 1 kg of sole leather.

2.12.2 System boundary and system boundary options-ISO DIS 14067 requirements and recommendation

- **System boundary**

The system boundary determines which unit processes shall be included within the CFP study. The selection of the system boundary shall be consistent with the goal of the CFP study. The criteria used in establishing the system boundary shall be identified and explained (UNIDO 2012b).

- **System boundary options**

The setting of the system boundary can be different depending on the intended use of the CFP study. Where the assessment of the CFP is intended to be communicated to consumers, the quantification of the CFP shall comprise all stages of the life cycle (UNIDO 2012b).

- **Methodological approach to system boundaries**

In order to better analyses the different approaches included in the publications identified, a brief introduction shall be made to clarify some key points, as the harmonized definition of system boundaries represents one of the most important factor determining carbon footprint contribution. In order to proceed with a clear methodology that allows an agreement on system boundaries, it has been decided to implement a “step by step” approach, starting from the identification of all life cycle processes involved in leather production and ending up with a proposed identification of system boundaries, based on the review of background knowledge currently adopted, integrated with some harmonization considerations. Main reference standard for the implementation of the methodological approach on system boundaries is reference (Product Category Rules Finished Bovine Leather 2011).The identification of general system boundaries are logically divided as shown in the figure 2-5.

Figure 2-5 illustrates that all relevant unit processes taking place in leather production can be divided into upstream, core and downstream processes. The upstream processes include the inflow of raw materials and energy needed for leather production:

- raw material extraction
- generation of energy wares used in production
- chemical and ancillary production
- Production of auxiliary products used such as detergents for cleaning etc.
- agriculture, if relevant
- animal breeding, if relevant
- slaughterhouse

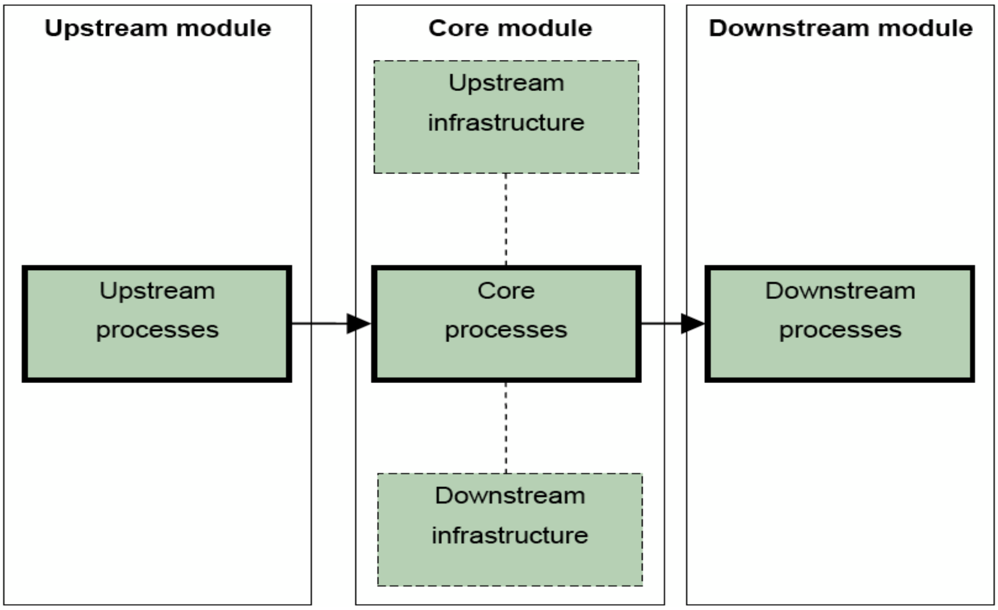

Figure 2-5: Representation of Unit Processes Source: UNIDO, 2012

The core processes include:

- production of finished leather
- production of leather based products
- production of packaging
- external and internal transportation of raw materials and energy wares to the core process

The downstream processes include transportation from final production to an average distribution platform. It is voluntary to include:

- the customer or consumer use of the product
- Recycling or handling of packaging waste/materials after use.

A graphical representation of the different processes included in the leather value chain is included in the following Figure 2-6 for illustration.

Whether raw hides and skins are to be considered as:

- Co-product
- By-product
- Waste

of the milk and/or meat industry, a rational explanation has been given in the following paragraph.

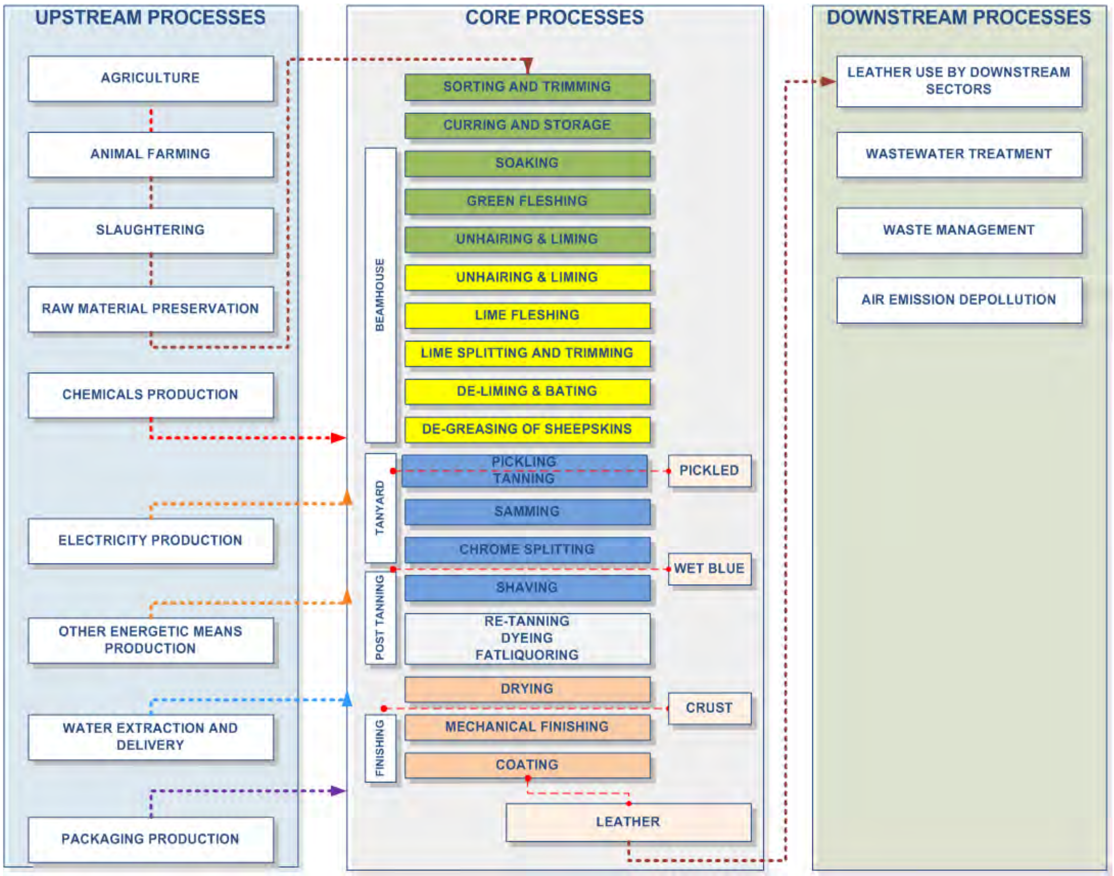

Figure 2-6: Representation of Main Processes of the Leather Production Value Chain.

Source: UNIDO, 2012

If raw hides and skins are considered as waste of the milk and meat industry, the whole environmental impact has to be allocated on the main product of the economic value chain (milk and meat). In that case rawhides and skins will be addressed as “recovered waste” in the basic LCA studies. This implies that agriculture and animal farming, as processes of the upstream module, shall be excluded from system boundaries of LCA studies on leather. In order to carry out a complete analysis, it should be also considered the casein which raw hides are considered as a by-product or co-product of the milk and meat industry, with the implication that part of the environmental impacts (and therefore of the CO_2 equivalent content) have to be allocated to the co-product itself, on the basis of different allocation criteria (economic, mass, and system expansion). The production of most renewable materials involves co-products. Traditionally, the environmental impacts have been allocated between the different co-products according to a more or less arbitrary allocation ratio. Following the ISO requirements, and based on SETAC recommendations, allocation shall be avoided whenever possible. The general belief has been that avoiding allocation through system expansion was not always possible for co-products from renewable material production, since the substitutions involved were considered to be too complex, difficult to determine, and sometimes involving endless regressions. However, these perceived problems can be solved by applying a stringent procedure for identifying the affected processes. The co-producing process has one determining product, i.e. the product that determines the production volume of that process. This is not necessarily the product used in the specific life cycle study. There may be any number of co- products, while at any given moment there can be only one determining product. That a product determining the production volume of a process is the same as saying that this process will be affected by a change in demand for this product (Weidema 1999). To say that there can be only one determining product at any given moment, is not the same as saying that the other co-products are not of importance. That the co-products can obtain a certain price on the market may well be a precondition for the process to expand its production volume. But when this precondition is fulfilled, it is still only a change in demand for the determining product that will be able to affect the production volume of the process (Weidema 1999). A graphical representation of the different processes involved is shown in the following figure 2-7.

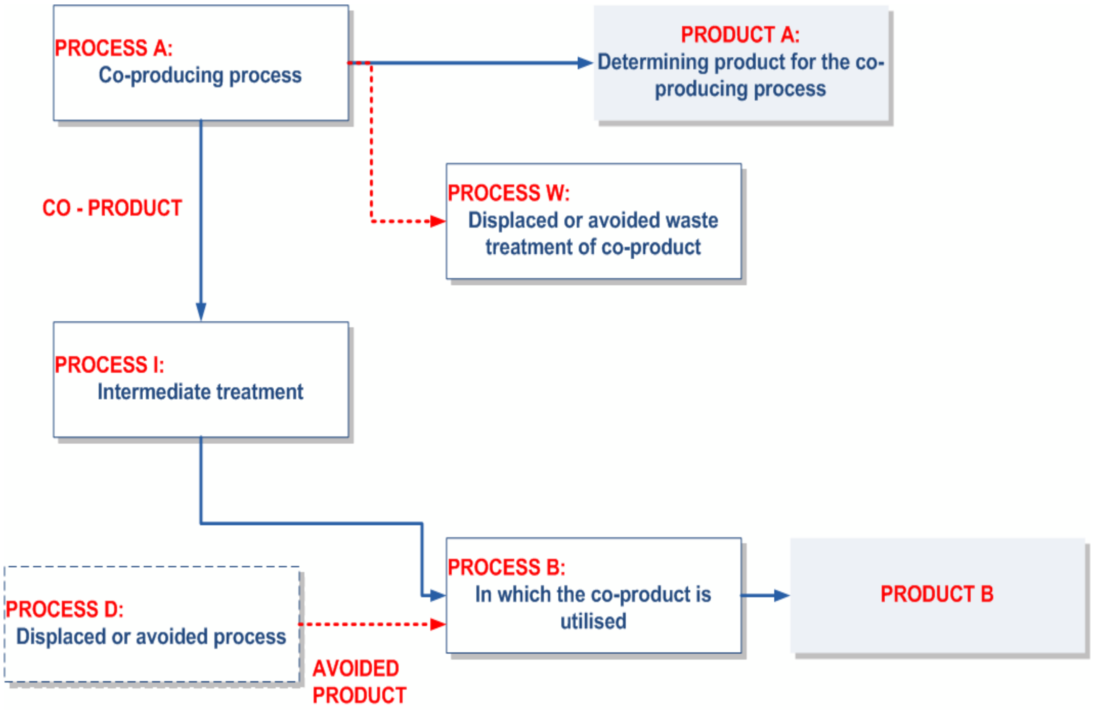

Figure 2-7: Model for describing system expansion and delimitation in relation to co-production. Source: Weidema, 1999

Performing a system expansion in relation to co-products is to identify exactly how the production volume of the processes in figure given above will be affected by a change in demand for the product that is used by the life cycle study in question (both when this is the determining product for the co-producing process (A) and when it is the product in which the co-product is utilized (B). The answer to this question can be summarized in four simple rules:

1. The co-producing process shall be ascribed fully (100%) to determine the product for this process.
2. Under the conditions that the non-determining co-products are fully utilized in other processes and actually displaces other products there, product A shall be credited for the processes, which are displaced by the other co-products, while the intermediate treatment (and other possible changes in the further life cycles in which the co-products are used, which are a consequence of differences in the co-products and the displaced products) shall be ascribed to product A. If the two conditions stated in rule no.2 are not fulfilled, rule no.3 and 4 apply, respectively:
3. When a non-determining co-product is not utilized fully (i.e. when part of it must be regarded as a waste), but at least partly displaces another product, the intermediate treatment shall be ascribed to product B, while product B is credited for the avoided

waste treatment of the co-product.

4. When a non-determining co-product is not displacing other products, all processes in the entire life cycle of the co-product shall be fully ascribed to product A.

When analyzing the particular situation of raw hides and skins, in relation to the requirements for the application of the system expansion, it can be clearly affirmed that:

- Raw hides and skins should be considered co-products of renewable materials are renewable resource is "a natural resource with the ability to reproduce through biological or natural processes and replenished with the passage of time. Renewable resources are part of our natural environment and form the eco-system". For bovines, ovines and goats, this definition applies perfectly to the meat production (determining product), which is a renewable material, that has co-products as raw hides and skins.
- Raw hides and skins, non-determining co-products are not utilized fully, but at least partly displace other products As widely known in sectoral literature, a small portion of the raw material input (around20–25%)is transformed into finished leather. The remaining portion consists of other by- products and waste of animal origin. At the same time, leather displaces other materials (mostly synthetic) in the realization of footwear, leather goods, garment, car interiors, and furniture.

Under these circumstances, applying in a conservative manner the 4 rules explained before, for the product finished leather realized with raw hides and skins coming from animals which have been farmed both for their milk production and for their meat, the rule applicable is number 3. Slaughtering is the intermediate processes "I". Finished leather, moreover, could be credited for the avoided waste treatment of raw hides and skins entering the tannery. According to the above discussion, the system boundaries are to be considered starting in the slaughterhouse, where activities and treatments are carried out in order to prepare the hides to be used for tanning (e.g. Conservation of the hides and skins by way of cooling systems or salting) and ending at the exit gate of the tannery.

The proposed, system boundaries are shown in the following Figure 2-8.

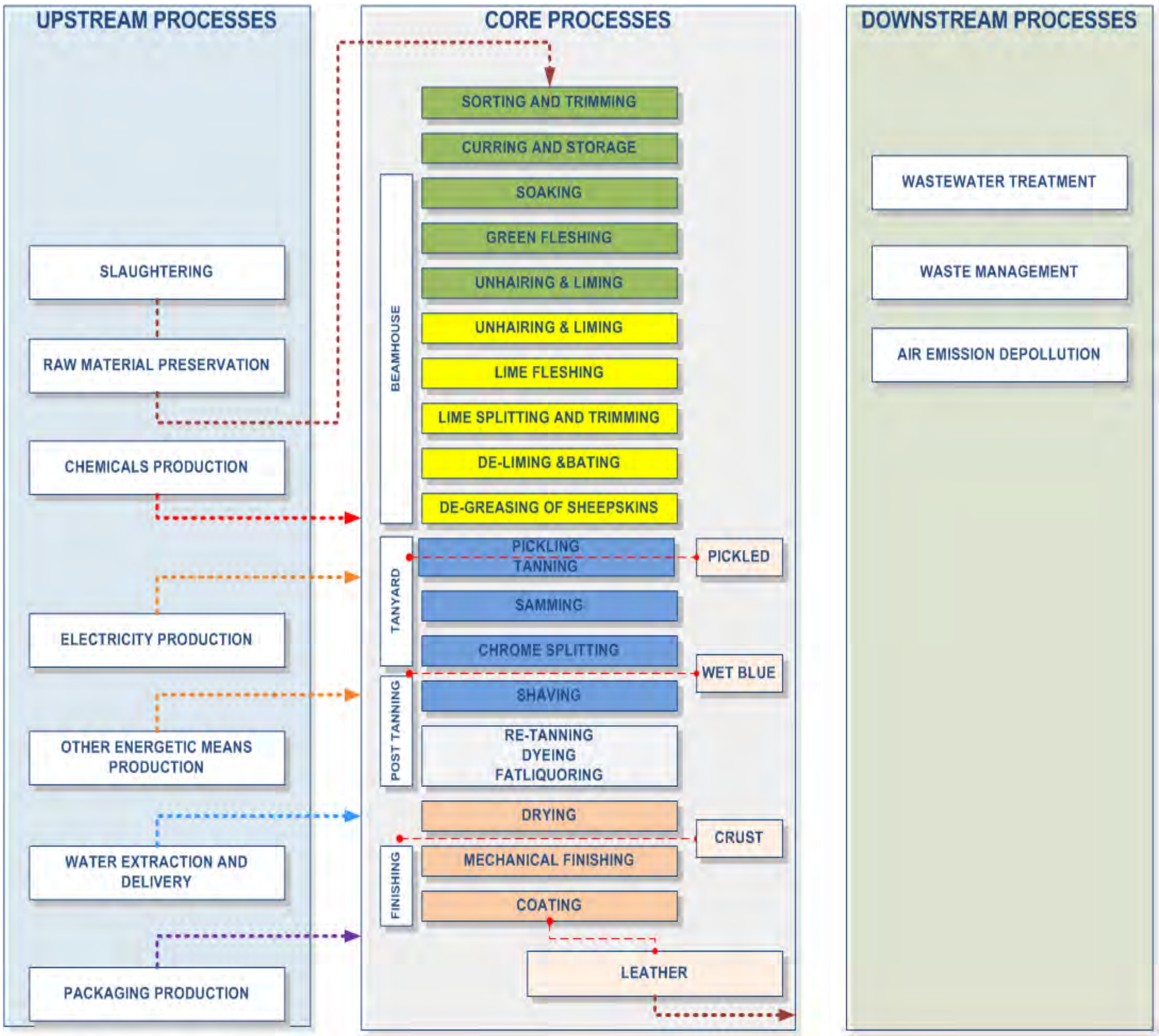

Figure 2-8: Proposed System Boundaries taken from UNIDO, 2012

As seen in the above Figure 2-8 ,agriculture, animal farming, and leather use by downstream sectors have been excluded from system boundaries, which now start from the “Cradle” (slaughterhouse), to “Gate” (that can be considered as the finished product warehouse exit gate of the tannery). In this context, downstream processes, with particular reference to waste management, air emission depollution, wastewater purification, as well as all kind of transportation (represented in the figure by the arrows) are to be always included in system boundaries.

2.12.3 Quantification-ISO DIS 14067 requirements and recommendation

Quantification carried out in accordance with this international standard shall include all GHG emissions and removals of those unit processes within the defined system boundary that have the potential to make a significant contribution to the CFP (UNIDO 2012).

The final aim of the process is to quantify the CPF of the product leather, which is defined in ISO DIS14067 as the "sum of greenhouse gas emissions and removals in a product system, expressed as CO_2 equivalent and based on a life cycle assessment". The CO_2 equivalent of a specific amount of a greenhouse gas is calculated as the mass of a given greenhouse gas multiplied by its global warming potential. According to this definition and to the previous definition of the functional unit, a CF of leather shall be expressed as:

Kg of CO_{2eq}/m^2 of finished leather.

In order to be able to quantify the CF defined above, the ISO DIS 14067, specifies that: ''A CFP study assesses the GHG emissions and removals in the life cycle of a product. The unit processes comprising the product system shall be grouped into lifecycle stages; e.g., raw material acquisition, production, distribution, use and end-of-life. GHG emissions and removals from the product's lifecycle shall be assigned to the life cycle stage in which the GHG emissions and removals occur. Partial CFPs may be added together to quantify the CFP, provided that they are performed according to the same methodology''. According to the described "Modular approach", the methodology is based on the quantification of CO_{2eq} content of all the different products and material entering the tannery (upstream processes), summing them to the CO_{2e} produced in the tannery itself (core processes),and the CO_{2eq} produced for water purification, waste recycling/disposal and air purification (downstream processes). Some assumptions have to be made. Considerations are to be intended on tanneries producing finished leather, starting from preserved raw hides and skins (therefore carrying out in their production facilities the full production cycle). Time boundary is one calendar year. No outsourced production processes are foreseen. For the sake of simplicity, splitting is foreseen only on pelts (lime splitting) Splits are calculated to account for 50% of the weight of the pelt. Splits exit the system as co- products, while grain leather continues until the end of the process and it is then sold as a finished product. All environmental impacts before splitting are then allocated 50% on the grain leather and 50% on the split. Raw hides and skins are bought on the basis of their weight (expressed in kilograms)

Slaughtering and raw material preservation (salting) are carried out in the same production facilities. Quantification methodologies of core processes are to be made on yearly production of the whole tannery. The tannery is selling finished leather on the basis of the surface (expressed in m^2). Range of thickness of finished leather does not vary substantially from one article to the other. Transport of hides and skins, of chemicals and all other auxiliaries shall be included, but no specific calculation criteria have been identified Wastewater treatment is carried out within the same production site of the tannery, but is treated as an independent facility. Air emissions cleaning impact, being mostly linked to electric energy consumption and to waste production, even if considered as downstream processes, is to be included in the core processes consumption and emission indicators.

2.12.4 Cut-off criteria-ISO DIS 14067 requirements and recommendation

Consistent cut-off criteria that allow the omission of certain processes of minor importance shall be defined within the goal and scope definition phase. The effect of the selected cut-off criteria on the outcome of the study shall also be assessed and described in the CFP study report (UNIDO 2012). The total omitted emission shall not exceed 0.1% compared to the total emission from all processes within defined system boundary.

2.12.5 Data and data quality-ISO DIS 14067 requirements and recommendation

Site-specific data shall be collected for all individual processes under the financial or operational control of the organization undertaking the CFP study, and shall be representative of the processes for which they are collected. Site-specific data should be used for those unit processes that contribute considerably to the CFP, as determined in the sensitivity analysis (UNIDO 2012).One of the most time consuming elements in LCA work is acquiring the data needed for the inventory calculations and to justify their quality and reliability (EU 2008). Carbon footprint studies should use data that reduce bias and uncertainty. Determination of the best data quality could be supported by a data scoring framework that allows the different attributes of data quality to be combined.

2.12.6 Time boundary for data-ISO DIS 14067requirements and recommendation

The time boundary for data is the time period for which the quantified figure for the CFP is representative (UNIDO 2012).The data shall be representative for the year/time frame for which the EPD is valid (maximum 3 years) (Product Category Rules Finished Bovine Leather 2011).One year should be the time boundary necessary for a complete quantification of the emission considered.

2.12.7 Use stage and use profile-ISO DIS 14067 requirements and recommendation

When the use stage is included within the scope of the CFP study, GHG emissions and removals arising from the use stage of the product during the product’s service life shall be included (UNIDO 2012). Leather use by downstream sectors have been excluded from system boundaries, which now start from “Cradle” (the slaughterhouse), to “Gate” (that can be considered as the finished product warehouse of the tannery).

2.12.8 End-of-life stage-ISO DIS 14067requirements

The end-of-life stage begins when the used product is ready for disposal, recycling, reuse, etc. All the GHG emissions and removals arising from the end-of-life stage of a product shall be included in a CFP study, if this stage is included in the scope (UNIDO 2012).

2.12.9 Life cycle inventory analysis for the CFP-ISO DIS 14067requirements

LCI is the phase of LCA involving the compilation and quantification of inputs and outputs for a product throughout its lifecycle. After the goal and scope definition phase, the LCI of a CFP study shall be performed, which consists of the following steps, for which the following pertinent provisions, adapted from ISO 14044:2006, listed below shall apply. If CFP-PCR are adopted for the CFP study, the LCI shall be conducted following the requirements in the CFP-PCR.

- Data collection;
- Validation of data;

Relating data to unit process and functional unit (UNIDO 2012).

2.12.10 Allocation-ISO DIS 14067requirements and recommendation

The inputs and outputs shall be allocated to the different products according to the clearly stated and justified allocation procedure. The sum of the allocated inputs and outputs of a unit process shall be equal to the inputs and outputs of the unit process before allocation. Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach. The interest of this topic is generally recognized and methodologies keep an open approach on this subject, in order to remain flexible (UNIDO 2012).

Allocation between different products and co-products shall be based on physical relationships. If physical relationships cannot be established or used, allocation can be based on other relationships, for example economic allocation. Any other allocation procedures must be justified. The process of slaughtering shall be treated by physical allocation (mass). Related to the splitting activities, it is used a surface criteria, so the environmental impact, until this cycle phase, is equally allocated between split hide (50%) and grain leather (50%). It should be differentiated between the splitting in the beam house and splitting WB. Furthermore calculations shall consider the correct mass of raw hides necessary for the production of the declared product unit, having particular care of the weight variations in the manufacturing phases. The weight variations that have to be applied are specified. "All tanning processes have to be included in the study. Manufacturing processes not listed may be included. However, the production of the raw materials used for production of all product parts shall be included according to the cut off rules" (Product Category Rules Finished Bovine Leather 2011) .Meat is the main product of slaughtering, the allocation of environmental burdens to leather was based on total market value share of rawhide (14%) amongst the slaughterhouse products (Joseph & Nithya 2009). Allocation shall be avoided whenever possible and, if unavoidable, it should be made according to the physical relationship within the single process under consideration (UNIDO 2012).

2.13 Motivation for the study

Climate change arising from anthropogenic activity has been identified as one of the greatest challenges facing countries, governments, business and individuals, with major implications for both human and natural systems. In response, international, regional, national and local initiatives are being developed and implemented to limit greenhouse gas (GHG) concentrations in the Earth’s atmosphere. Such GHG initiatives rely on the assessment, monitoring, reporting and verification of GHG emissions and/or removals. GHGs are emitted and removed throughout the life cycle of a product. The increased awareness of the importance of environmental protection and assessment of the GHGS emission, and the possible impacts associated with products both manufactured and consumed, has led to the development of life cycle assessment (LCA) methods to better understand and address impacts which assists in identifying opportunities to improve the environmental performance of products at various points in their life cycle, informing decision-makers in industry, government or non-government organizations. The leather tanning process is composed of several batch stages associated with the consumption of large amounts of freshwater as well as the generation of liquid and solid wastes. There is a perception that leather industries has been polluting the environment significantly. This poses a challenge to the future sustainability of the leather industry with a growing number and layers of non-tariff barriers, including environmental considerations and eco-criteria emanating from major export markets. The leather industry in Bangladesh is considered as one of the investment potential sectors with considerable growth opportunities. To evaluate the environmental burdens associated with leather produced in Bangladesh, and to assess the carbon footprint, life cycle analysis or assessment (LCA) has been chosen. This whole procedure has been carried out in a leading LCA software having different impact assessment methods for calculating carbon footprint and assessing the impacts of products or services. To do so two representative tanning processes namely full-chrome and chrome retanned were considered and compared for improvement options.

2.14 LCA Software package-SimaPro

SimaPro is the world's leading LCA software and chosen by industry, research institutes, and consultants in more than 80 countries. SimaPro provides with a professional tool to collect, analyze and monitor the sustainability performance of products and services. SimaPro has all of the features anyone would expect from a professional LCA software package (Pre Consultants B.V. n.d.). It provides uncertainty analysis in inventory results using a Monte Carlo analysis (not available in Faculty version). It analyses complex waste treatment and recycling scenarios. With SimaPro, one can easily model and analyze complex life cycles in a systematic and transparent way, measure the environmental impact of products and services across all life cycle stages and identify the hotspots in all aspects of supply chain. SimaPro comes fully integrated with various databases and impact assessments, and is used for a variety of LCA applications:

- Carbon footprint assessment
- Water footprint assessment
- Environmental performance monitoring
- Product design and eco-design (DfE)
- Environmental Product Declarations (EPD)
- Environmental reporting (GRI)
- Determination of key performance indicators (KPI)

2.15 Previous studies on carbon footprint of leather

A representative leather tannery industry in a Latin American developing country has been studied from an environmental point of view, including both technical and economic analysis. Life cycle analysis (LCA) methodology has been used for the quantification and evaluation of the impacts of the chromium tanning process as a basis to propose further improvement actions having limited system boundary. Studies were limited to production system namely Beamhouse, tanyard and Retanning excluding total supply chain. Electricity consumption has not been fully covered. Impact assessment done using suspended Eco-indicator 99 method where impact categories and subsequent damage categories are limited compared to present endpoint assessment method. Up to crust, finishing has not been included (Rivela et al. 2004). Another paper presented a study on the resource and environmental profile of leather for communicating to the consumers about the environmental burdens of leather products. The results indicated that environmental impacts were caused during the tanning and finishing of leather as well as the electricity production and transportation required in the life cycle. Though a system boundary was considered but not details were provided; furthermore, no impact assessment was done (Joseph & Nithya 2009). Another paper aimed at identifying the economic and environmental improvements through leather supply chain by applying the industrial ecology principles. The results of the LCA of bovine leather manufactured in Italy and Spain have been described in order to put in evidence the eco-profile of the two systems and to find out if the difference in the adopted technologies and cooperative management solutions have led to significant environmental differences. On the other hand, all inputs and outputs, during almost all of the leather life cycle were measured in mass and referred to a mass flow of leather (not a surface of leather). Characterization has been carried out per macro phase of the system life cycle: slaughterhouse, storage, tannery, tannery solid waste management, tannery waste water treatment, chrome recovery. Here unit processes in the production phases have not been analyzed (Bruno et al. 2011).Studies of carbon footprint have not been carried out so far in Bangladesh for leather production supply chain. Especially leather industries in Bangladesh is struggling in terms of environmental legislation. This study will help to identify environmental burden and scope of improvement of the tanneries, utilization of potential energy savings and reductions in different impact categories. This study will also help sustainable leather production and establishment of subsectors based on the leather sectors.

CHAPTER 3 METHODOLOGY

3.1 Introduction

LCA is composed of several inter related components goal definition and scope, inventory analysis, impact assessment and improvement assessment. The points considered under each component are described as follows.

3.2 Goal definition and scope

The goal of this study is to determine and compare the environmental burden of most representative leather articles full-chrome and chrome retanned crust leather which will help to identify the hot spots of different impact categories over the life cycle of these crust leather articles in an export-oriented tannery in Bangladesh. Therefore, to find out where the environmental performance can be improved. This study has been carried out through the application of the LCA methodology from cradle to gate approaches, for assessing and comparing in parallel the above mentioned systems for full-chrome and chrome retanned crust leather production supply chain. The differences found between the two systems can be used to identify improvement possibilities. Moreover it serves as a source of information for other tanneries or industries which may be interested to study the impact of their products /processes by applying the LCA methodology. Since the LCA methodology has not been verified by independent LCA expert reviewer and the concern company is not willing to refer its name, so this result cannot be disclosed to the public in the name of that company but it can be used for learning purposes.

Some important issues regarding the system under the current study

- The tannery is producing crust leather, starting from preserved raw hides that means carrying out full production cycle in their production facilities.
- The tannery is selling crust leather on the basis of the surface (expressed in m^2). Time boundary is one calendar year from June, 2013 to June, 2014.
- No outsourced production processes has been foreseen in that tannery.
- Splits exit the system as co-products, while grain leather continues until the end of the process and it is then sold as a finished product.
- All environmental impacts of slaughtering are allocated 14% on the raw hides (Joseph & Nithya 2009) based on total market value share of rawhide amongst the slaughterhouse products and this is applicable in the context of Bangladesh.

- Range of thickness of curst leather does not vary substantially from one article to the other. It was assumed based on in house observation.
- Use stage and use profile and End-of-life stage have been excluded since cradle to gate approach was considered only.
- No critical review has been performed.
- Target audience are the stakeholders with a view to get informed.

- **Functional unit**

The functional unit chosen is 1 square meter leather. Therefore all the emissions are calculated in relation to the production of 1 square meter leather.

- **System boundaries**

Here two product systems were analyzed namely full-chrome and chrome retanned crust leather and their system boundaries given below in figure 3-1 and 3-2:

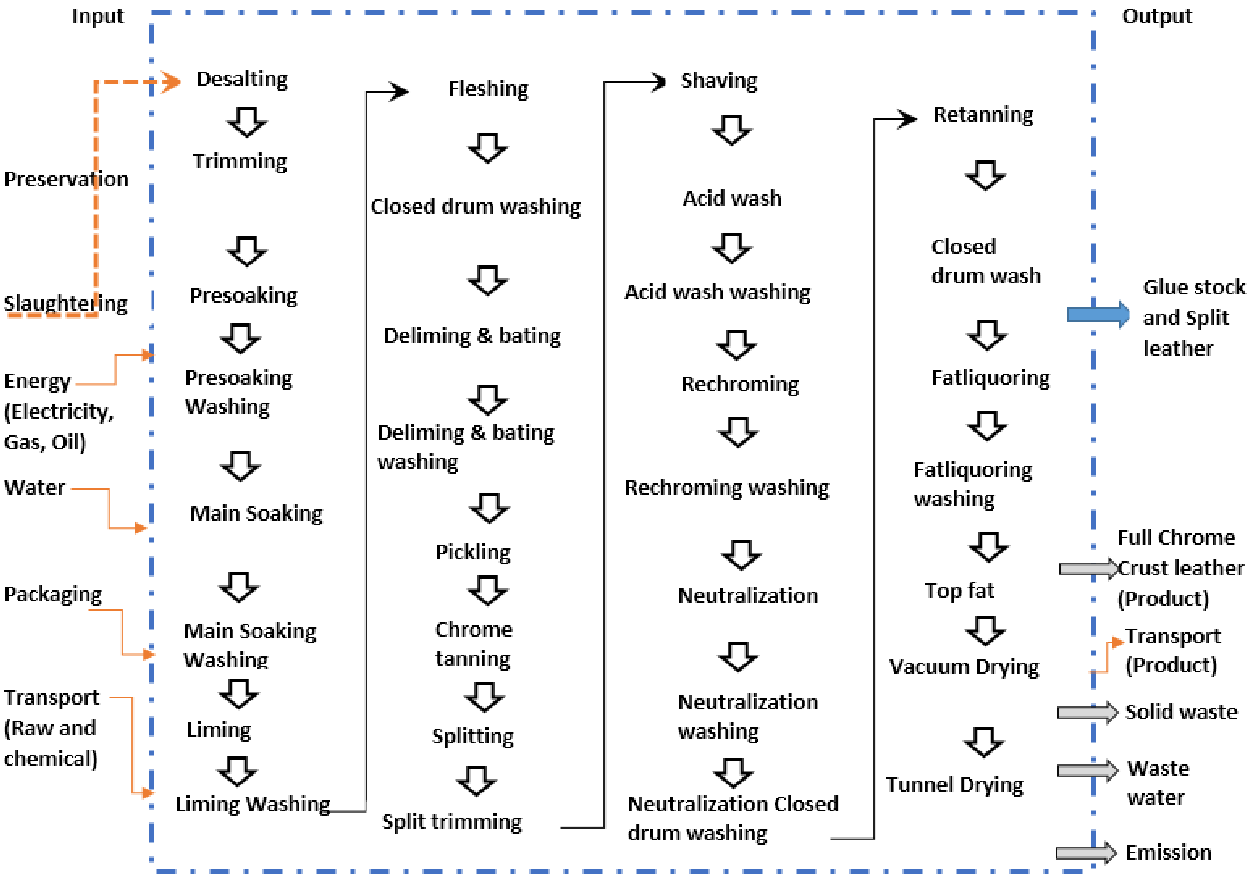

Figure 3-1: System boundary for full-chrome crust leather

Figure 3-2: System boundary for chrome retanned crust leather

According to the detail system boundaries illustrated in Figure 3-1 and 3-2, it differs only in tanning methods between two systems up to tanning. Full-chrome follows chrome tanning whereas chrome retanned follows pretannage which is defined as incomplete and more or less superficial tannage of pelt with some special tanning agent before the main tannage in order to facilitate this.[4] In the crust section, full-chrome follows different washing like acid wash washing, rechroming washing, neutralization washing, neutralization closed drum washing, retanning closed drum washing and fatliquoring washing whereas chrome retanned leather follows only acid wash washing, retanning washing and fatliquoring washing.

- **Quantification**

According to the definition of quantification and to the previous definition of the functional unit, a CF of leather shall be expressed as

Kg of CO_{2eq}/m^2 of finished leather.

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[4] http://www.iultcs.org/leather_terms/search.asp?look_for=pretannageandsubmit=Search

Since systems under studies are limited to crust production only and it is the representative production phase in Bangladesh, so it was considered as
Kg of CO_{2eq}/m^2 of crust leather.

- **Cut-off criteria**

The total omitted emission considered less than 0.1% compared to the total emission from all processes within defined system boundary.

- **Allocation**

All environmental impacts of slaughtering is allocated 14% on the raw hides. Here raw hides has been considered as a by-product of meat processing industry. Meat is the main product of slaughtering. So the allocation of environmental burdens to leather has been given 14% calculated based on total market value share of rawhide amongst the slaughterhouse products (Joseph & Nithya 2009) and this assumption was based on Indian context. It has been observed that the prices of raw hides vary from 10 to 15% based on total market value share of slaughterhouse products over the year in Bangladesh but to be reasonable, 14% considered.

- **Data Quality**

The intended application of this study is to identify environmental “hot spots” in the life cycle of Bangladeshi leather. Data are based on Bangladeshi system that reasonably approximate this country’s practices and conditions for the purposes of “hot spot” analysis. All data used here are less than 10 years old to provide a reasonable approximation of current practices and energy systems for the life cycle of Bangladeshi leather. Ideally, all data are based on Bangladesh average for each unit process within the specified temporal coverage period. All the data related to the inputs and outputs of the process were obtained directly from the company within June, 2013 to June, 2014. The proxy processes used in this thesis are Transport for raw material, Chemical and Product delivery (from gate to Chittagong port); Electricity production country mix data taken from Malaysia since it resembles our production system; packaging material production data, electricity generation using diesel generator and emission data of diesel fueled steam boiler .All these proxy processes data including packaging material production taken from SimaPro database libraries (Ecoinvent v3). Slaughtering data was sourced from Joseph and Nithya, 2009.

- **Life cycle inventory**

An analysis of the physical and chemical characterization of wastewater emissions of the leather processes was performed. The major tests conducted were chloride (Cl) , chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), NH_3-N, NO_2-N,NO_3-N, total Kjeldahl nitrogen (TKN), sulfide (as H_2S), PO_4-P, total chromium, chromium (as Cr^{6+}), TDS, TS. Data collection included annual wet-salted raw hides/skins consumption, input chemicals consumption, water and steam consumption, tannery solid waste generation, electricity, fuel oil consumption for generator and steam boiler. Transportation data (miles travelled annually) for raw materials, chemicals supply and final products have been collected for calculating the corresponding emissions. Tests were conducted at Environmental Engineering laboratory, Dept. of Civil Engineering, Bangladesh University of Engineering and Technology (BUET). The samples being analyzed were waste liquor of presoaking, main soaking, liming, deliming and bating, pickling, chrome tanning (full-chrome), pretannage (chrome retanned), acid wash (for both), rechroming (for both), neutralization (for both), retanning (for both), fatliquoring (both) and top fat (both). It has been observed that emission loads are same for both system boundaries production processes from presoaking to pickling. In addition, other washing processes have also been considered for water use. The collected samples were representative of the high production time of the company. Due to lack of measuring instruments the emissions as a result of boiler fuel oil combustion, emission from generator were not measured but proxy process have been used. The use of proxy data sets is the quickest and easiest solution for bridging data gaps (Canals et al. 2011). The idea for using proxy data is usually keeping the data gap unfilled which allows for the estimation of an approximate contribution of the target part of the entire system. The obvious advantage of using proxies is that they facilitate the impact estimation when the cost of conducting a full study becomes prohibitive. It should be noted that, the tannery at present has no instrument to quantify the amount of steam and process water consumed at each process stage. To have a reasonable judgment simple mathematical calculation have been used in this thesis. Details of inventory data has been given in Chapter 4.

3.3 Impact assessment

Impact assessment is a technical quantitative, and/or qualitative process to characterize and assess the effects of the environmental burdens identified in the inventory. The impact assessment was conducted based on impact 2002+methodology. This is due to the availability of information and data in relation to the above methods. In other methods the methodology applied and their application to developing countries condition is minimal. And also the environmental problems being considered are simply reflecting current condition of the developed countries. The chemicals used by the developed countries are mostly non-harmful due to the strict environmental regulation. Whereas in developing countries the chemical usage is not controlled and susceptible to serious environmental problems. As a result the environmental impacts are many as compared to the developed countries. Of the available LCA methods the above methods are applicable taking into account the existing problem of the developing countries. Figure 3-3 shows that the IMPACT 2002+ links all types of LCI results via several midpoint categories like human toxicity , respiratory inorganics, respiratory organics, ionizing radiation, ozone layer depletion, aquatic ecotoxicity, terrestrial ecotoxicity, aquatic acidification, aquatic eutrophication, terrestrial acidification/nitrification, land occupation, global warming, nonrenewable energy consumption, mineral extraction to four damage categories (human health, ecosystem quality, climate change, and resources). Figure 3-3 shows arrows, which symbolize that a relevant impact pathway is known and quantitatively modeled. Impact pathways between midpoint and damage levels represented by dotted arrows are assumed to exist, but not modeled quantitatively due to missing knowledge or in development.

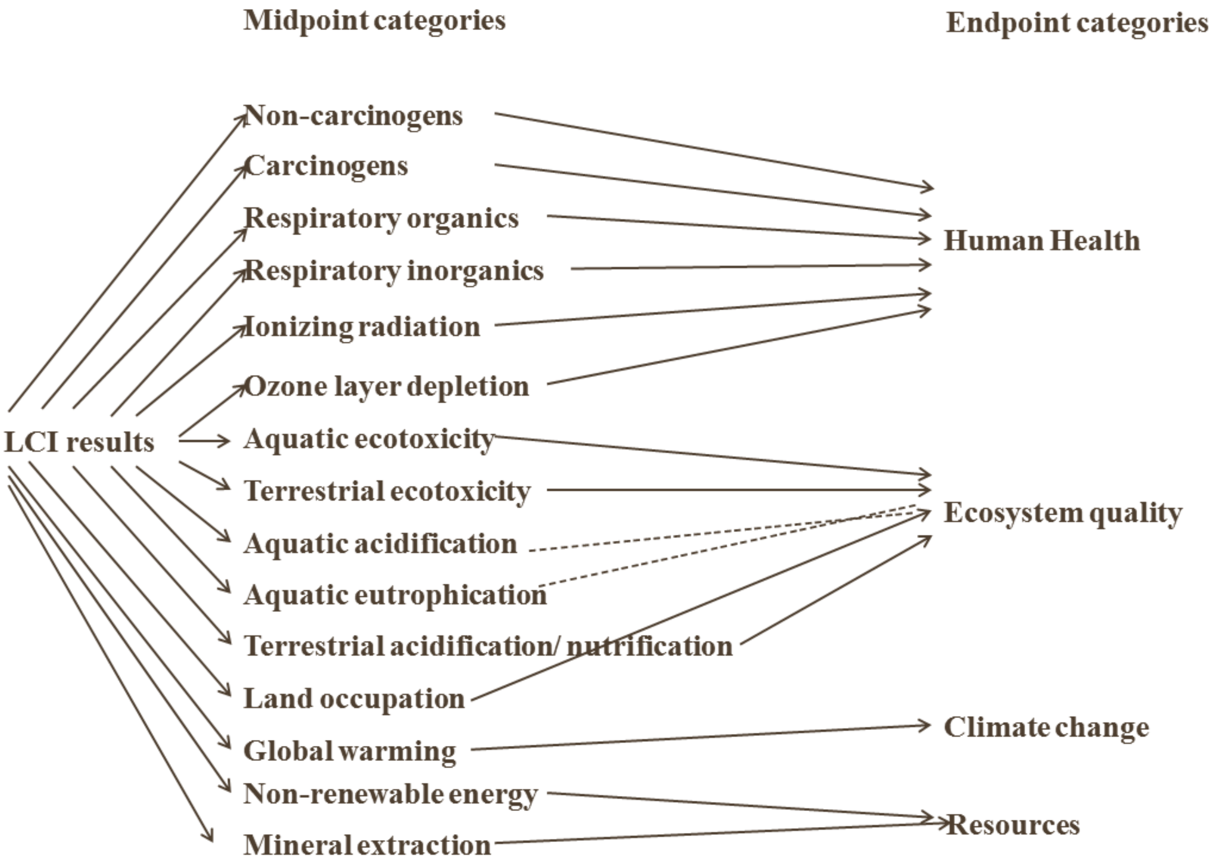

Figure 3-3: Overall scheme of the IMPACT 2002+ framework, linking LCI results via the midpoint categories to damage categories (Jolliet et al., 2003).

IMPACT 2002+ is a combination of four methods: IMPACT 2002 (Pennington et al. 2005), Eco-indicator 99, CML (CML and VROM 2001) and IPCC (Intergovernmental Panel on Climate Change (IPCC) 2001). The IMPACT 2002+ method was largely based on Eco-indicator 99. As shown in figure 4-3, a midpoint indicator characterizes the elementary flows and other environmental interventions that contribute to the same impact. The term ‘midpoint’ expresses the fact that this point is located somewhere on an intermediate position between the LCI results and the damage on the impact pathway. In consequence, a further step may allocate these midpoint categories to one or more damage categories, the latter representing quality changes of the environment. A damage indicator result is the quantified representation of this quality change and calculated by multiplying the damage factor with the inventory data. The damage indicator result is often also named damage impact score or simply damage category.

3.3.1 Units

Different types of units are used in IMPACT 2002+.

- **At midpoint level**

kg substance s_{-eq} (kg equivalent of a reference substance s) expresses the amount of a reference substance s that equals the impact of the considered pollutant within the midpoint category studies (e.g., the Global Warming Potential on a 500 yr. scale of methane is 7 times higher than CO_2, thus its CF is 7 kg $CO_{2\text{-eq}}$).

- **At damage level**

DALY (Disability-Adjusted Life Years) characterizes the disease severity, accounting for both mortality (years of life lost due to premature death) and morbidity (the time of life with lower quality due to an illness, e.g., at hospital). Default DALY values of 13 and 1.3 [years/incidence] are adopted for most carcinogenic and non-carcinogenic effects, respectively. For example, a product having a human health score of 3 DALYs implies the loss of three years of life over the overall population. PDF·m^2·y (Potentially Disappeared Fraction of species over a certain amount of m^2during a certain amount of year) is the unit to measure the impacts on ecosystems. The PDF·m^2·y represents the fraction of species disappeared on 1 m^2 of earth surface during one year. For example, a product having an ecosystem quality score of 0.2 PDF·m^2·y implies the loss of 20% of species on 1 m^2 of earth surface during one year. MJ (Mega Joules) measures the amount of energy extracted or needed to extract the resource.

- **At normalized damage level**

Points are equal to pers·y. A point represents the average impact in a specific category caused by a person during one year in Europe. In a first approximation, for human health, it also represents the average impact on a person during one year (i.e., an impact of 3 points in ecosystem quality represents the average annual impact of 3 Europeans. This last interpretation is also valid for climate change and resources.) It is calculated as the total yearly damage score due to emissions and extractions in Europe divided by the total European population.

3.3.2 Midpoint categories

- **Human toxicity (carcinogenic and non-carcinogenic effects)**

Human toxicity represents all effects on human health, except for respiratory effects caused by inorganics, ionizing radiation effects, ozone layer depletion effects and photochemical oxidation effects that are considered separately. This is mainly due because their evaluation is based on different approaches. CFs for chronic toxicological effects on human health, termed‘ human toxicity potentials’ at midpoint-and ‘human damage factors’ at damage level, provide estimates of the cumulative toxicological risk and potential impacts associated with a specified mass (kg) of a chemical emitted into the environment. The damage CFs are expressed in DALY/kg. For the midpoint CFs the reference substance is chloroethylene emitted into air and the CFs are expressed in kg chloroethylene into air$_{\text{- eq}}$/kg.

- **Respiratory effects (caused by inorganics)**

This impact category refers to respiratory effects which are caused by inorganic substances. The CFs are given for emissions into air only (as it is not very likely that these pollutants will be emitted into soil or water). Damage CFs are expressed in DALY/kg and taken directly from Eco-indicator 99 (PRé 2000). The midpoint CFs are expressed in kg PM$_{2.5\text{-eq}}$into air/kg and obtained by dividing the damage factor of the considered substance by the damage factor of the reference substance (PM$_{2.5}$ into air).

- **Ionizing radiation**

For the impact category ionizing radiation the CFs are given for emissions into air and water. No CFs are currently available for emissions into soil. Damage CFs are expressed in DALY/Bq$_{\text{emi}}$ and Midpoint CFs are expressed in BqCarbon-14$_{\text{-eq}}$ into air/kg$_{\text{emi}}$ and obtained by dividing the damage factor of the considered substance by the damage factor of the reference substance (Carbon-14 into air).

- **Ozone layer depletion**

The CFs of ozone layer depletion are given for emissions into air only, as it is not very likely that the considered pollutants will be emitted into soil or water. The midpoint CFs are expressed in kg CFC-11$_{\text{-eq}}$ into air/kg$_{\text{emi}}$ and obtained from the US Environmental Protection Agency Ozone Depletion Potential List (EPA). Damage CFs are expressed in DALY/kg$_{\text{emi}}$ and for the midpoint reference substance (CFC-11= Trichlorofluoromethane) taken from (PRé 2000).The damage CFs for other substances are obtained by multiplying the midpoints (inkgCFC-11$_{\text{-eq}}$into air/kg$_{\text{emi}}$) with the CFC-11damage CF (in DALY/kg$_{\text{emi}}$).

- **Aquatic ecotoxicity**

The CFs of aquatic ecotoxicity” are given for emissions into air, water and soil and quantify the ecotoxicity effects on (surface) freshwater (referring to streams and lakes). No CFs are available for emissions into groundwater, stratosphere and oceans. The aquatic ecotoxicity CFs for *heavy metals* only apply for metals emitted in dissolved form (ions). The damage CFs are expressed in PDF·m^2·y/kg. The midpoint CFs are expressed in kg Triethylene glycol into water-$_{eq}$/kg and obtained by dividing the damage CF of the substance considered by the damage CF of the reference substance (Triethylene glycol into water).

- **Terrestrial ecotoxicity**

Terrestrial ecotoxicity CFs are calculated in a similar way as aquatic ecotoxicity CFs for emissions into air, water and soil. CFs for heavy metals only applies for metals emitted in dissolved form (ions). It has been estimated that the substances have ecotoxic effects only by exposure through the aqueous phase in soil. Damage CFs are expressed in PDF·m^2·y/kg. The midpoints CFs are expressed in kg Triethylene glycol into soil-eq / kg and obtained by dividing the damage CF of the considered substance by the damage CF of the reference substance (Triethylene glycol into soil).

- **Aquatic acidification**

Characterization factors are given for emissions into air, water and soil. Midpoints for aquatic acidification (kg $SO_{2\text{-}eq}$into air/kg_{emi}) have been taken directly from CML (CML and VROM 2001). No aquatic acidification damage factors (in PDF·m^2·yr. /kg_{emi}) are given. Indeed, currently, no available studied support the assessment of damage factors for aquatic acidification.

- **Aquatic eutrophication**

Characterization factors are given for emissions into air, water and soil. Midpoints for aquatic eutrophication (kg $PO4^{3-}$-$_{eq}$ into water/kg_{emi}) have been taken directly from CML (CML and VROM 2001). No aquatic eutrophication damage factors (in PDF·m^2·yr. /kg_{emi}) are given. Indeed, currently, no available studies support the assessment of damage factors for aquatic eutrophication.

- **Terrestrial acidification and nitrification**

Characterization factors are given for emissions into air only. Terrestrial acidification and nutrification (damage, in PDF·m^2·yr./kg_{emi}) are taken directly from Eco- indicator99 (PRé 2000). Midpoints (kg SO_{2-eq} into air/kg_{emi}) have been obtained from damage by dividing the damage factor of the substance considered by the damage factor of the reference substance (SO_2 into air).

- **Land occupation**

Land occupation damage characterization factors (in PDF·m^2·yr./m^2·yr.) are taken directly from Eco indicator 99 (PRé 2000). Although Eco-indicator 99 gives two "sub-categories" for land-use (land occupation and land conversion), in IMPACT 2002+ only land occupation is considered. Midpoints characterization factors (m^2 Organic arable $land_{-eq}$·yr.) have been obtained by dividing the damage factor of the considered flow by the damage factor of the reference flow (Organic arable land.yr). Although this midpoint unit is given, land occupation is often directly expressed in damage units (PDF·m^2·yr. /m^2·yr.). As specified in Eco-indicator 99, the damage factors are based on empirical observations of the number of plant species per area type. In such observations all effects of the area type are included. This means that also the effects of emissions (pesticides and fertilizers) are included. To avoid double counting in these categories (ecotoxicity of pesticides and acidification and eutrophication potential of fertilizers), only emissions that "leave" the field (through water, erosion and harvest) and emissions that are "above normal use" should be taken into account in the LCI.

- **Global warming**

Characterization factors are given for emissions into air only. Midpoints characterization factors for global warming (kg CO_{2-eq}into air/kg_{emi}) have been taken from the IPCC list (IPCC2001, and IPCC2007 for CH_4, N_2O and CO). The global warming potentials have been used with a 500 years' time horizon.

- **Non-renewable energy**

Characterization factors for non-renewable energy consumption, in terms of the total primary energy extracted, are calculated with the upper heating value. Non-renewable energy (in MJ total primary non-renewable energy/kg_{used}) for versions2.1 are taken from Ecoinvent.

Midpoints (kg Crude oil$_{-eq}$ (860kg/m^3)/kg$_{used}$) have been obtained by dividing the damage factor of the considered substance by the damage factor of the reference substance (crude oil (860kg/m^3)). Even if midpoint categories for non-renewable energy depletion can be expressed in terms of kg substance X$_{-eq}$, they are commonly expressed in MJ-total primary non-renewable energy (MJ).

- **Mineral extraction**

Mineral extractions (in MJ surplus energy/kg$_{extracted}$) are taken directly from Eco-indicator 99· Midpoints (kg Iron$_{-eq}$ (in ore)/kg$_{extracted}$) have been obtained by dividing the damage factor of the considered substance by the damage factor of the reference substance (iron (in ore)).Even if midpoint categories for mineral extraction depletion can be expressed in terms of “kg Substance X-eq”, they are commonly expressed in MJ-surplus energy (MJ).

3.3.3 Damage categories

As shown in Figure4-3, all midpoint categories can be grouped into four damage categories.

- **Human health**

The “human health” damage category is the sum of the midpoint categories human toxicity, respiratory effects, ionizing radiation, ozone layer depletion and photo chemical oxidation. Human health impact is expressed in DALYs. The human health average damage is 0.0071 DALY/point and is dominated by respiratory effects caused by inorganic substances emitted into air.

- **Ecosystem quality**

The ecosystem quality category is the sum of the midpoint categories aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acid/nutr and land occupation. Theoretically, the midpoint categories aquatic acidification and aquatic eutrophication are also contributing to ecosystem quality impacts. Ecosystem quality impact is expressed in PDF· m^2·yr. The ecosystem quality damage is dominated by terrestrial ecotoxicity and land occupation.

- **Climate change**

The damage category climate change is the same category as the midpoint category global warming. Even if it is considered as a damage category, climate change impact is still expressed in kg $CO_{2\text{-eq}}$. The climate change damage factor of 9’950 kg $CO_{2\text{-eq}}$/ point is largely dominated by CO_2 emissions.

- **Resources**

The damage category resources is the sum of the midpoint categories non-renewable energy consumption and mineral extraction. This damage category is expressed in MJ. The resources damage factor of 152’000MJ/point is largely dominated by non-renewable energy consumption.

3.3.4 Normalization

Normalization has been used to analyze the respective share of each impact to the overall damage of the considered category. It facilitates comparison of different categories on the same graph with the same units and weighting. Indeed, it gives an estimation of the magnitude of the weighting factors one should determine to still discriminate between the different categories. The normalization has been performed by dividing the impact (at damage categories) by the respective normalization factors. A normalization factor represents the total impact of the specific category divided by the total European population. The total impact of the specific category is the sum of the products between all European emissions and the respective damage factors. The normalized characterization factor is determined by the ratio of the impact per unit of emission divided by the total impact of all substances of the specific category, per person per year. The unit of all normalized characterization factors is therefore [point/$\text{unit}_{\text{emission}}$] = [pers. yr. /$\text{unit}_{\text{emission}}$]. Currently IMPACT World+ has been developed in response to the need of regionalized impact assessment covering the whole world but it is yet to be published[5].

3.3.5 Weighting

According to ISO norms, weighting is not usable for comparative assertions disclosed to the public (ISO14044) but one could use self-determined weighting factors or a default weighting factor of one, unless other social weighting values are available. Here weighting factor 1 has been considered for all damage categories.

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[5] http://www.impactworldplus.org/en/presentation.php

4.1 Introduction

The objective of the study is to collect the primary data and use it in a LCA software to find the environmental hotspot with a view to approach improvement actions over the supply chain of leather production in an export oriented industry in Bangladesh. Major data collection covers raw material supply, input chemical consumption, water and steam consumption, pollutant emission due to utilization of processing chemicals, annual electricity consumption, fuel oil consumption for generator and steam boiler. In addition extensive amount of data related to packaging production, electricity production, transportation, in house electricity production using generator, emission data of generator and diesel fueled steam boiler have been used from the software as proxy processes (application and database software). The following table 4-1 shows some values which were calculated or assumed to facilitate the analysis.

Table 4-1: Assumed values of few selected parameters

Particulars	**unit**	**Amount**
Total area of leather produced/yr.	m^2	650321
Total pieces of raw materials (Hides)		350000
Total weight of raw material	ton	3269
Total full-chrome crust leather (percent share is 60% of total crust leather production)	m^2	390192 (650321*0.6)
Total annual production of full-chrome natural(percent share is 70% of total full-chrome crust leather production)	m^2	273134 (390192*0.7)
Total retanned leather/yr. (percent share is 20% of total crust leather production)	m^2	130064 (650321*0.2)
Total chrome retanned crust leather/y (percent share is 20% of total crust leather production)	m^2	130064 (650321*0.2)
Total chrome retanned natural crust leather/yr.(percent share is 20% of total Chrome retanned crust leather production)	m^2	65032 (130064*0.5)
Average hide area	m^2	1.86

Particulars	unit	Amount
bale (a large wrapped bundle of paper/leather) capacity of distribution truck		160
area of one bale leather (consists of four roll leather)	m^2	83.61
Truck carrying capacity of crust leather	ton	20
Average weight of 1 m^2 crust leather accounting 90 pieces*1.86*250 (post-tanning input of leather)	Kg	1.49
Average carrying capacity of leather by Truck	ton	20
Average distance of Chittagong from Dhaka	km	263
Average distance of Nator from Hazaribagh, Dhaka	km	201
Average distance of Pabna from Hazaribagh, Dhaka	km	207
Average distance of Sirajgong from Hazaribagh, Dhaka	km	141
Average distance of different places of Dhaka from Hazaribagh	km	15
Total transport load for raw hides and skins	tkm	629857
Average working day	day	190
packaging material required for one bale	gram	549
packaging material required for 1 m^2 leather (divided by average area of one bale)	gram	6.56 (549/83.61)
Average annual electricity from in plant generator, (300 KVA is equivalent to 240 KW. Average run time of generator is 1 hr. and average working day is 190 days and the efficiency of the generator taken 90%)	kwh	41040 (240*1*190*0.9)
Annual electricity consumption from national power grid	kwh	149196
Annual total electricity	kwh	190236
Average diesel required daily for boiler	liter	200
Diesel consumption for generator(300 KVA, 40L) daily (Average run time 1 hr./day)	liter	50

Particulars	**unit**	**Amount**
Average raw material weight	kg	9.34
Average raw material capacity of truck		900
Average capacity of truck for raw material transport	ton	8.40 (9.34*900/1000)
Average amount of water flow in the pipe	m^3/min	0.092
Average input weight of raw material in presoaking having 150 pieces	Kg	1400
Average weight of limed pelt input in deliming having 75 pieces	Kg	1000
Average weight of shaved leather input in Acid wash having 90 pieces	Kg	250
Full-chrome processes steam consumption	tons/yr	121
Full-chrome processes steam consumption	tons/m^2	0.00044
Chrome retanned processes steam consumption	tons/yr	14
dryer steam consumption per hour	kg	140
Annual dryer steam consumption assuming ten hours working time a day and accounting 190 working days	ton	266 (140*190*10/1000)
Dryer steam consumption of full-chrome crust leather calculated by multiplying the percent share of total production	tons/m^2	0.00041 (266*0.6*0.7/273134)
Dryer steam consumption of chrome retanned crust leather calculated by multiplying the percent share of total production	tons/m^2	0.00041 (266*0.2*0.5/273134)
Full-chrome dryer steam consumption	tons/m^2	0.00097
Chrome retanned dryer steam consumption	tons/m^2	0.00409
Full-chrome production process steam consumption	tons/m^2	0.00044
Chrome retanned production process steam consumption	tons/m^2	0.00022
Annual vacuum dryer steam consumption assuming ten hours working a day and accounting 190 working days	ton	355

Particulars	**unit**	**Amount**
Full-chrome/chrome retanned vacuum steam consumption	tons/m^2	0.00055

4.2 Raw material supply

The company purchased 350000 pieces of raw wet salted cow hides in the fiscal year of 2013 to 2014 from different regions (Nator, Pabna, Sirajgong and different locations of Dhaka). The average percent share of each region is shown on the following table 4-2.

Table 4-2: Total raw material sources of company over the fiscal year 2013-2014

sources	**% share in decimal**	**Quantities in pieces (total raw 350000)** **A= 350000* percent**	**Raw weight, in tons (single raw weight,9.34 kg)** **B= A*9.34/1000**	**Number of trip require (truck average capacity, 8.406 ton)** **C=B/8.406**	**Distance from Hazaribagh, km** **D**	**Single trip Transport load in tkm** **E= 8.406*D**	**Total trip Transport load in tkm** **F=C*E**
Nator	0.86	301000	2811	334	201	1694	566766
Pabna	0.05	17500	163	19.44	207	1746	33964
Sirajgong	0.06	21000	196	23.33	141	1185	27655
Dhaka, different area (average distance)	0.03	10500	98	11.67	15	126	1471
						Total	629857.84

4.3 Input chemical consumption

In order to determine the chemical input for full-chrome and chrome retanned crust leather, 2013/14 budget year data were applied. During this time the company produced full-chrome, chrome retanned and retanned leather which will be used as shoe upper, bag leather. Of these, full-chrome leather shares were the maximum (around 60%) and this 60% again sub divided into 70% (full-chrome natural) and 30% (full-chrome of different colors). Chemical consumption to process 1 square meter raw material was calculated by using the standardized process recipe at each process stage. The input chemicals in the major production processes are given in table 4-3 and 4-4.The company have different process drum having different process capacity. Pre-soaking, soaking and liming drum can process 1400 Kg (150 pieces) of raw wet-salted hides per drum. Chemicals are usually added on the basis of percentage of raw hide's weight. After completing the above mentioned processes, next processes are deliming-bating, pickling and chrome tanning or pretanning (chrome retanned leather) where chemicals are added on the basis of limed pelt weight. They usually process 1000Kg (75 pieces) pelts per drum up to tanning. Then following some mechanical operations (sammying, splitting and shaving)wet-blue leather is subject to further processes like acidwash, rechroming or light rechroming (chrome retanned leather), neutralization, retanning, fatliquoring and top fat where chemicals are added on the basis of shaved weight. The drum capacity is 250 (90 pieces) kg shaved leather up to topfat process.

Table 4-3: Input chemical share of each processes for full-chrome crust leather

Production Processes	**Amount in Ton**	**process contribution in Decimal**	**Transport load in ton-km**
Pre-Soaking	4.12	0.0047	0.00
Soaking	15.10	0.0171	0.01
Liming	104.00	0.1180	0.10
Deliming and Bating	127.00	0.1442	0.12
Pickling	190.00	0.2152	0.18
Chrome tanning	178.00	0.2019	0.17
Acid wash	4.08	0.0046	0.00
Rechroming	62.50	0.0707	0.06
Neutralization	12.30	0.0139	0.01
Retanning	112.00	0.1267	0.11
Fatliquoring	61.00	0.0691	0.06
Top fat	12.30	0.0139	0.01
Total amount	883.00		

Table 4-4: Input chemical share of each processes for chrome retanned crust leather

Processes name	**Amount in ton**	**process contribution in Decimal**	**Transport load in ton-km**
Pre-Soaking	0.000015	0.00	0.0009
Soaking	0.000055	0.02	0.0035
Liming	0.000382	0.11	0.0239
Deliming and Bating	0.000466	0.14	0.0292
Pickling	0.000739	0.22	0.0463
Pretannage	0.000481	0.14	0.0301
Acid wash	0.000014	0.00	0.0008
Light Rechroming	0.000060	0.02	0.0038
Neutralization	0.000060	0.02	0.0038
Retanning	0.000840	0.25	0.0526
Fatliquoring	0.000266	0.08	0.0167
Top fat	0.000040	0.01	0.0025
Total amount	0.00342		

4.4 Water and steam consumption

The water consumption and the percentage share of boiled water and the boiled water temperature for each process have been shown at table 4-5, 4-6, 4-7 and 4-8. Each process water is calculated from the percent water given in the recipe. Calculation system used in calculating the amount of each chemical's weight is followed for this purpose. Finally the amount of water for a process in m^3 is converted to m^3 per $m^2$of substance by diving the corresponding area of process substance. For example, percent water of presoaking taking 1400kg as input is 2800 L (200% water) or 2.8 m^3 which is then divided by 150 (number of pieces of raw in presoaking) * 1.86 (average area of raw) and total discharge per year has been calculated by multiplying the total area of corresponding system. It has been found on an average that 0.092 m^3 water per minute is recharged into the drum while washing and washing is done in running water. Total amount of water required to wash after a chemical process is calculated by multiplying this flow rate with the total amount of washing time.

Table 4-5: Water consumption of each processes for full-chrome crust leather

Processes	**% water in decimal**	**water in m^3 (A)**	**Wash time in min**	**Wash water in m^3 (0.0920 m^3/min) (B)**	**Total in m^3 (A+B)**	**Per m^2 of Leather in m^3**	**total water per year per process in m^3**
Slaughtering Source : Joseph, K., et al. 2009	0	0	0	0	0	0.0090	2460
Presoaking	2	2.8	0	0	2.8	0.0100	2740
Presoaking Washing	0	0	45	4.14	4.14	0.0149	4060
Main soaking	0.8	1.12	0	0	1.12	0.0040	1100
Main Soaking Washing	0	0	45	4.14	4.14	0.0149	4060
Liming	1.1	1.54	0	0	1.54	0.0055	1510
Liming Washing	0	0	90	8.28	8.28	0.0297	8110
Closed drum wash	3	3	0	0	3	0.0215	5880
Deliming and Bating	1.5	1.5	0	0	1.5	0.0108	2940
Deliming-bating washing	0	0	60	5.52	5.52	0.0396	10800
Pickling	0.35	0.35	0	0	0.35	0.0025	686
chrome tanning	0.55	0.55	0	0	0.55	0.0040	1080
Acid wash	2	0.5	0	0	0.5	0.0030	817
Acid wash washing	0	0	5	0.46	0.46	0.0028	751
Rechroming	1.8	0.45	0	0	0.45	0.0027	735
Rechroming washing	0	0	15	1.38	1.38	0.0083	2250
Neutralization	1.5	0.375	0	0	0.375	0.0022	613
Neutralization washing	0	0	15	1.38	1.38	0.0083	2250
Neutralized closed drum washed	2	0.5	0	0	0.5	0.0030	817
Retanning	0.8	0.2	0	0	0.2	0.0012	327
Retanned closed drum wash	2	0.5	0	0	0.5	0.0030	817
Fatliquoring	1	0.25	0	0	0.25	0.0015	408
Fatliquoring washing	0	0	10	0.92	0.92	0.0055	1500
Top fat	1.5	0.375	0	0	0.375	0.0022	613

Table 4-6: Water consumption of each processes for chrome retanned crust leather

Processes	**% water in decimal**	**water in m^3 (A)**	**Wash time in min**	**Wash water in m^3 (0.0920 m^3/min) (B)**	**Total in m^3 (A+B)**	**Per m^2 of Leather in m^3**	**total water per year per process in m^3**
Slaughtering	0	0	0	0	0	0.0090	585
Presoaking	2	2.8	0	0	2.8	0.0100	653
Presoaking Washing	0	0	45	4.14	4.14	0.0149	966
Main soaking	0.8	1.12	0	0	1.12	0.0040	261
Main Soaking Washing	0	0	45	4.14	4.14	0.0149	966
Liming	1.1	1.54	0	0	1.54	0.0055	359
Liming Washing	0	0	90	8.28	8.28	0.0297	1930
Closed drum washing	3	3	0	0	3	0.0215	1400
Deliming and Bating	1.5	1.5	0	0	1.5	0.0108	700
Deliming and bating washing	0	0	60	5.52	5.52	0.0396	2580
Pickling	0.35	0.35	0	0	0.35	0.0025	163
Pretannage	0.35	0.35	0	0	0.35	0.0025	163
Acid wash	2	0.5	0	0	0.5	0.0030	194
Acid wash washing	0	0	5	0.46	0.46	0.0028	179
Light Rechroming	1	0.25	0	0	0.25	0.0015	97
Neutralization	1	0.25	0	0	0.25	0.0015	97
Retanning	1.5	0.375	0	0	0.375	0.0022	146
Retanning washing	0	0	10	0.92	0.92	0.0055	358
Fatliquoring	1.5	0.375	0	0	0.375	0.0022	146
Fatliquoring Washing	0	0	10	0.92	0.92	0.0055	358
Top fat	1.5	0.375	0	0	0.375	0.0022	146

Consumption of steams by different leather processes have been calculated by the following ways. Chrome retanned crust leather shares is around 20% of total leather production and this 20% again sub divided into 50% (chrome retanned natural) and other half is chrome retanned of different colors. The following assumptions were taken.

Temperature at boiler inlet 28.2° C (T_{i1})

Temperature at drum inlet 28.2° C (T_{i2})

Temperature at boiler outlet steam 300° C (T_{o1})

Temperature at drum inlet-2 (desired water) 60° C (T_{o2})

Maximum flow rate of water through boiler 1955 kg/hr

Boiler working hours, 10 hrs. /day

Total industry working day per year, 190 days

Process temperature T_{o3}(varied for each process)

Mass of steam m_s

Mass of water m_w

Volume of steam V_s

Volume of waterV_w

Specific heat C_p

Calculation of process steam for chrome retanned crust leather

Acid wash:

Process output temperature T_{o3}=35° C=308 K

Steam input -1$T_{i2} = 60° \text{ C} = 333\text{K}$

Water input$T_{i2} = 28.2° \text{ C} = 301.2\text{K}$

Volume of (water + steam)$1.94X10^2 m^3$

Properties of steam from steam table: for steam at 60° C

$h_{f1} = 251.1\ KJ/Kg$, $h_{fg} = 2358.6\ KJ/Kg$ and $h_{g1} = 2609.7\ KJ/Kg$

For saturated water at 35° C

$V_f = 0.001006\ m^3/Kg$, $h_{f2} = 146.5\ KJ/Kg$ and $h_{g2} = 2565\ KJ/Kg$

We know, heat rejected = Heat absorbed

$m_s\left(h_{g1} - h_{f2}\right) = m_w C_p \Delta T$

$m_s\,(2609.7 - 146.5) = m_w x 4.186 x (35 - 28.2)$

$2463.2 m_s = 28.4648\ m_w$

$m_w = 86.53 m_s$

But volume of water + steam = 194 m^3

So mass =194x1/0.001006 kg

Mass =192842.9 kg

$m_s + m_w = 192842.9$

$$m_s = 2203.16\frac{\text{kg}}{\text{yr}}$$

The same thing have been done for rechroming, neutralization, retanning, fatliquoring and Topfat processes of chrome retanned leather. In addition, Acidwash, rechroming, neutralization, neutralization closed drum washing, retanning, retanning closed drum washing, fatliquoring and Topfat processes of full-chrome followed the same calculation.

Table 4-7: share of boiled water and boiled water temperature of full-chrome crust leather

Processes name	**Corresponding temperature in °C**	**Amount in m^3**	**Steam consumed ton/ Year**
Acid wash	35	817	12.34
Rechroming	35	735	10.93
Neutralization	40	613	14.16
Neutralization closed Drum washing	45	817	25.6
Retanning	40	327	7.55
Retanning closed Drum Washing	45	817	25.56
Fatliquoring	50	408	16.1
Top Fat	35	613	9.12
Total steam			121.36
Steam consumed/m^2 of full-chrome crust leather			0.000444

Table 4-8: share of boiled water and boiled water temperature of chrome retanned crust leather

Processes name	**Corresponding temperature in °C**	**Amount in m^3**	**Steam consumed ton/ Year**
Acid wash	35	194	2.86
Retanning	35	146	2.1
Fatliquoring	45	146	4.52
Top fat	45	146	4.52
Total steam			14
Steam consumed/m^2 of chrome retanned crust leather			0.000215

In addition, vacuum dryer steam consumption for full-chrome and chrome tanned crust leather per m^2 are same and it is 0.0005 m^3. Dryer steam consumption of full-chrome and chrome retanned crust leather calculated by multiplying the percent share of total production and the value is same for both systems which is 0.0004 m^3 per m^2. Annual average total amount steam consumed by dryer is 266 tons, percentage share of all full-chrome crust leather of total crust leather production is 60%, full-chrome natural crust leather percentage share is 70% of total full-chrome share and total area of full-chrome natural crust leather is 273134 m^2. Calculation of dryer steam consumption by chrome retanned crust leather followed the same procedure above but the percentage share of all chrome retanned crust leather is 20% of total leather production, and chrome retanned natural crust leather percentage share is 50% of total chrome retanned share. Total area of chrome retanned natural crust leather is 65032 m^2.

4.5 Pollutant emission characterized from wastewater of full-chrome and chrome retanned crust leather

In the production of full-chrome and chrome retanned crust leather different types of chemicals are used in each processing stage. As a result each process stage has its own contribution on the overall chemical load of the effluent. Understanding the chemical load at each stage helps to identify which process contributes the highest share for pollution. It is also true for the lowest pollution share. In order to determine the emissions to water samples were collected from pre-soaking, main soaking, liming, deliming-bating, pickling, chrome tanning/pretannage (chrome retanned), acid wash, rechroming/light rechroming (chrome retanned), neutralization, retanning, fatliquoring and top fat and analyzed at Environmental Engineering laboratory, Civil Engineering, BUET. The table 4-9 to 4-12 below show the wastewater load of the production processes. The amount of different pollution loads from different processes are expressed as loads per m^2 of crust leather for both systems. As mentioned earlier presoaking to liming processes drums process 150 pieces of raw hides per drum and deliming to tanning drums process 75 pieces of pelts per drum and the all subsequent processes by diving the corresponding area of process substance. For example, percent water of presoaking taking 1400kg raw hides as input is 2800 L (200% water) or 2.8 m^3 which is then divided by 150 (number of pieces of raw in presoaking) * 1.86 (average area of raw). Total discharge per year has been calculated by multiplying the total area of corresponding system. This procedure has been followed for both systems.

Table 4-9: Waste water characterization of full-chrome crust leather production

	Unit	**Pre-soaking**	**Main soaking**	**Liming**	**Deliming-bating**	**Pickling**	**Chrome tanning**	**Acidwash**	**Re chroming**	**Neutralization**	**Re tanning**	**Fat liquoring**	**Top Fat**
pH		6.7	7.49	12.1	8.14	2.38	3.48	3.66	3.71	4.28	3.98	3.71	3.93
Chloride	mg/l	28000	26000	550	1650	26000	36000	2350	925	550	500	375	250
BOD_5	mg/l	3200	4600	8800	12000	2500	1800	400	800	1800	4400	4400	4400
COD	mg/l	8300	12600	34600	38100	4880	14500	4060	4380	5110	18400	13100	15600
TDS	mg/l	46	37	23	54	70	122	6	9	9	21	7	7
TS	mg/l	47	32	25	57	75	130	7	10	9	22	9	14
NO_3-N	mg/l	10	23	16	7	7	6	6	5	4	4	17	27
NO_2-N	mg/l	1	1	1	0	0	0.083	0.038	0.065	0.057	0	0.338	0.272
NH_3-N	mg/l	123	62	387	516	789	1080	22	22	5	106	97	98
PO_4	mg/l	122	37	22	13	94	3	4	5	4	10	10	8
SO_4	mg/l	425	713	interference	23800	12500	32500	1850	4530	3750	12100	4060	1480
S^{-2} (H_2S)	mg/l	0	5210	1350	4180	0	0	50	125	75	1780	4200	2650
Total Cr	ppm	Not done	Not done	Not done	Not done	Not done	7680	1320	7700	1770	Not done	Not done	Not done
Cr^{+6}	ppm	Not done	Not done	Not done	Not done	Not done	0.1400	0.0040	0.0240	0.0470	Not done	Not done	Not done
Organic N	mg/l	0	125	234	2790	1420	1170	10	89	5	303	377	28
TKN	mg/l	123	188	621	3310	2210	2250	32	111	10	409	474	126

Table 4-10: Waste water characterization of full-chrome crust leather production/m^2 result.

	Unit	**Pre-soaking**	**Main soaking**	**Liming**	**Deliming - bating**	**Pickling**	**Chrome tanning**	**Acidwash**	**Re chroming**	**Neutralization**	**Re tanning**	**Fat liquoring**	**Top Fat**
Chloride	mg/m^2	281000	104000	3040	17800	65300	142000	7030	2490	1230	598	561	561
BOD_5	mg/m^2	32100	18500	48600	129000	6280	7100	1200	2150	4040	5260	6580	9870
COD	mg/m^2	83400	50600	191000	410000	12300	57400	12100	11800	11500	22000	19500	34900
TDS	mg/m^2	458	147	128	582	176	481	18	25	19	26	10	17
TS	mg/m^2	475	127	137	608	188	512	20	26	20	26	13	31
NO_3-N	mg/m^2	100	92	88	75	16	24	18	14	8	4	25	61
NO_2-N	mg/m^2	5	6	5	2	0.136	0.328	0.114	0.175	0.128	0.086	0.505	0.610
NH_3-N	mg/m^2	1240	250	2140	5560	1980	4250	66	59	10	127	145	219
PO_4	mg/m^2	1220	148	122	138	237	11	11	14	9	12	14	18
SO_4	mg/m^2	4270	2860	interference	256000	31400	128000	5530	12200	8410	14500	6070	3310
S^{-2} (H_2S)	mg/m^2		52400	5430	23100	0	0	197	374	202	3980	5020	3960
Total Cr	ppm/m^2	not done	not done	not done	not done	not done	30300	3950	20700	3980	not done	not done	not done
Cr^{+6}	ppm/m^2	not done	not done	not done	not done	not done	0.553	0.012	0.065	0.105	not done	not done	not done
TKN	mg/m^2	1240	754	3430	35600	5550	8860	95	298	21	489	709	282

Table 4-11: Waste water characterization of chrome retanned crust leather production

	Unit	Pre-soaking	Main soaking	Liming	Deliming-bating	Pickling	Chrome tanning	Acidwash	Re chroming	Neutralization	Re tanning	Fat liquoring	Top Fat
pH		6.7	7.49	12.1	8.14	2.38	2.98	3.39	3.18	4.06	4.59	3.8	4.04
Chloride	mg/l	28000	26000	550	1650	26000	1550	1550	660	850	575	625	375
BOD$_5$	mg/l	3200	4600	8800	12000	2500	2250	175	100	350	2800	10400	1800
COD	mg/l	8300	12600	34600	38100	4880	6920	360	650	2640	30500	23900	6160
TDS	mg/l	46	37	23	54	70	61	3	3	7	28	13	3
TS	mg/l	47	32	25	57	75	63	4	3	7	12	13	4
NO$_3$-N	mg/l	10	23	16	7	7	6	6	5	4	7	3	4
NO$_2$-N	mg/l	1	1	1	0	0	0	0.018	0.020	0.018	0.081	0.247	0.290
NH$_3$-N	mg/l	123	62	387	516	789	544	4	6	7	448	47	13
PO$_4$	mg/l	122	37	22	13	94	212	21	18	33	83	56	22
SO$_4$	mg/l	425	713	interference	23800	12500	30800	475	1000	2830	675	1530	675
S^{-2} (H$_2$S)	mg/l	to b done	5210	1350	4180	0	0	25	25	25	5450	6400	2450
Total Cr	ppm	not done	not done	not done	not done	not done	2150	236	2490	1260	not done	not done	not done
Cr^{+6}	ppm	not done	not done	not done	not done	not done	0.060	0.011	0.013	0.009	not done	not done	not done
Organic N	mg/l	0	125	234	2790	1420	492	6	8	100	235	169	25
TKN	mg/l	123	188	621	3310	2210	1040	10	14	107	683	217	38

Table 4-12: Waste water characterization of chrome retanned crust leather production/m^2 result

	Unit	**Pre-soaking**	**Main soaking**	**Liming**	**Deliming-bating**	**Pickling**	**Chrome tanning**	**Acidwash**	**Re chroming**	**Neutralization**	**Re tanning**	**Fat liquoring**	**Top Fat**
Chloride	mg/m^2	281000	104000	3040	17800	65300	3890	4630	987	1270	1290	1400	841
BOD_5	mg/m^2	32100	18500	48600	129000	6280	5650	523	149	523	6280	23300	4040
COD	mg/m^2	83400	50600	191000	410000	12300	17400	1080	972	3950	68400	53600	13800
TDS	mg/m^2	458	147	128	582	176	154	10	5	11	62	29	8
TS	mg/m^2	475	127	137	608	188	158	11	5	11	26	30	8
NO_3-N	mg/m^2	100	92	88	75	16	15	16	7	6	16	7	9
NO_2-N	mg/m^2	5	6	5	2	0.136	0.108	0.054	0.029	0.027	0.182	0.554	0.650
NH_3-N	mg/m^2	1240	250	2140	5560	1980	1370	12	8	10	1000	106	30
PO_4	mg/m^2	1220	148	122	138	237	532	62	27	49	187	126	49
SO_4	mg/m^2	4270	2860	0	256000	31400	77200	1420	1490	4220	1510	3420	1510
S^{-2} (H_2S)	mg/m^2	0	52400	5430	23100	0	0	63	75	37	8150	14400	5490
Total Cr	ppm/m^2	not done	not done	not done	not done	not done	5410	704	3720	1880	not done	not done	not done
Cr^{+6}	ppm/m^2	not done	not done	not done	not done	not done	0.151	0.033	0.019	0.014	not done	not done	not done
TKN	mg/m^2	1240	754	3430	35600	5550	2600	31	21	160	1530	486	86

4.6 Electricity and transport loads

In a tannery different types of machineries are used and also the water consumption is too much as compared to other industries (Hoekstra 2010). The processes from the tanning operation to top fat use steam for facilitating the chemical penetration. For this purpose the company produces steam by using boiler using diesel oil and gas but presently they are using only diesel. For the delivery of chemicals, raw material and for other purpose the company uses vehicles that consume diesel oil. Table 4-13 and 4-14 show annual average electricity consumption of full-chrome and chrome retanned crust leather. Calculation of electricity consumption per $m^2$is obtained dividing the percent share of electricity by total area of that particular leather. Percentage share of all full-chrome crust leather of total crust leather (principle) production is 60%, full-chrome natural crust leather (studied article) percentage share is 70% of total full-chrome share and total area of full-chrome natural crust leather is 273134 m^2. Calculation of electricity (from national grid and in house generator) consumption by chrome retanned crust leather followed the same procedure above but the percentage share of all chrome retanned crust leather is 20% of total leather production, and chrome retanned natural crust leather percentage share is 50% of total chrome retanned leather. Total area of chrome retanned natural crust leather is 65032 m^2.

Table 4-13: Annual electricity consumption of full-chrome and chrome retanned crust leather from national grid.

	Full-chrome crust leather in Kwh	**Chrome retanned crust leather in Kwh**
Annual electricity from power grid	149196	149196
Average share of principal article (60% and 20% of total production respectively)	89517	29839
Average share of studied article (70% and 50% of Principal article respectively)	62662	14919
Average share/m^2	**0.229**	**0.229**

Table 4-14: Annual electricity consumption of full-chrome and chrome retanned crust leather from generator.

	Full-chrome crust leather in Kwh	**Chrome retanned crust leather in Kwh**
Annual electricity from Generator	41040	41040
Average share of principal article (60% and20% of total production respectively)	45600	8208
Average share of studied article (70% and50% of Principal article respectively)	31920	4104
Average share/m^2	0.117	0.028

Transport load of full-chrome and chrome retanned crust leather for raw material, chemical and delivery have been shown in table 4-15 to 4-17. A ton-kilometer, abbreviated as tkm, is a unit of measure of freight transport which represents the transport of one ton of goods by a given transport mode (road, rail, air, sea, inland waterways, pipeline etc.) over a distance of one kilometer[6].Calculation of total transport load of raw materials has been shown in the table 4-2 which is 629857 tkm. Then transport load for raw material of both systems have been calculated according to the percent share concept mentioned earlier.

Table 4-15: transport load of full-chrome and chrome retanned crust leather for raw material.

	Full-chrome crust leather, transport load in tkm	**Chrome retanned crust leather, transport load in tkm**
Average share of principal article (60% and 20% of total production)	377914 (629857*0.6)	125971 (629857*0.2)
Average share of studied article (70% and 50% of Principal article)	264540	62985

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[6] https://www.google.com.bd/search?q=define+freight+tonne+kilometersandoq=define+ton+kilometandaqs=chrome.1.69i57j0.28843j0j9andsourceid=chromeandespv=2andes_sm=122andie=UTF-8#q=define+tkm

Average share/m^2	0.97	0.97

Total amount of chemicals have been calculated from the recipes which is shown in table 4-20. Chemicals are usually added on the basis percentage of substance's weight. Amount of chemical used in pre-soaking, soaking and liming processes calculated based on 1400 Kg (150 pieces) of raw wet-salted hides. After completing the above mentioned processes, next processes are deliming and bating, pickling and chrome tanning or pretanning (chrome retanned crust leather) where amount of chemicals calculated based on limed pelts weight which is 1000Kg (75 pieces). Then the amount of chemicals of the following processes acidwash, rechroming or light rechroming (chrome retanned leather), neutralization, retanning, fatliquoring and top fat calculated based on shaved weight which is 250kg (90 pieces). Assuming truck capacity 20 tons, total trip number has been calculated from the total amount of chemicals. Transport load for a single trip is obtained multiplying the distance of Chittagong (263 km) with the truck capacity. After having this value, total transport load was calculated by multiplying single trip load with the total number of trips. Finally the amount of transport load per m^2 in tkm was obtained dividing the total load by total area of each leather.

Table 4-16: transport load of chemical for full-chrome and chrome retanned crust leather.

	Unit	**Full-chrome crust leather**	**Chrome retanned crust leather**
total amount of chemical	ton	883	222
Average capacity of cargo truck	ton	20	20
total trips required		44	11
total distance travelled	km	11600	2920
single trip transport load	tkm	5260	5260
Total trip transport load	tkm	232000	58500
Transport load/m^2	Tkm/m^2	0.851	0.214

Table 4-17: transport load of full-chrome and chrome retanned crust leather for product delivery.

	Unit	**Full-chrome crust leather**	**Chrome retanned crust leather**
Average cargo truck capacity	ton	20	20

	Unit	**Full-chrome crust leather**	**Chrome retanned crust leather**
Total amount of leather,	m^2	273000	65000
Average crust weight		1.49	1.49
total weight of leather	ton	408	97
total trip required		20	5
Transport load for single trip	tkm	5260	5260
Total transport load	tkm	107000	25600
Transport load/m^2	tkm/m^2	0.393	0.393

4.7 Solid waste generation of both systems

Solid waste generation corresponding to both systems has been listed below in table 4-18 sourced from the book titled "From collagen to leather - the theoretical background" by Günter Reich (Reich 2007).

Table 4-18: Amount of solid waste generated during production of both systems.

Waste/byproduct name	**Amount kg/m^2**
Dedusted salt	0.15
Trimming waste	0.8307
Glue stock	1.5975
split waste (machine offal)	0.8307
split and trimming waste	0.3834
Split leather in m^2/m^2	0.42
Shaving waste	0.639
crust trimming	0.045

4.8 Air emission from combustion of diesel in boiler

The primary pollutants from generator are oxides of nitrogen (NO_x), hydrocarbons and other organic compounds, carbon monoxide (CO). Ash and metallic additives in the fuel also contribute to the particulate content of the exhaust. Sulfur oxides also appear in the exhaust. The sulfur compounds, mainly sulfur dioxide (SO_2), are directly related to the sulfur content of the fuel. Pollutant emission factors for diesel combusted in industrial boiler (Table 4-19) sourced from U.S environmental protection agency and Ventura county air pollution control district websites indicated below at the footnote number 6-7. SimaPro proxy process "Diesel combusted in industrial boiler" input unit is liter so these emission factors simply converted into kg/l.

Table 4-19: Pollutant emission factors for fuel oil diesel combustion in industrial boiler

Pollutants	**internal combustion Emissions (lb./1000 gal)**	**Emissions (Kg/l)**
Benzene	0.186	0.000022
Formaldehyde	1.730	0.000207
PAH's (including naphthalene)	0.056	0.000007
Naphthalene	0.020	0.000002
Acetaldehyde	0.783	0.000094
Acrolein	0.034	0.000004
1,3-butadiene	0.217	0.000026
Hexane	0.027	0.000003
Toluene	0.105	0.000013
Xylenes	0.042	0.000005
Hydrogen chloride	0.186	0.000022
Arsenic	0.002	0.0000002
Cadmium	0.002	0.0000002
Total chromium	0.001	0.0000001
Hexavalent chromium	0.000	0.0000000
Copper	0.004	0.0000005
Lead	0.008	0.000001
Manganese	0.003	0.0000004
Mercury	0.002	0.0000002
Nickel	0.004	0.0000005
Selenium	0.002	0.0000003
Zinc	0.022	0.000003
SO_2	150	0.018000
SO_3	2	0.000240
Nitrogen oxides	20	0.002400
CO	5	0.000599
PM	7	0.000839
TOC	0.556	0.000067
ethane	0.216	0.000026

4.9 Production processes of full-chrome and chrome retanned leather

Production recipe of full-chrome and chrome retanned leather has been shown in table 4-20. It shows only chemicals with their corresponding amounts per meter square used during production. Process total implies only the total amount of chemical of concern unit process excluding water amount.

Table 4-20: Comparative representation of full-chrome and chrome retanned crust leather recipe

Processes name	**Quantities in kg per m^2 of full-chrome crust leather**	**Chemical used For full-chrome curst leather**	**Quantities in kg per m^2 of chrome retanned crust leather**	**Chemicals used For chrome retanned crust leather**
Pre-Soaking	10 0.005 0.010	Water Busperse 7794(surfactant) Sodium Hydroxide	Same	Same
Process total, kg	0.015			
Soaking	4.020 0.010 0.015 0.025 0.005	Water Bushan 40L (bactericides) Busperse 7794 Sodium Carbonate Vinkol A (proteolytic enzymes)	Same	Same
Process total, kg	0.055			
Liming	4.020 0.060 0.075 0.010 0.040 0.035 0.050 0.025 1.510 0.075 0.010	Water Busperse7743 A Lime Adusin P Sodium sulfide Sodium sulfide Sodium sulfide sodium Hydrosulfide Water Lime Busperse 7794 **Fleshing, Scudding and Weighing**	Same	Same
Process total, kg	0.382			

Processes name	**Quantities in kg per m^2 of full-chrome crust leather**	**Chemical used For full-chrome curst leather**	**Quantities in kg per m^2 of chrome retanned crust leather**	**Chemicals used For chrome retanned crust leather**
Deliming-bating	21.50	Water	Same	same
	10.80	Water		
	0.036	Ammonium Sulfate		
	0.036	Sodium Meta bi sulfate		
	0.086	Busperse 7796 (Nitrogen free deliming agent)		
	0.022	Sodium Meta bi sulfate		
	0.179	Ammonium Sulfate		
	0.072	Tripsol D (Protease enzyme for bating)		
	0.036	Busperse 7794		
Process total, kg	0.466			
Pickling	5	water	5.02	water
	0.574	Sodium Chloride	Same	Same
	0.007	Impropel CO (Sodium chlorite)	0.014	Impropel CO (Sodium chlorite)
	0.043	Forming Acid	Same	Same
	0.072	Sulfuric Acid	Same	Same
Process total, kg	0.696		0.739	

Processes name	**Quantities in kg per m^2 of full-chrome crust leather**	**Chemical used For full-chrome curst leather**	**Quantities in kg per m^2 of chrome retanned crust leather**	**Chemicals used For chrome retanned crust leather**
Chrome tanning/Pretannage	0.014 0.287 0.287 0.014 0.050 1.440	hypo (Sodium thiosulfate) Chrome powder (Basic chromium sulfate) Chrome powder Bushan 30L MON (Magnesium oxide) water having 50°C temperature pile up	0.036 0.144 0.025 0.013 0.018 0.144 0.072 0.065 0.002	hypo Chrome powder (Basic chromium sulfate) PEM (Chrome stable fat) Bushan 30L Derugan Z(Styrene acrylate with glutardialdehyde) RWP (phenol based condensation syntan) Tanigan OS (pretanning syntan) Sodium Bi carbonate Bushan 30L pile up
Process total, kg	0.653		0.481	
Acid wash	2.990 0.003 0.003 0.009	water Busperse 7794 Atlasol 177C (Chrome stable fat) oxalic acid	Same 0.006 0.007	Same Busperse 7794 oxalic acid
Process total, kg	0.015		0.014	
Rechroming/Light Rechroming	1.20 0.03 0.001 0.09 0.06 0.015 0.012 0.015 1.49 0.006	water Relugan RF (Acrylic co-polymer) Formic acid Tankrom AB (Basic chromium sulfate) CP super (Chrome Syntan) Sodium Formate Atlasol 177C Sodium Formate water Sodium Bi carbonate	1.490 0.030 0.030	water Z-100/PF Tankrom AB (Basic chromium sulfate)

Processes name	**Quantities in kg per m^2 of full-chrome crust leather**	**Chemical used For full-chrome curst leather**	**Quantities in kg per m^2 of chrome retanned crust leather**	**Chemicals used For chrome retanned crust leather**
Process total, kg	0.229		0.06	
Neutralization	2.240 0.030 0.015 2.990	water Sellasol NG (Neutralizing syntan) Sodium Formate water	1.49 0.03 Same 0.015	water PAKS Same Leukatan 1084
Process total, kg	0.045		0.06	
Retanning	1.20 0.075 0.009 0.009 0.06 0.06 0.06 0.06 0.03 0.003 0.030 0.015 2.990	water RCN 40 (Acrylic resin) perfectol HQ (water proofing fat) 400R (Fish oil) Basyntan DLE (Bleaching syntan) SA (Bleaching syntan) Tanigan OS (pretanning syntan) DF 585 (Dicyamine di amide) R7 (Dicyamine di amide) R 1-2 (Lanoline fat) MAU (Amphoteric melamine resin) Formic acid water	1.490 0.075 0.030 0.007 0.120 0.030 0.030 0.060 0.015 0.075 0.006 0.120 0.045 0.030 0.030 0.015 0.045 0.030 0.030 0.030 0.007 0.747 0.004 0.007	water Leukatan 1084 SMC SL 335 Mimosa SD Quebracho Basyntan AN DF 585 (Dicyamine di amide) GM Chittagur Trilon B (EDTA) Mimosa SD R7 SA (Bleaching syntan) Tanigan OS (pretanning syntan) GM Mimo GS Basyntan AN Tanigan OS (pretanning syntan) GM Provol 100 water Trilon B (EDTA) Formic acid
Process total, kg	0.41		0.84	

Processes name	**Quantities in kg per m^2 of full-chrome crust leather**	**Chemical used For full-chrome curst leather**	**Quantities in kg per m^2 of chrome retanned crust leather**	**Chemicals used For chrome retanned crust leather**
Fatliquoring	1.49 0.036 0.001 0.06 0.03 0.009 0.006 0.006 0.001 0.06 0.015	water Butan 1908 (Filler syntan) Trilon B (EDTA) Atlasol 178 (semi synthetic fat) FL 327 (synthetic fat) OSL (synthetic fat) 30 CT (Neats fool oil) Provol BA (synthetic softener) Bushan 30L (fungicide) MT (Styrene maleic acid resin copolymer) Formic acid	2.24 0.03 0.003 0.052 0.045 0.022 0.022 Same 0.045 0.022	water Leukatan 1084 Trilon B (EDTA) FL 327 (synthetic fat) SL 335 Butan oil 1919 Provol BA (synthetic softener) Polyol AK Same SMC Formic acid
Process total, kg	0.224		0.266	
Top fat	2.24 0.03 0.009 0.006 Horse up, Setting out, vacuum dry, hang to dry	water SA (Bleaching syntan) CA (cationic fat) 1919 (cationic surface lubricant)	2.240 0.007 0.015 0.007 0.003 0.007	water Provol BA (synthetic softener) Provol 100 Telgas T Trilon B (EDTA) Formic acid Horse up, Setting out, vacuum dry, hang to dry
Process total, kg	0.045		0.04	
Total amount of chemicals for 1 m^2leather, kg	3.23		3.42	

CHAPTER 5 RESULT AND DISCUSSION

5.1 Introduction

This chapter deals with the results obtained from SimaPro. SimaPro is used to analyze and compare the life cycles of two systems namely full-chrome and chrome retanned crust leather which is a LCA software tool used to collect, analyze and measure the environmental impact of products (full-chrome and chrome retanned leather) across all life cycle stages and identify the hotspots in all aspects of supply chain. This software is integrated with various databases and impact assessment methods. As the Company is export oriented it is mandatory to give priority for improving the environmental activities. To do so the goal and scope of LCA defined and the major production related activities were considered. The required data in relation to the fore mentioned activities were collected. Primary and secondary data were used along with the few proxy processes like electricity production, packaging, and diesel combusted in industrial boiler, energy from generator, transport for raw material, transport for chemical and transport for product delivery. Slaughtering and production processes having different pollution loads were created as new processes in the inventory section of the software. Then all the upstream, core stream and downstream processes of full-chrome and chrome retanned crust leather were assembled into corresponding product assemblies according to the basic principle of LCA (here cradle to gate approach considered).The next step after collecting and input as inventory data was conducting impact assessment. Impact 2002+ impact assessment method were chosen to analyze and compare two systems which characterizes and assesses the effects of the environmental burdens identified in the inventory. In LCA the production system is examined from an environmental perspective using category indicators. This method links all types of LCI results via several midpoint categories like carcinogens, non-carcinogens, respiratory inorganics, respiratory organics, ionizing radiation, ozone layer depletion, aquatic ecotoxicity, terrestrial ecotoxicity, aquatic acidification, aquatic eutrophication, terrestrial acidification/nitrification, land occupation, global warming, non-renewable energy consumption and mineral extraction to four damage categories (human health, ecosystem quality, climate change and resources). Linking to midpoint is associated with certain conversion factors for each pollutant and conversion to damage categories is also associated with damage factors. The full-chrome and chrome retanned systems have been analysed in parallel through the LCA methodology in order to identify the hot spots, to find which production systems are less burdening to environment and to find where the environmental performance can be improved. The midpoint characterized values and endpoint damages values indicated which life cycles processes contributed much and the comparative assessment of these values indicated which system is less burden to environment.

5.2Characterization assessment

Environmental loads are same for both systems up to pickling process since they consume same input and same process flow. It will be same for any comparison between these two systems. Fig. 5-1 to 19 show the relative contribution to the following impact categories namely carcinogens, non-carcinogens , respiratory inorganics, respiratory organics, ionizing radiation, ozone layer depletion, aquatic ecotoxicity, terrestrial ecotoxicity, aquatic acidification, aquatic eutrophication, terrestrial acidification/nitrification, land occupation, global warming, non-renewable energy consumption, mineral extraction. Fig. 5-24 to 29 show the contribution to four damage categories namely human health, ecosystem quality, climate change, and resources. In addition, fig. 5-20 to 5-23 show the software generated damage assessment results.

5.2.1 Aquatic ecotoxicity

Fig. 5-1 shows the comparative contribution of life cycle processes to the aquatic ecotoxicity between two systems namely full-chrome and chrome retanned crust leather production and Fig 5-2 (a) and (b) show the percentage share of different life cycle processes to aquatic ecotoxicity of each system. According to figure 5-1, 5-2 (a) and (b), aquatic ecotoxicity category is strongly dominated by production processes. In all cases, full-chrome processes contributed more compared to chrome retanned crust leather. Among these processes, tanning, rechroming and acidwash of full-chrome system contribute more than 5.5 times higher compared to those in chrome retanned system. According to fig. 5-1, in both systems, largest contribution comes from tanning followed by rechroming, neutralization and acidwash which are 1.37E+04 and 2.45E+03, 9.38E+03 and 1.69E+03, 1.80E+03 and 8.52E+02 and 1.79E+03 and 3.19E+02 kg TEG water per m^2 respectively. Noticeably, the rest of the processes include transport, raw; transport, chem; electricity; electricity, gen; diesel, refinery, trans; diesel, refinery, gen.; diesel, boiler; transport, diesel; deliming-bating; tanning; acidwash; rechroming; neutralization; packaging and transport, prod contribute least among all processes which is 3.23E+01and 2.85E+01 kg TEG water per m^2

for both systems respectively. According to Fig 5-2 (a) and (b), in case of full-chrome system, tanning contributed much which is 51% followed by rechroming amounting 35% compared to 46% and 31% respectively of chrome retanned crust leather . In addition, Neutralization of chrome retanned system contributed much higher, which is 16% compared to corresponding process of full-chrome system which is only 7%. The ecotoxicity of these processes mentioned above is due to the associated heavy metal chromium emission into water. It is clear from the above results that production processes of both systems contributed almost 100% to this category and this category is mainly associated with high heavy metal chromium emission. In addition, release of ammonia into air and water also contributed to this characterization category.

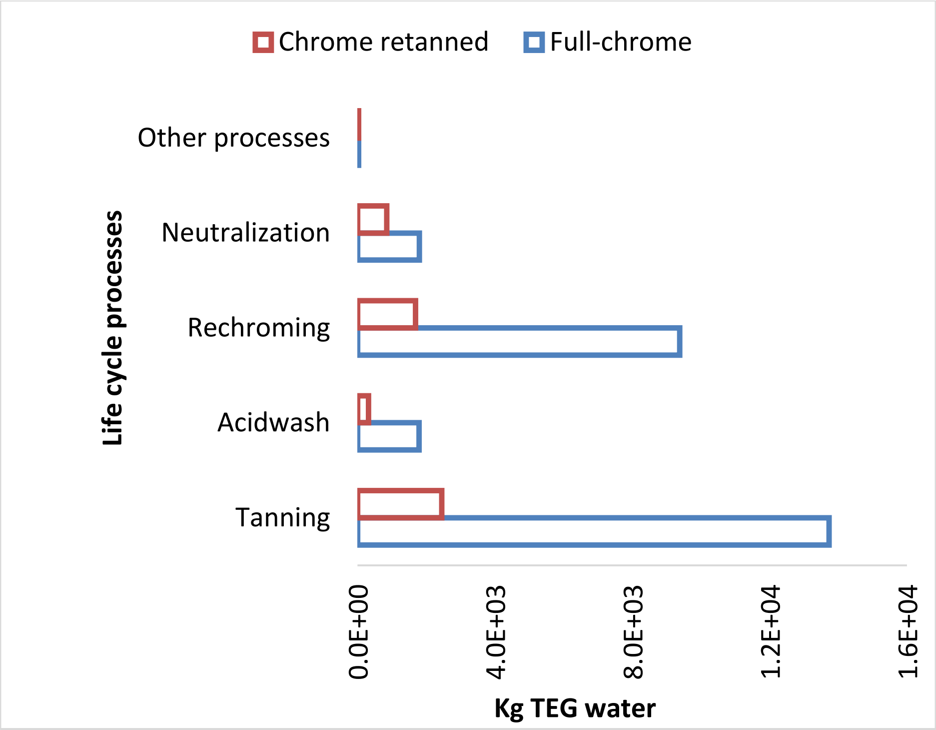

Figure 5-1: This figure shows the relative contribution of life cycle processes to the aquatic ecotoxicity between full-chrome and chrome retanned curst leather production.

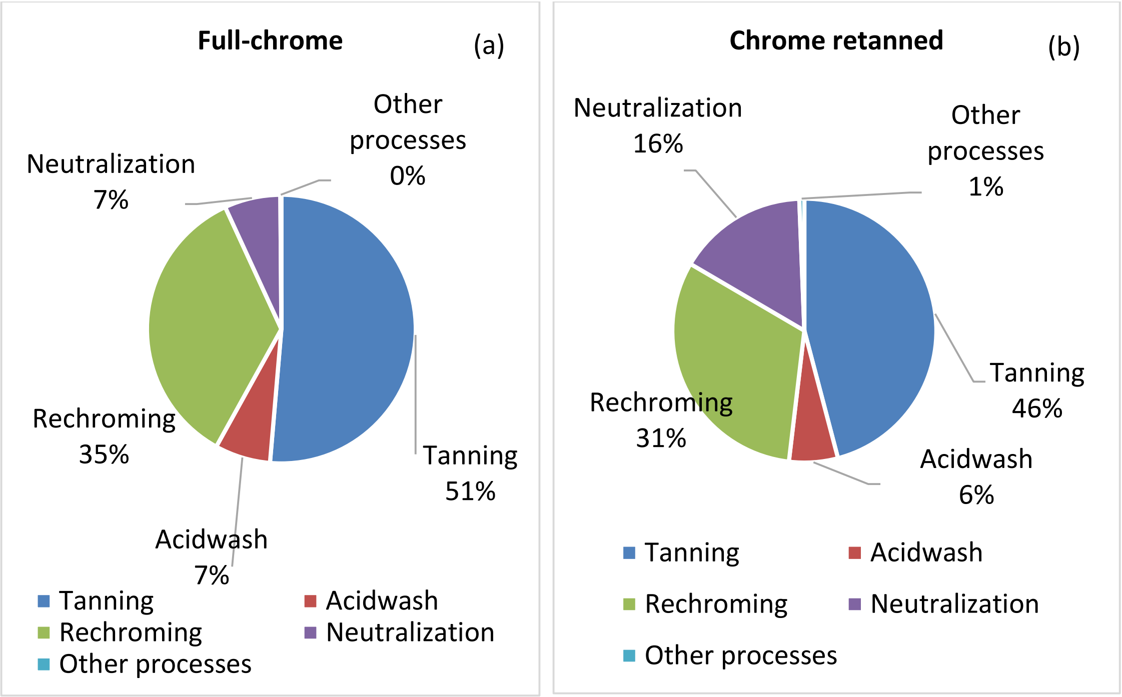

Figure 5-2 (a) and (b): These show the comparative approach to aquatic ecotoxicity of different life cycle processes for both systems.

5.2.2 Aquatic acidification

Fig. 5-3 shows the relative contribution of different life cycle processes to the aquatic acidification and Fig 5-4 (a) and (b) show the percentage share of different life cycle processes to aquatic ecotoxicity of each system. According to figure 5-3, 5-4 (a) and (b), aquatic acidification category is dominated by mainly production processes but supply chain processes contribution is also noticeable. Jointly deliming and bating process contributed much higher followed by liming, pickling and presoaking where deliming and bating is about 3 times higher than pickling. Other processes like transport for raw, chemical and main soaking having same value contributed less compared to above mentioned processes. According to fig. 5-3 the amount of Kg SO_2 eq emitted by deliming-bating, liming, pickling and presoaking processes are 0.0127, 0.0049, 0.0045and 0.0028 per m^2 respectively for both systems. Among the processes having different contributions, tanning of full-chrome contributed much higher compared to chrome retanned process which is more than 3 times greater and this is the 2nd highest emitter where corresponding amounts are 0.0097 and 0.0031 kg SO_2 eq per m^2 respectively. In addition, retanning of chrome retanned system is about 8 times higher than corresponding process of full-chrome system and top fat and fatliquoring contributed least. Other processes include electricity; electricity, gen; diesel, refinery, trans; diesel, refinery, gen.; transport, diesel; acidwash; rechroming; neutralization; packaging and transport, prod. According to Fig.5-4 (a) and (b), in case of full-chrome system, deliming and bating contributed much which is 30% followed by tanning amounting to 23% compared to 34% and 8% respectively of chrome retanned leather. Liming and pickling of chrome retanned crust leather contributed higher than corresponding tanning which are 13% and 12% respectively. Above all, more than 90% contributed by production processes in both system. The aquatic acidification of these processes mentioned above is due to ammonia emission into air and water; ammonia as N and hydrogen sulfide emission into water.

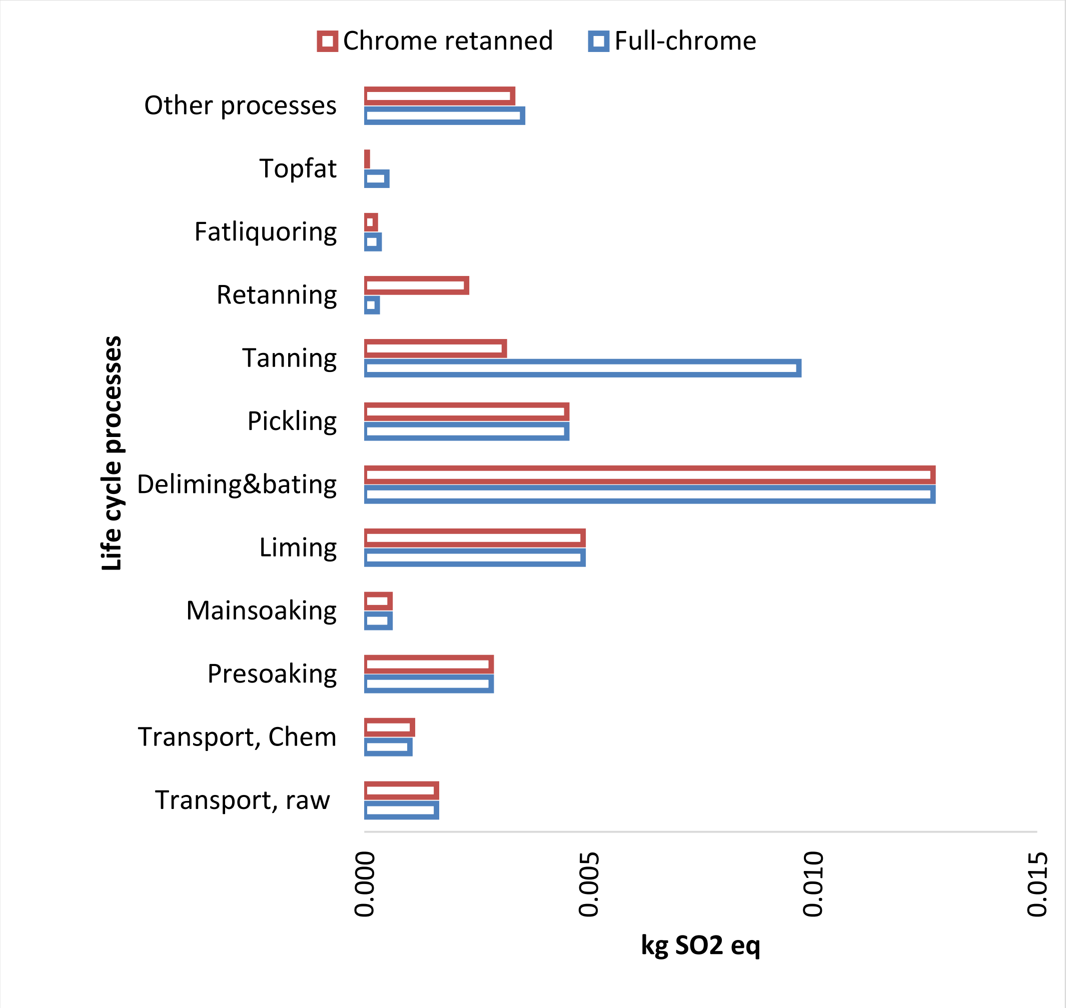

Figure 5-3: This figure shows the relative contribution of life cycle processes to the aquatic acidification between full-chrome and chrome retanned leather production.

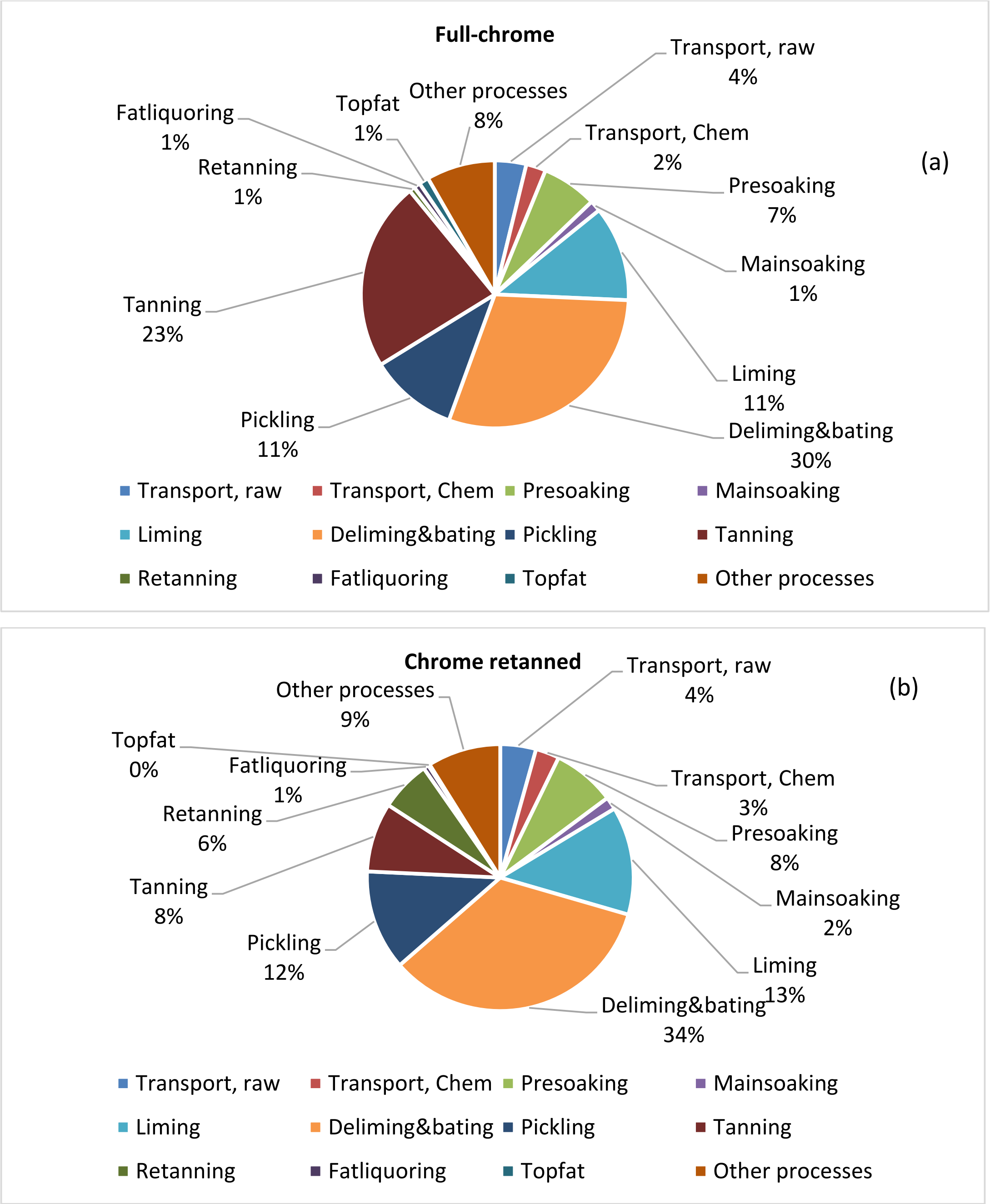

Figure 5-4 (a) and (b): These figures show the comparative approach to aquatic ecotoxicity of different life cycle processes for both systems.

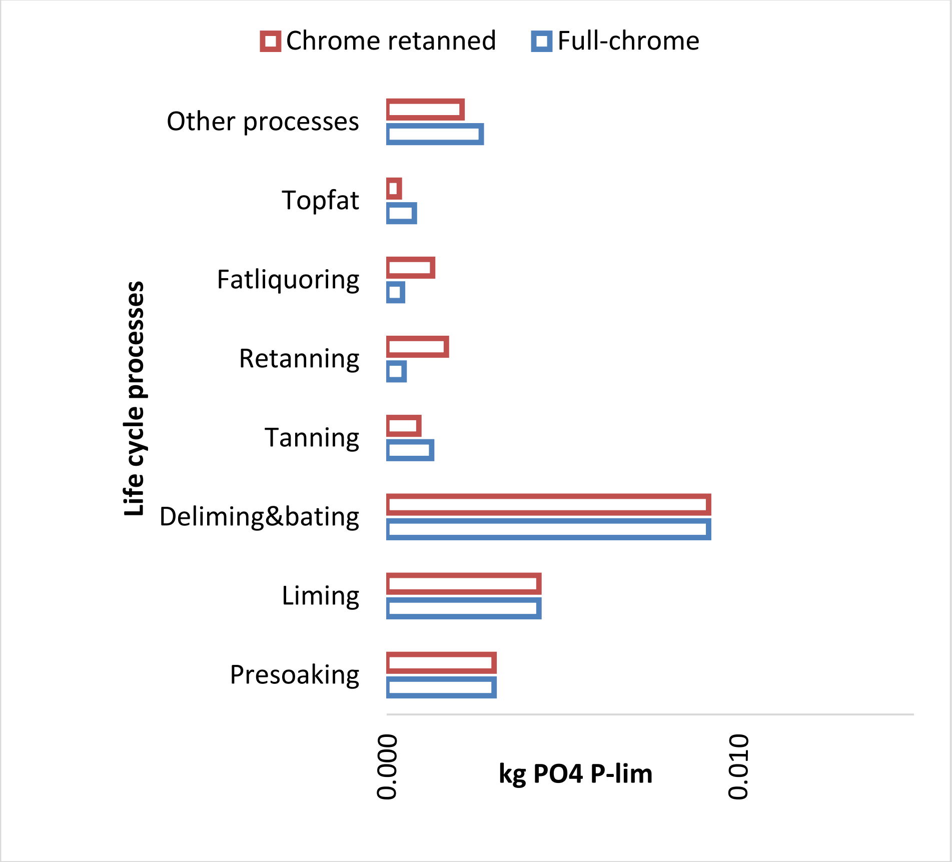

Figure 5-5: This figure shows the relative contribution of life cycle processes to the aquatic eutrophication between full-chrome and chrome retanned leather production.

5.2.3 Aquatic eutrophication

Fig. 5-5 shows the relative contribution of different life cycle processes to the aquatic eutrophication and Fig 5-6 (a) and (b) show the percentage share of different life cycle processes to aquatic eutrophication of each system. According to figure 5-5, 5-6 (a) and (b), aquatic eutrophication category is contributed by the production processes. Jointly deliming-bating process contributed much higher followed by liming and presoaking. According to fig. 5-5, the amount of kg PO_4 P-lim emitted by the above processes are 0.0092, 0.0043 and 0.0031per m^2 respectively. Noticeably, deliming-bating is 3 times greater than presoaking and more than 2 times of liming process. Though retanning, fatliquoring, tanning and top fat production processes of both systems contributed less compared to above mentioned processes but retanning and fatliquoring of chrome retanned system are about 3.5 and 3 times greater than corresponding processes of full-chrome system. In addition, top fat and tanning of full-chrome are more than 2 times and about

1.5 times higher than corresponding chrome retanned processes. Other processes include slaughtering, electricity, diesel, refinery, trans; diesel, refinery, gen.; main soaking, pickling; acidwash; rechroming; neutralization and packaging. According to Fig. 5-6 (a) and (b), deliming-bating contributed much followed by liming and presoaking and the corresponding percent share of full-chrome crust leather for the above processes are 41%, 19% and 14% respectively and chrome retanned system is almost same in terms of percent share. It is clear that production processes of both systems contributed more or less 90% to this category. The aquatic eutrophication of these processes mentioned above is due to higher COD and PO_4 discharge into water.

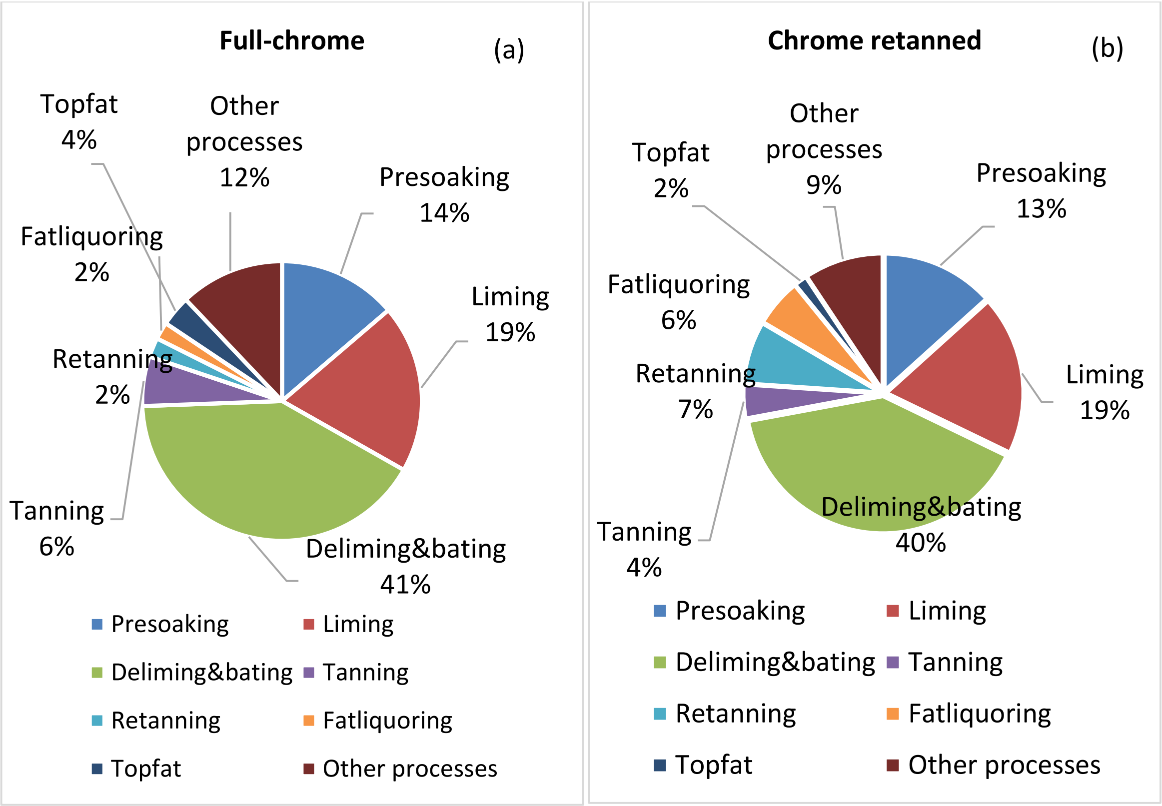

Figure 5-6 (a) and (b): These figures show the comparative approach to aquatic eutrophication of different life cycle processes for both systems.

5.2.4 Carcinogens

Fig. 5-7 shows the relative contribution of different life cycle processes to carcinogenic impact. According to Fig. 5-7, this carcinogen category is mainly dominated by upstream and downstream processes. Jointly electricity contributed much higher to carcinogen impact followed by transport of raw and chemical where latter processes are half of the electricity. In addition, electricity is about 5 times higher than transport of product. In all cases, chrome retanned systems are just slightly higher compared to full-chrome system since chrome retanned possesses have less production share. According to Fig. 5-7, the amount of kg C_2H_3Cl eq emitted by the above processes are 0.0096 and 0.0095, 0.0048 and 0.0045 and 0.0043 per $m^2$for chrome retanned and full-chrome system respectively. Other processes include diesel, refinery, trans; diesel, refinery, gen.; transport, diesel and packaging. It is clear from the above figure that supply chain solely contributed to this category. PAH (polycyclic aromatic hydrocarbons) (CF 3537.48), aromatic hydrocarbons (CF 3537.48, air), hexachloro-ethane (CF 1.14, air), 1.2-dichloro-ethane (CF 2.47, air),1,1,1,2-tetrachloro-Ethane (CF 1.75, air), chromium (CF 121.67, air), chromium VI (CF 122.64, air), Chloroform (CF 2.25, air) and some other pollutants emitted to air, water and soil from electricity, transport and boiler contributed to this impact category. Emission to air of these pollutants contribute much to this category followed by water and soil. A short description on how these pollutants were modelled for carcinogenic effect explained in the appendix C.

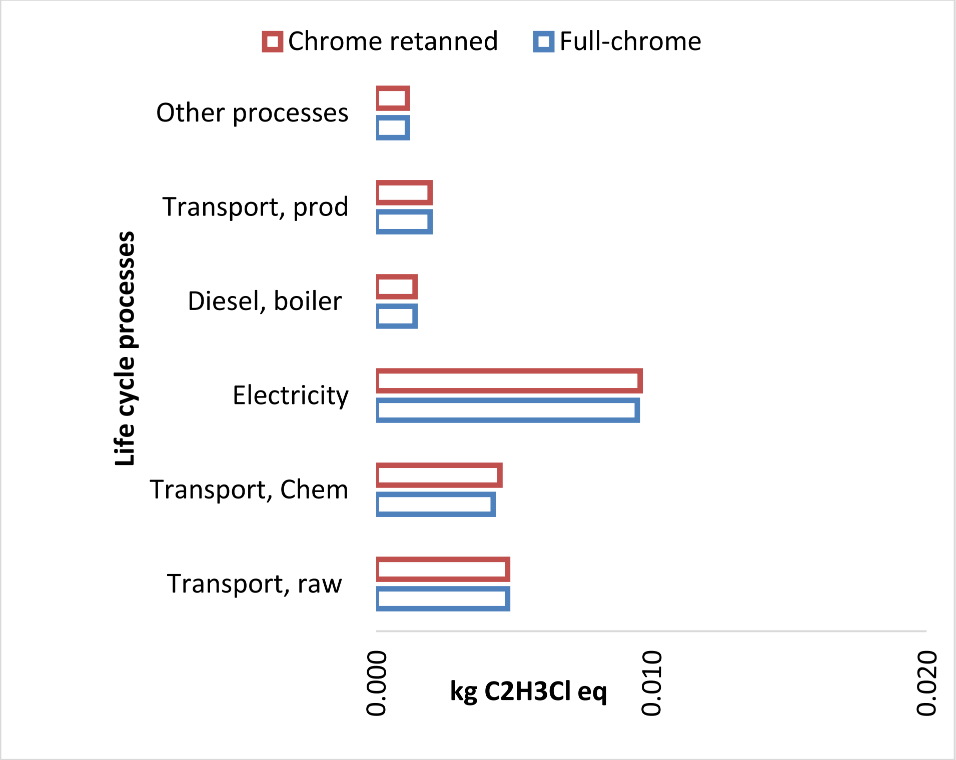

Figure 5-7: This figure shows the relative contribution of life cycle processes to the carcinogen between full-chrome and chrome retanned crust leather production.

5.2.5 Global warming

Fig. 5-8 shows the relative contribution of different life cycle processes to the global warming. According to Fig. 5-8, Global warming category is mainly dominated by upstream and downstream processes. Jointly electricity comes with the highest contribution to this category followed by transport of raw, chemical, product and electricity by generator. Transport of chemical process is almost half and electricity by generator and transport are less than one fourth of top contributor. In all cases, chrome retanned systems are just a bit higher compared to full-chrome system since chrome retanned possesses less production share of company's total production. According to 5-8, the amount of kg CO_2 emitted by the above processes are 0.229 and 0.226, 0.220, 0.118 and 0.111, 0.0514 and 0.0494 per m^2 respectively for chrome retanned and full-chrome system. Other processes include diesel, refinery, trans; diesel, refinery, gen.; transport, diesel and packaging.

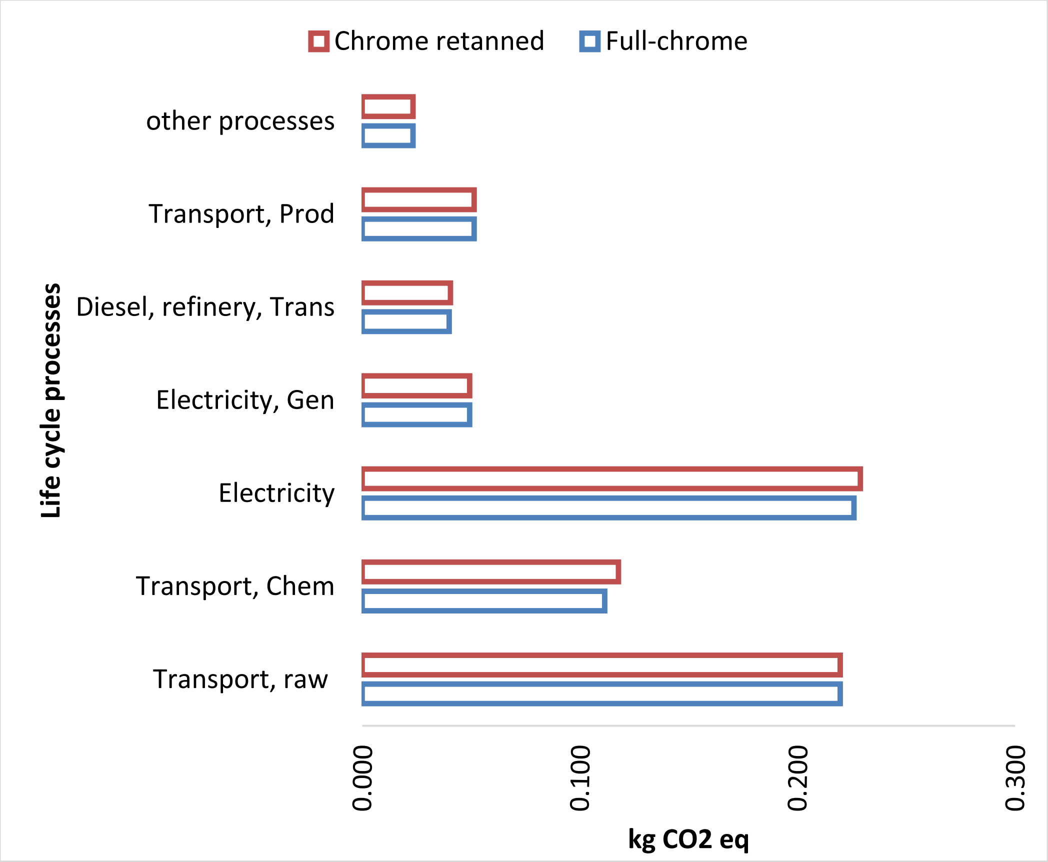

Figure 5-8: This figure shows the relative contribution of life cycle processes to the global warming between full-chrome and chrome retanned crust leather production.

5.2.6 Ionizing radiation

Fig. 5-9 shows the relative contribution of different life cycle processes to the impact category ionizing radiation. According to fig. 5-9, this ionizing radiation category is mainly dominated by upstream and downstream processes. Electricity contributed much higher to ionizing radiation impact followed by packaging and diesel, refinery, transport. Electricity is more than 2 times higher than diesel, refinery, Trans and almost double of packaging. According to fig. 5-9, the amount of Bq C-14 emitted by the above processes are 0.217 and 0.214, 0.111 and 0.105 and 0.103 per m^2respectively for chrome retanned and full-chrome system.Carbon-14 (CF 1, air), Cesium-134 (CF 0.057, air), Cesium-137 (CF 0.061, air), Cobalt-58 (CF 0.0020, air), Cobalt-60 (CF 0.076, air), Iodine-129 (CF 4.476, air), Plutonium-238 (CF 0.31, air), Thorium-230 (CF 0.21, air), Uranium-234 (CF 0.46, air) and some other radioactive substances emitted to air and water contributed to this impact category. A short description on how these pollutants modelled for ionizing radiation effect explained in the appendix C.

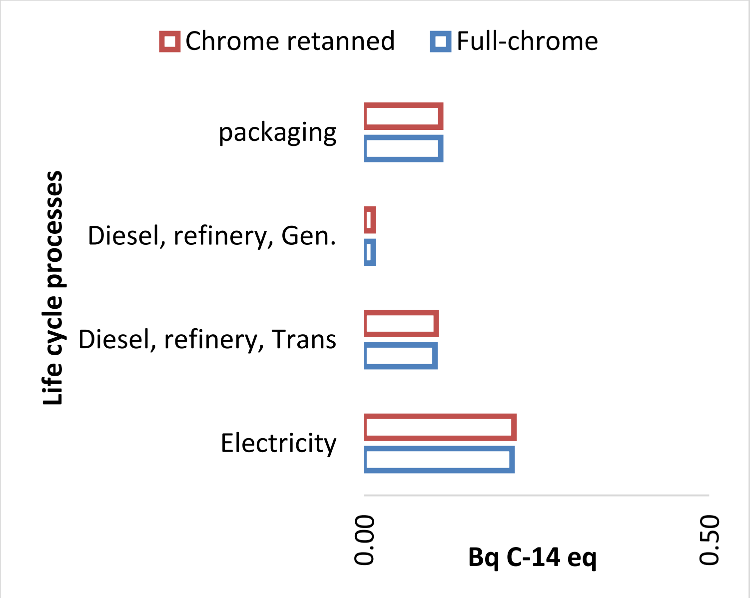

Figure 5-9: This figure shows the relative contribution of life cycle processes to the impact category ionizing radiation between full-chrome and chrome retanned crust leather production.

5.2.7 Land occupation

Fig. 5-10 shows the relative contribution of different life cycle processes to land occupation. According to Fig. 5-10, this land occupation category is mainly dominated by upstream and downstream processes. Electricity contributed much higher to land occupation impact followed by packaging. Electricity is more than 4 times greater than packaging. According to Fig. 5-10, the amount of m^2org.arable occupied by the above processes are 0.0010 and 0.00099 per m^2 and 0.00025 m^2org.arable per m^2 for chrome retanned and full-chrome respectively. Occupation of arable, non-irrigated (CF 1.055), occupation of construction site (CF 0.77), occupation of dump site (CF 0.77), occupation of forest, intensive (CF 0.1), occupation of industrial area (CF 0.77), occupation of mineral extraction site (CF 0.771), occupation of pasture and meadow, intensive (CF 1.03), occupation of urban, continuously built (CF 1.055) and some other areas that have been occupied are given as input in case of electricity and packaging. How these occupation contribute to this impact category have been discussed shortly in the appendix C.

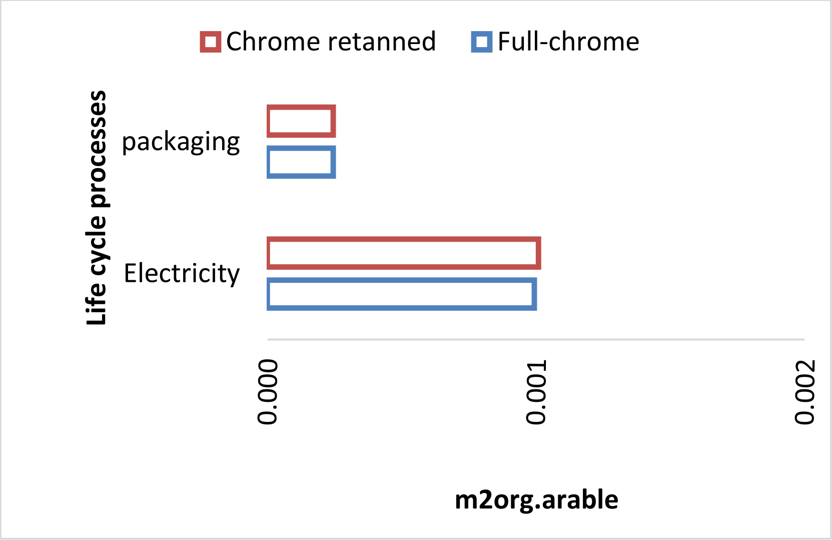

Figure 5-10: This figure shows the relative contribution of life cycle processes to the land occupation between full-chrome and chrome retanned crust leather production.

5.2.8 Mineral extraction

Fig. 5-11 shows the relative contribution of different life cycle processes to mineral extraction. According to Fig. 5-11, this mineral extraction category is mainly dominated by upstream and downstream processes. Electricity contributed much higher to mineral extraction impact followed by packaging. Diesel, refinery for transport and generator contributed negligible amount. Electricity is more than 7 times greater than packaging of corresponding chrome retanned system and 6.5 times of corresponding full-chrome system. In all cases, chrome retanned systems are just a bit higher compared to full-chrome system since chrome retanned possesses less share. According to Fig. 5-11, the amount of MJ surplus emitted by electricity are 9.30E-04 and 1.00E-03 per m^2 for full-chrome and chrome retanned system respectively. Packaging is 0.00014 MJ surplus per m^2 for both systems. Aluminum (CF 2.38), Chromium (CF 0.91), Iron (CF 0.051), Lead (CF 7.35), Manganese (CF 0.313), Molybdenum (CF 41), Tin (CF 600), zinc (CF 4.09) and some other materials taken from ground as raw input for electricity, packaging and other processes contributed to the impact category mineral extraction. Details of mineral extraction have been discussed in the appendix C.

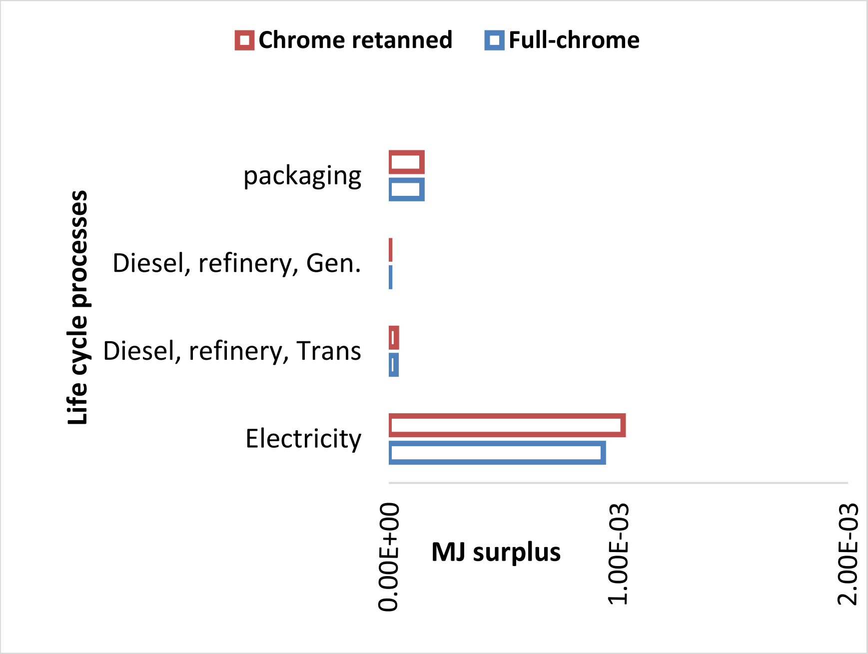

Figure 5-11: This figure shows the relative contribution of life cycle processes to the impact category mineral extraction between full-chrome and chrome retanned crust leather production.

5.2.9 Non-carcinogens

Fig. 5-12 shows the relative contribution of different life cycle processes to the non-carcinogens and Fig 5-13 (a) and (b) show the percent share of different life cycle processes to non-carcinogens of each system. According to Fig. 5-12, 5-13 (a) and (b), in both cases, full-chrome processes contributed much higher compared to chrome retanned crust leather. Among these processes, tanning comes with first followed by rechroming, neutralization and acidwash. Among these processes tanning, acidwash and rechroming of full-chrome system are more than 5.5 times higher compared to corresponding chrome retanned system. In addition, neutralization is more than 2 times higher than corresponding chrome retanned system. According to fig. 5-12, in both system, the emission value of the tanning, rechroming, neutralization and Acidwash are 0.137 and 0.0244, 0.0934 and 0.0168, 0.0180 and 0.0085 and 0.0178 and 0.0032 Kg C_2H_3Cl eq per $m^2$for full-chrome and chrome retanned system respectively. Other processes include transport, raw; transport, chem; electricity; electricity, gen; diesel, refinery, trans; diesel, refinery, gen.; diesel, boiler; transport, diesel; packaging and transport, prod. According to Fig. 5-13 (a) and (b), tanning of full-chrome system contributed much which is 53% followed by rechroming amounting 37% compared to 41% and 28% respectively of chrome retanned crust leather. Neutralization of chrome retanned system contributed much higher, which is 14% compared to corresponding process of full-chrome system. Full-chrome production processes contributed more than 95% and chrome retanned production processes around 90%. The Non-carcinogens effect of these processes mentioned above is due to the associated heavy metal chromium emission into water and ammonia release into air and water.

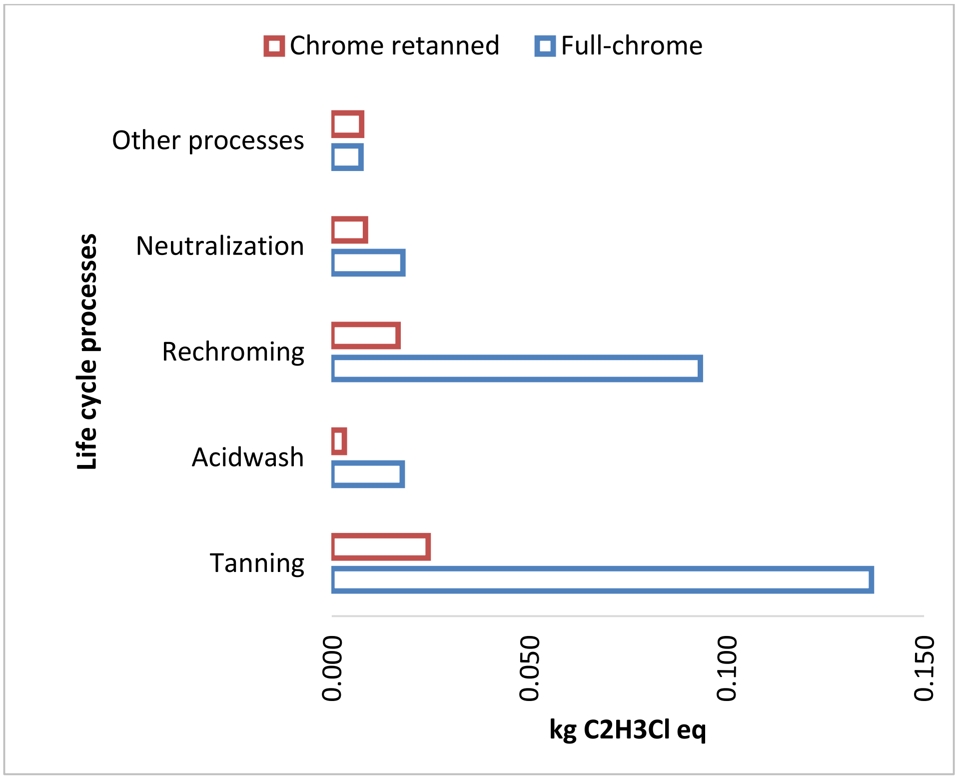

Figure 5-12: This figure shows the relative contribution of life cycle processes to the non-carcinogens between full-chrome and chrome retanned leather production.

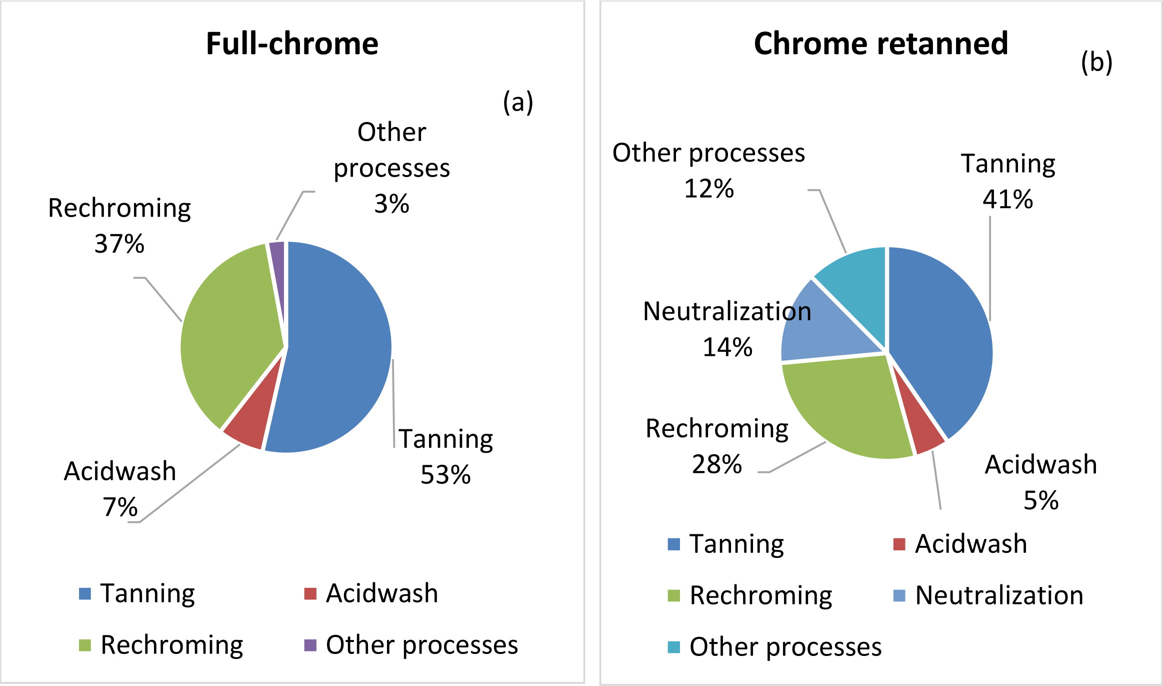

Figure 5-13 (a) and (b): These figures show the comparative approach to non-carcinogens of different life cycle processes for both systems.

5.2.10 Non-renewable energy

Fig. 5-14 shows the relative contribution of different life cycle processes to non-renewable energy impact. Since this category is mainly due to consumption of different energy carrier and forms of energy as input, this category is mainly dominated by supply chain processes. Diesel, refinery, transport process contributed much higher to this impact category followed by electricity, diesel, refinery for generator and packaging contributed negligible amount. Diesel, refinery, transport is more than 10 times greater than packaging and about two times than electricity. Diesel, refinery, transport of chrome retanned systems are just a bit higher since transport (chemical) possesses higher share. According to Fig. 5-14, the amount of MJ primary by diesel, refinery, transport and electricity are 6.21 and 6.11, 3.29 and 3.25 per m^2 for full-chrome and chrome retanned system respectively. Packaging is same for both system which is 0.615 per m^2. Diesel refinery transport means diesel used in the transportation of raw, chemical and products extracted from crude oil at refinery which uses energy from coal (CF 1), energy from natural gas (CF 1), energy from oil (CF 1), energy from uranium (CF 1), crude Oil (CF 45.8) and some other things as input which results in non-renewable energy impact. In addition, natural gas (CF 40.3), crude oil (CF 45.8), hard coal

(CF 19.1), brown coal (CF 9.9) and some other minor things used as input for electricity results in contribution to non-renewable energy.

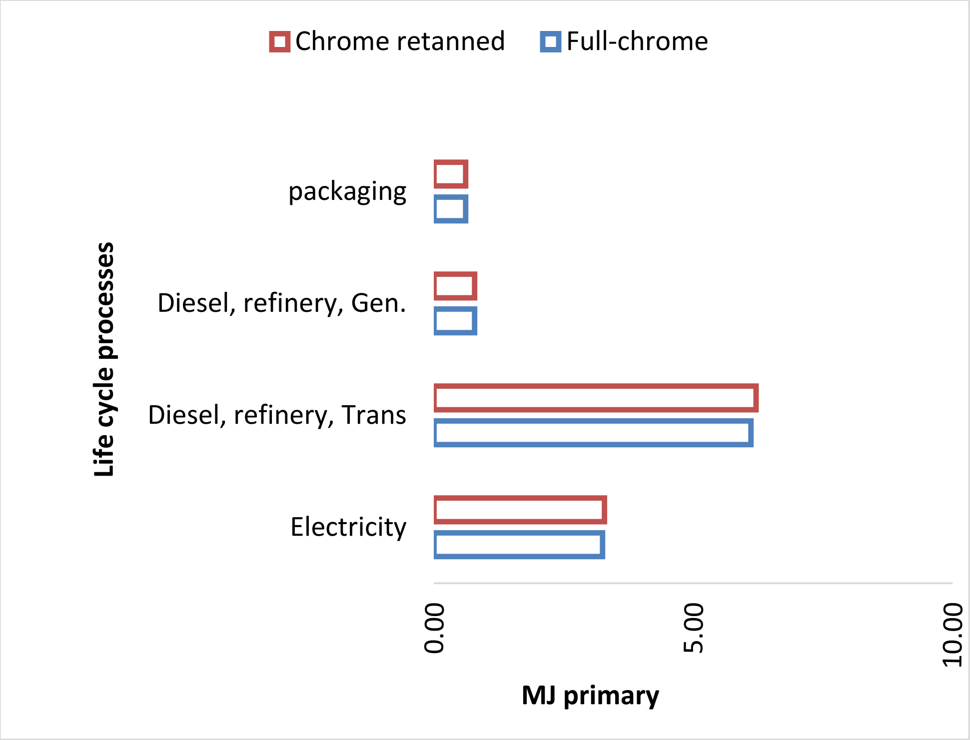

Figure 5-14: This figure shows the relative contribution of life cycle processes to the impact category non-renewable energy between full-chrome and chrome retanned crust leather production.

5.2.11 Ozone layer depletion

Fig. 5-15 shows the relative contribution of different life cycle processes to the impact category ozone layer depletion. According to the Fig. 5-15, this ozone layer depletion category is also mainly dominated by upstream and downstream processes. Electricity contributed much higher to this impact category followed by diesel, refinery, transport. Diesel, refinery for generator and packaging contributed negligible amount. Electricity is more than 7.5 times greater than packaging and more than 2 times than diesel, refinery, transport. According to Fig. 5-15, the amount of kg CFC-11 eq by electricity and diesel, refinery, transport are 2.00E-09 and 2.00E-09, 1.00E-09 and 9.00E-10 per m^2 for chrome retanned and full-chrome system respectively. Packaging is 3.00E-10 kg CFC-11 eq per m^2 for both system.

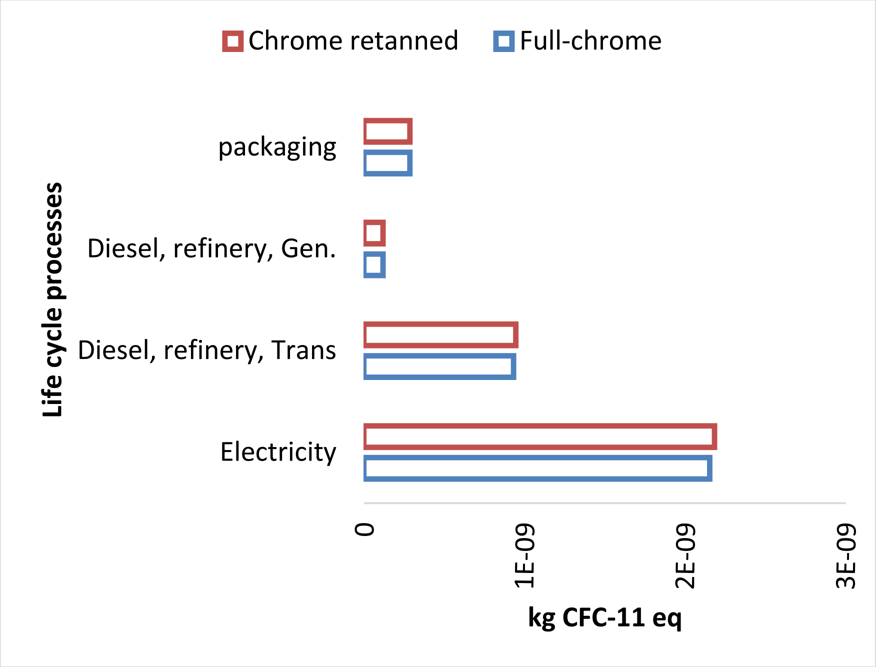

Figure 5-15: This figure shows the relative contribution of life cycle processes to the impact category ozone layer depletion between full-chrome and chrome retanned crust leather production.

5.2.12 Respiratory inorganics

Fig. 5-16 shows the relative contribution of different life cycle processes to the impact category respiratory inorganics. According to Fig. 5-16, this respiratory inorganics is another category which is also mainly dominated by upstream and downstream processes. Electricity contributed higher to this impact category followed by transport of raw and chemical. According to Fig. 5-16, the amount of kg $PM_{2.5}$ eq by electricity and transport of raw and chemical are 3.10E-04 and 3.20E-04, 3.00E-04 (same for both system) and 2.10E-04 and 2.20E-04 per m^2 for full-chrome and chrome retanned system respectively. Other processes include electricity, gen diesel, refinery; trans diesel, refinery gen.; transport, diesel; deliming-bating, packaging. Releases of ammonia (CF 0.121, air), carbon monoxide (CF 0.001, air), nitric oxide (CF 0.195, air), nitrogen dioxide (CF 0.127, air), particulates < 10 um (CF 0.535, air), particulates < 2.5 um (CF 1, air) and sulfur dioxide/ sulfur monoxide (CF 0.078, air) into air contribute to respiratory inorganic impact category. How these cause damage to human health has been modelled in the Impact 2002+ method. A short description is given in the appendix C.

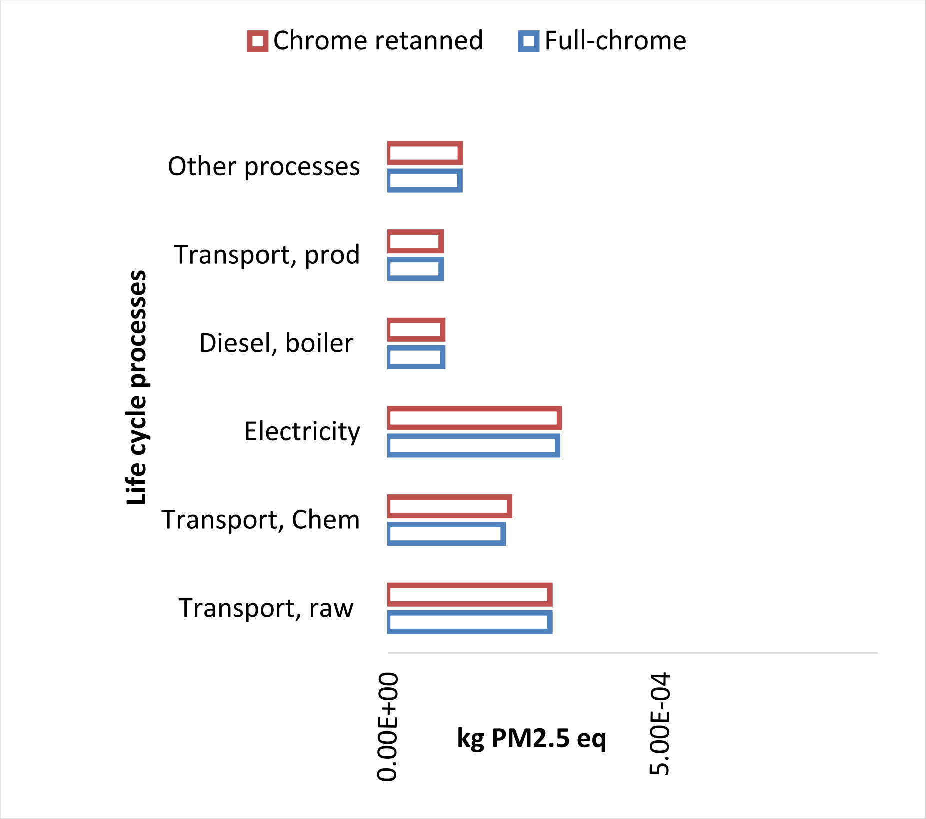

Figure 5-16: This figure shows the relative contribution of life cycle processes to the impact category respiratory inorganics between full-chrome and chrome retanned crust leather production.

5.2.13 Respiratory organics

Fig. 5-17 shows the relative contribution of different life cycle processes to the impact category respiratory organics. According to the Fig. 5-17, this respiratory organics category is also dominated by upstream and downstream processes. Jointly, transport of raw process comes with the greater contribution to this impact category followed by transport of chemical, electricity, diesel, refinery, transport; packaging and transport for products. Noticeably here in this category all above mentioned processes contributed in a closer context. According to Fig. 5-17, the amount of kg C_2H_4eq by transport for raw, products; electricity by generator, packaging and diesel boiler are same for both systems which are 4.90E-05, 2.00E-05, 2.60E-05, 2.10E-05 and 1.10E-05 per m^2 respectively. Other processes include diesel, refinery, gen. and transport, diesel. Release of 1,2,3-trimethyl- benzene (CF 1.27, air), 1,2,4-trimethyl- benzene (CF 1.27, air), 1,3,5-trimethyl- benzene (CF 1.39, air), Ethene (CF 1, air), hydrocarbons, aromatic (CF 0.98, air), propene (CF 1.11, air), 2-ethyl- toluene (CF 0.92, air), 3-ethyl- toluene (CF 1.03, air), 4-ethyl- toluene (CF 0.92, air), xylene (CF 1.037, air), non-methane volatile organic compounds (CF 0.60, air) and some other organic compounds from transportation, electricity, packaging etc. into air contribute to this impact category. A description of how these pollutants contribute to this category have been modelled in Eco indicator 99 method. A short description has been given in the appendix C.

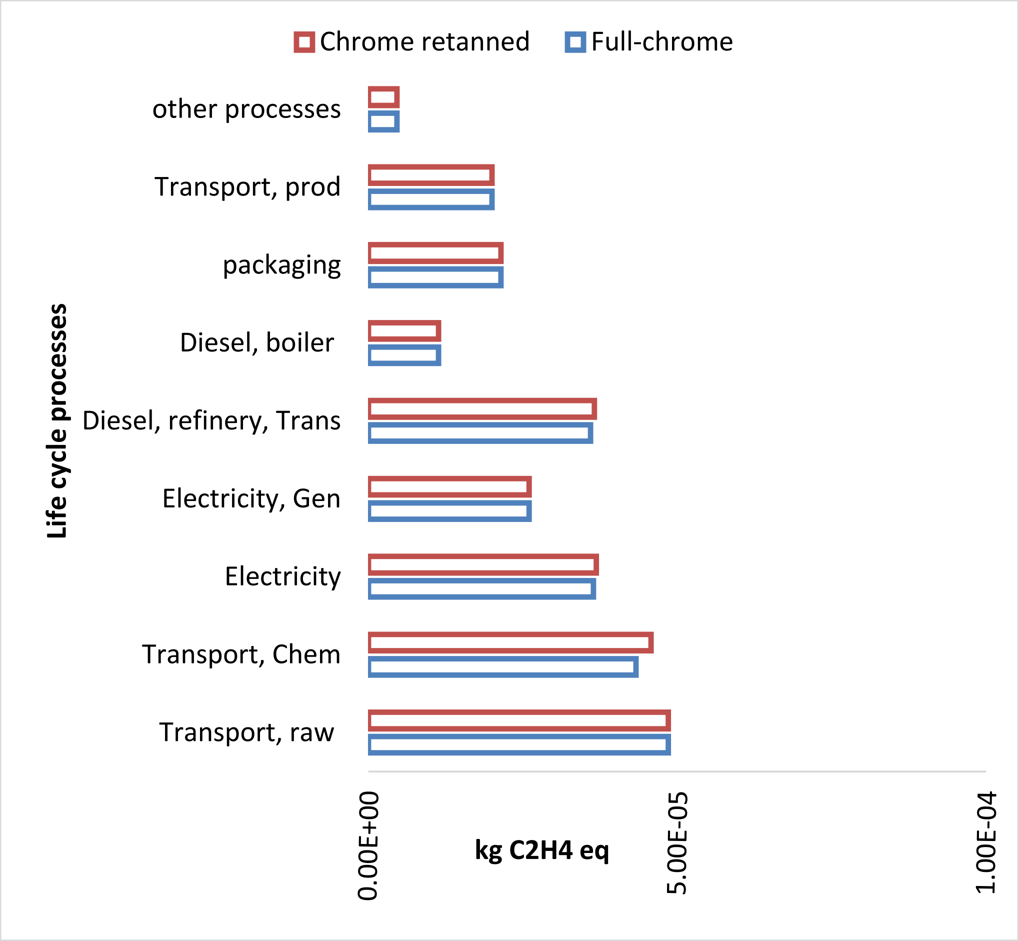

Figure 5-17: This figure shows the relative contribution of life cycle processes to the impact category respiratory organics between full-chrome and chrome retanned crust leather production

5.2.14 Terrestrial acidification- nutrification

Fig. 5-18 shows the relative contribution of different life cycle processes to the impact category terrestrial acidification- nutrification. According to the Fig. 5-18, this terrestrial acidification-nutrification category is mainly dominated by upstream and downstream processes. Jointly transport of raw process comes with the greater contribution to this impact category followed by transport of chemical, product and both types of electricity. In addition, transport for raw is more than 5.5 times and chemical is 3.5 times higher than electricity. According to Fig. 5-18, the amount of kg SO_2 eq contributed by transport for raw, product and electricity by generator are same for both systems and these are 0.0126, 0.0037 and 0.0026 kg SO_2 eq per m^2 respectively. The value of electricity and transport for chemical differ for both systems which are 0.0023 and 0.0023 and 0.0080 and 0.0084 kg SO_2 eq per m^2 respectively for full-chrome and chrome retanned system. Other processes include diesel, refinery, trans; diesel, refinery, gen.; transport, diesel; deliming-bating and packaging. The effect of this impact category of the above mentioned processes are due to the associated emission into water and ammonia release into air and water.

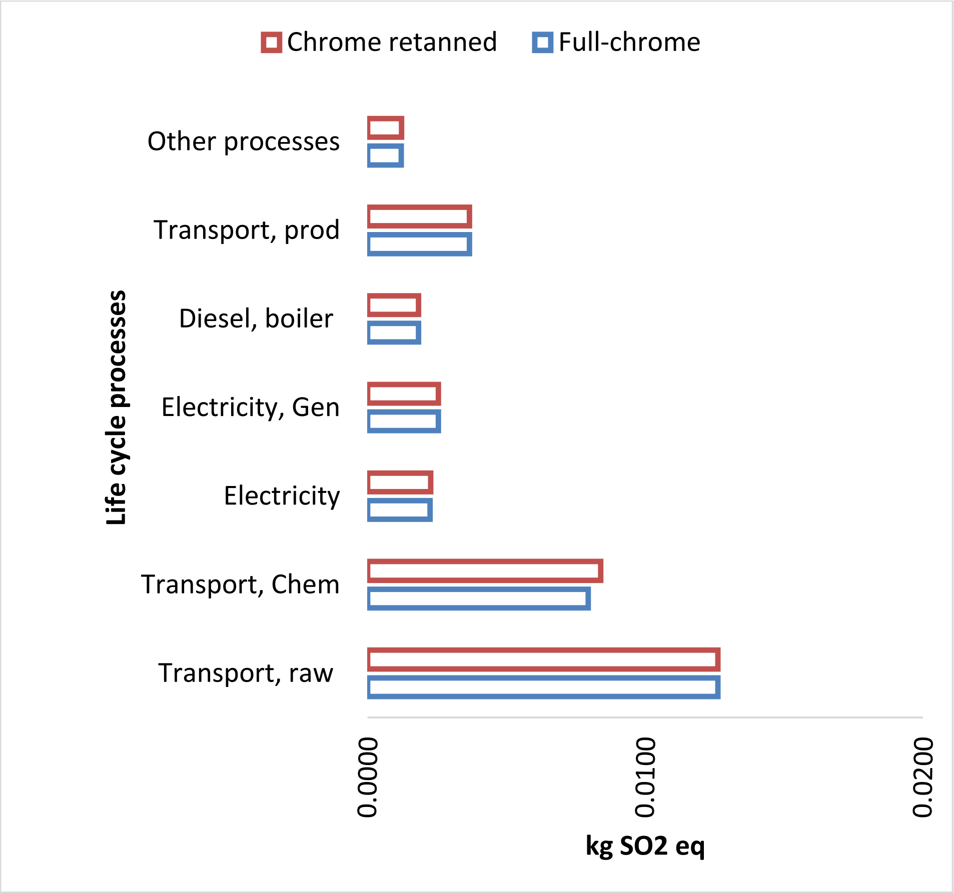

Figure 5-18: This figure shows the relative contribution of life cycle processes to the impact category terrestrial acidification- nutrification between full-chrome and chrome retanned crust leather production.

5.2.15 Terrestrial ecotoxicity

Fig. 5-19 shows the relative contribution of life cycle processes to the impact category terrestrial ecotoxicity. According to Fig. 5-19, this terrestrial ecotoxicity category is mainly dominated by supply chain processes. Transport for raw comes with the greater contribution to this impact category followed by transport for chemical and production. Electricity contributed negligible amount considering the above processes. Transport for raw is about 27 times greater than electricity of corresponding chrome retanned system and about 5 times than transport for chemical. According to Fig. 5-19, the amount of kg TEG soil emitted by transport for raw and products are same which are 29.0 and 5.87 per m^2 for both system respectively. the value for transport, chemical and electricity differ slightly which are 12.7 and 13.4 and 1.07 and 1.09 kg TEG soil per m^2 of full-chrome and chrome retanned systems respectively .Other processes include electricity, gen; diesel, refinery, trans; diesel, refinery, gen.; diesel, boiler; transport, diesel; deliming-bating and packaging. Release of pollutants such as Ethephon (CF 1325.64, soil), Lead (CF 753773.64, soil), Mercury (CF 26544638.59, soil), Nickel (CF 3297056.854, soil), Zinc (CF 5912455.497, soil) along with other pollutants mentioned in respiratory organics and inorganics into soil, air and water contribute to this category. How this pollutants contribute to this category discussed in the appendix C.

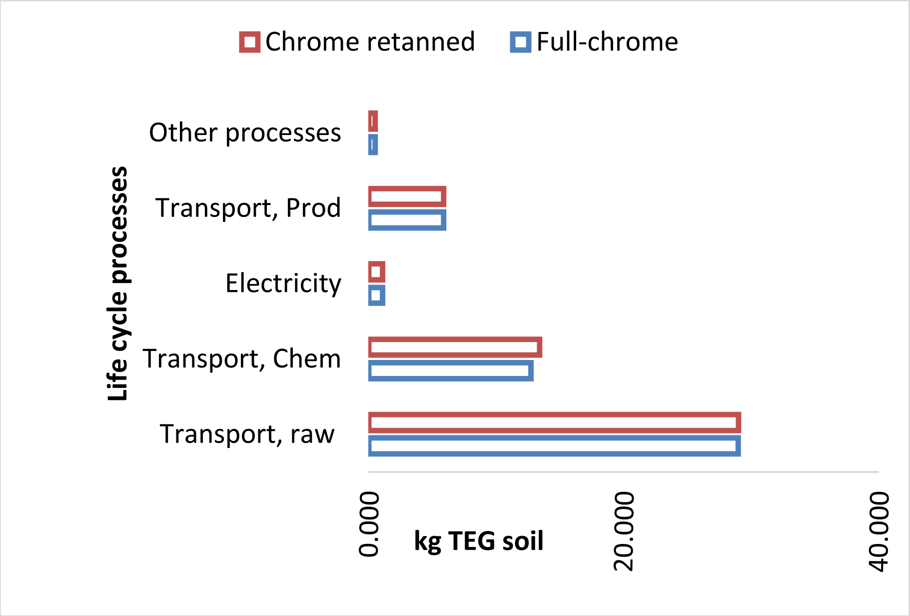

Figure 5-19: This figure shows the relative contribution of life cycle processes to the impact category terrestrial ecotoxicity between full-chrome and chrome retanned crust leather production.

5.3 Damage assessment

All midpoint categories except aquatic acidification and aquatic eutrophication have been grouped into four damage categories using conversion factors (Appendix A -16,17,18 and 19) namely climate change, human health, ecosystem quality and resources. These two midpoint categories are represented separately from the four damage categories. In modelling damage to human health four sub-steps are used. First, Fate analysis, which links an emission (expressed as mass) to a temporary change in concentration. Second, exposure analysis which links this temporary concentration to a dose. Third, effect analysis which links the dose to a number of health effects, like the number and types of cancers, and respiratory effects etc. Finally, damage analysis which links health effects to the number of years lived disabled (YLD) and Years of Life Lost (YLL). In modelling damage to ecosystem two different approaches are used. First, toxic emissions and emissions that change acidity and nutrients levels go through the procedure of fate analysis and effect analysis which links concentrations to toxic stress or increased nutrient or acidity levels. Then, damage analysis which links these effects to the increased potentially disappeared fraction for plants. Land occupation is modelled on the basis of empirical data on the quality of ecosystems, as a function of the land use type and the area size. Damage to resources is modelled in two steps. First, resource analysis, which can be regarded as a similar step as the fate analysis, as it links an extraction of a resource to a decrease of the resource concentration. Then, damage analysis which links lower concentration to the increased efforts to extract the resource in the future (PRé 2001).Schematic illustration of damage category human health generated from the software have been shown in the following Fig. 5-20 to 5-23 for both systems.

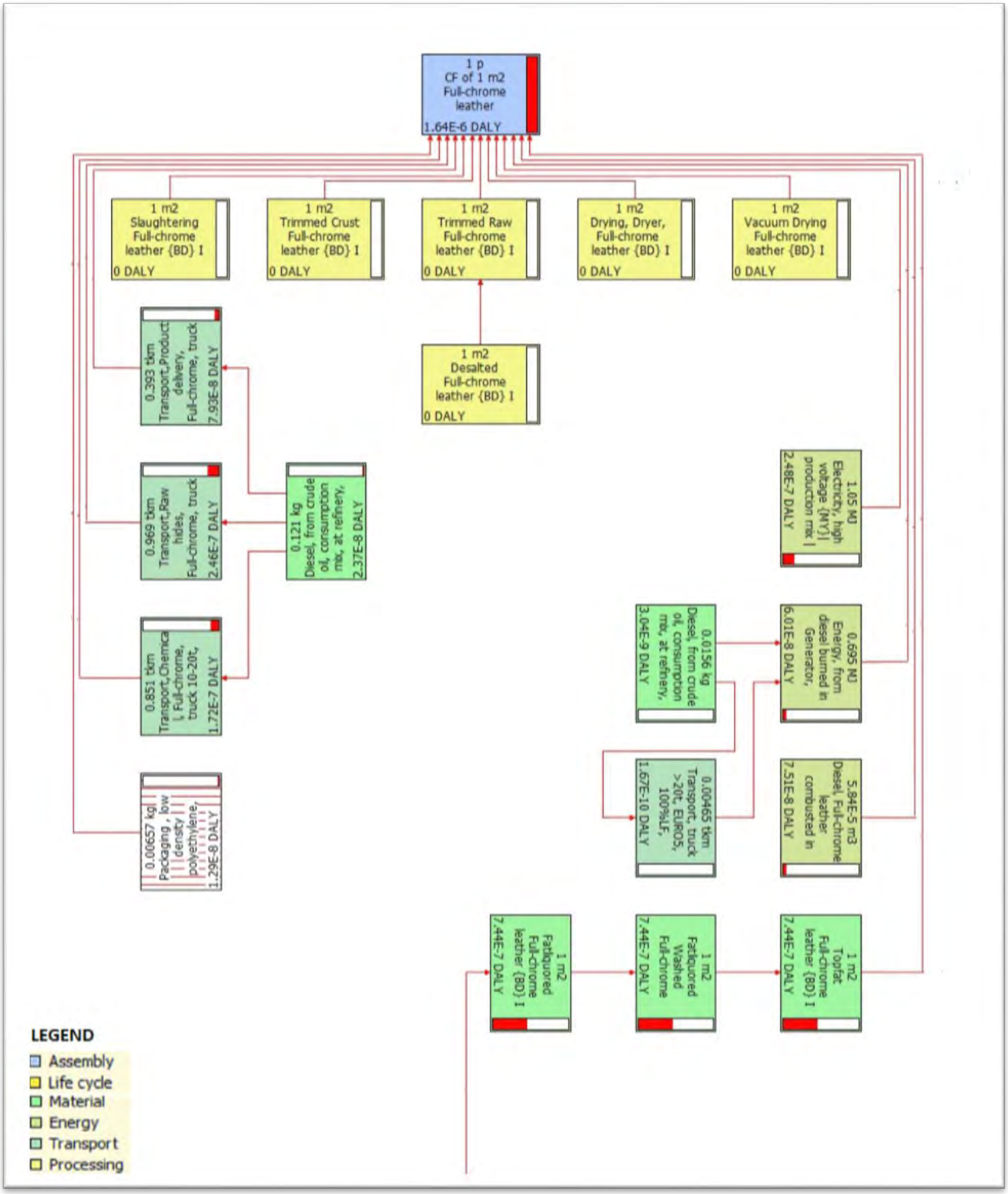

Figure 5-20: This figure shows the network view of life cycle processes to the damage category Human health of full-chrome crust leather production. Continued in the next page.

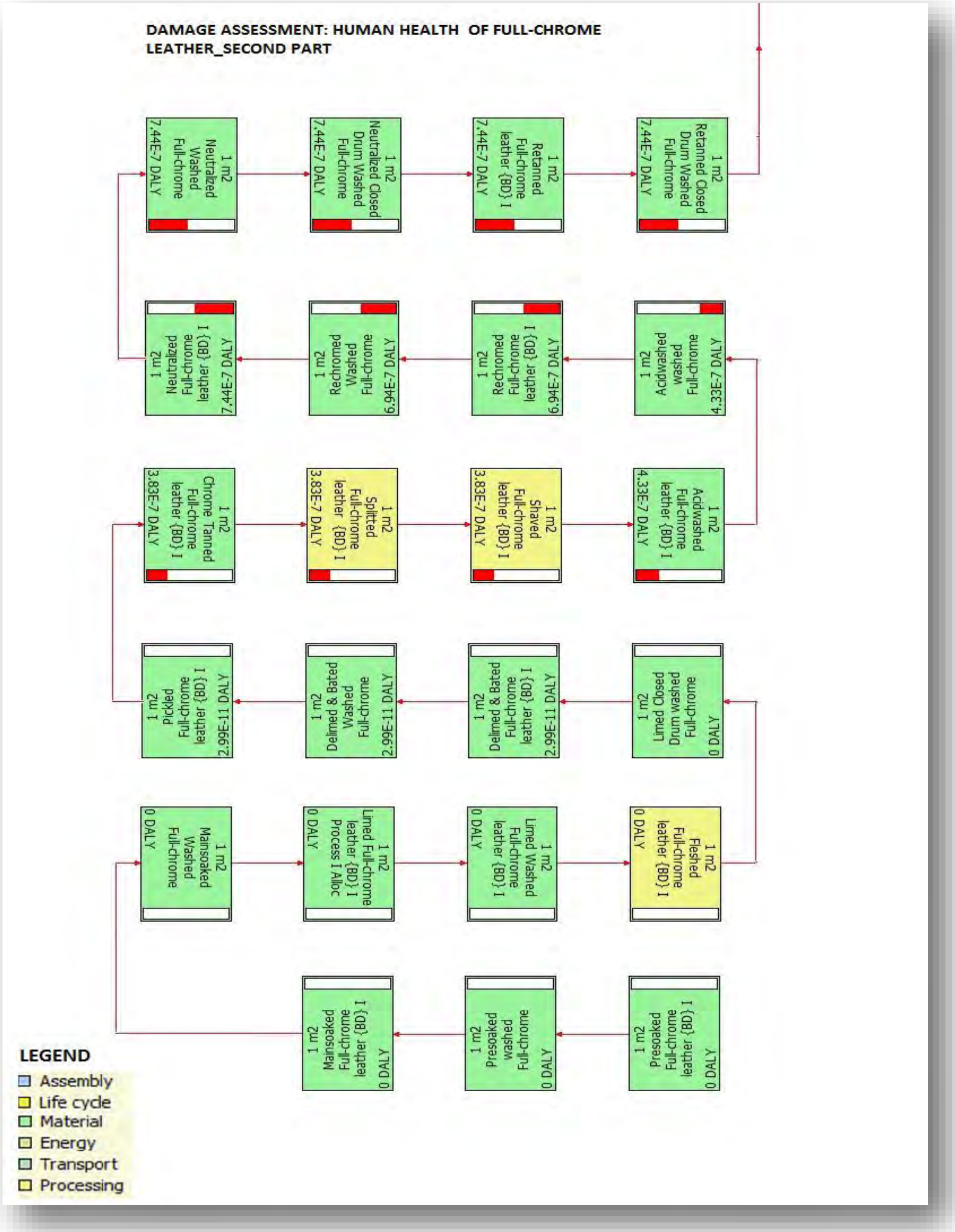

Figure 5-21: This figure shows the network view of life cycle processes to the damage category Human health of full-chrome crust leather production. Continued from the previous page.

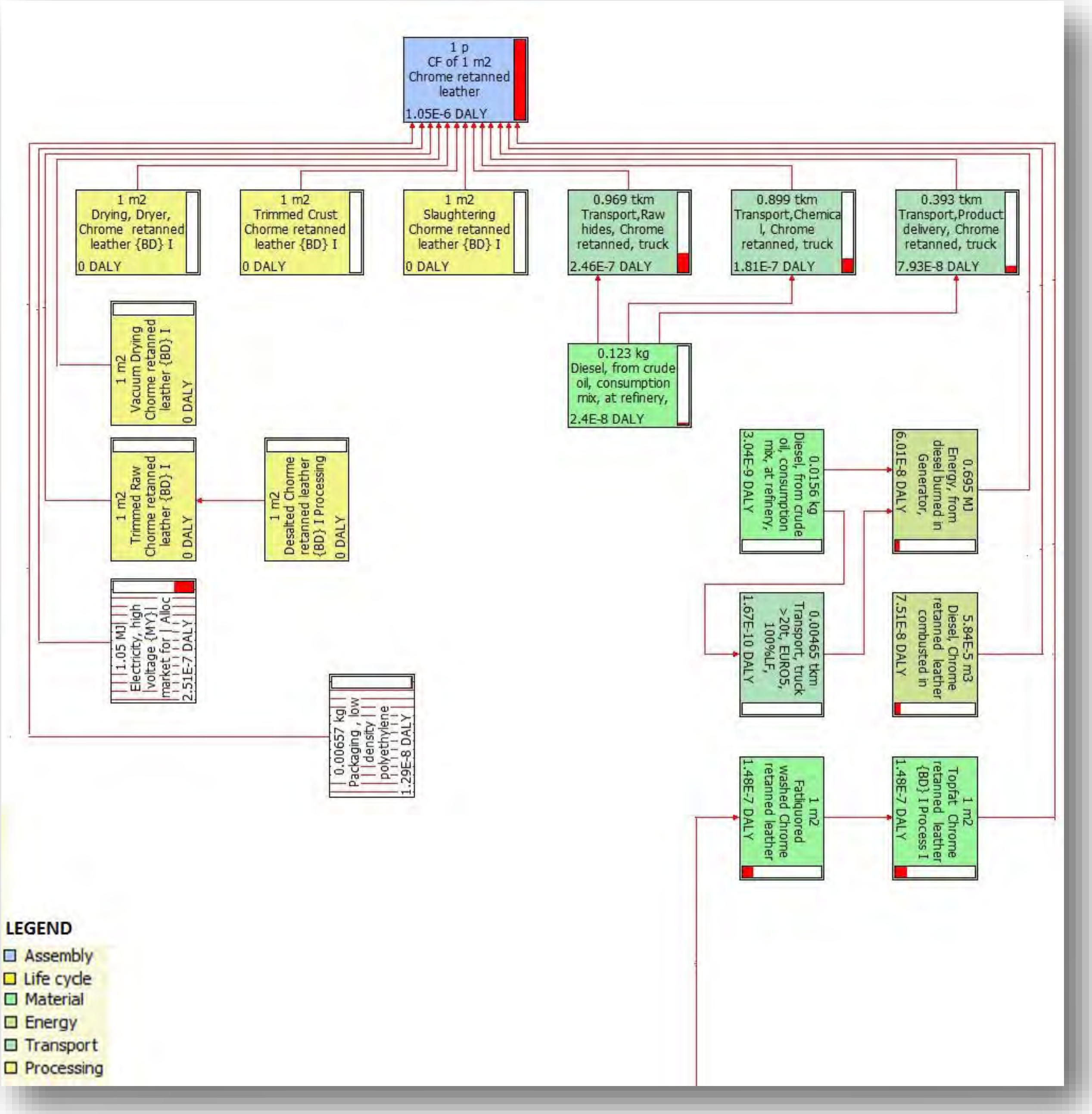

Figure 5-22: This figure shows the network view of life cycle processes to the damage category Human health of full-chrome crust leather production. Continued in the next page

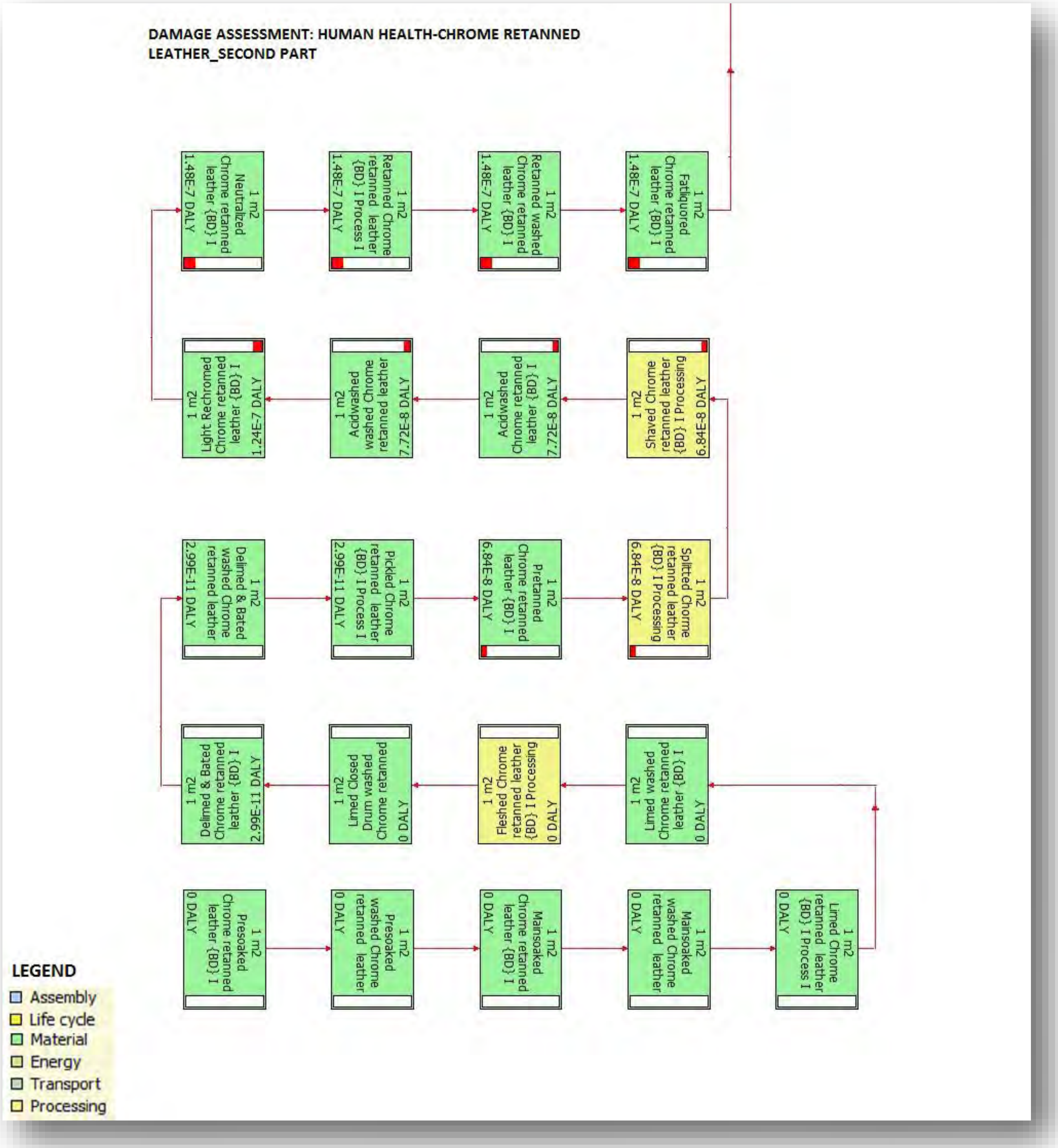

Figure 5-23: This figure shows the network view of life cycle processes to the damage category Human health of full-chrome crust leather production. Continued from the previous page.

5.3.1 Climate change

Climate change is the same category as global warming. Even if it is considered as a damage category, climate change impact is still expressed in kg CO_2 eq per kg CO_2 eq of global warming impact. Since the conversion factor from impact category to damage category is 1, so each figure is technically same as the value of global warming emission. According to the Fig. 5-24, this climate change damage category is mainly dominated by upstream and downstream processes. Jointly electricity comes with the highest contribution to this category followed by transport of raw, chemical, product and electricity by generator. Transport of chemical process is almost half and electricity by generator and transport are less than one fourth of top contributor. According to Fig. 5-24, the amount of kg CO_2eq emitted by the above processes are 0.229 and 0.226, 0.220 (same for both system), 0.118 and 0.111, 0.051 (same for both system) and 0.0494 (same for both system) per m^2 respectively for chrome retanned system. Other processes include diesel, refinery, gen.; transport, diesel and packaging.

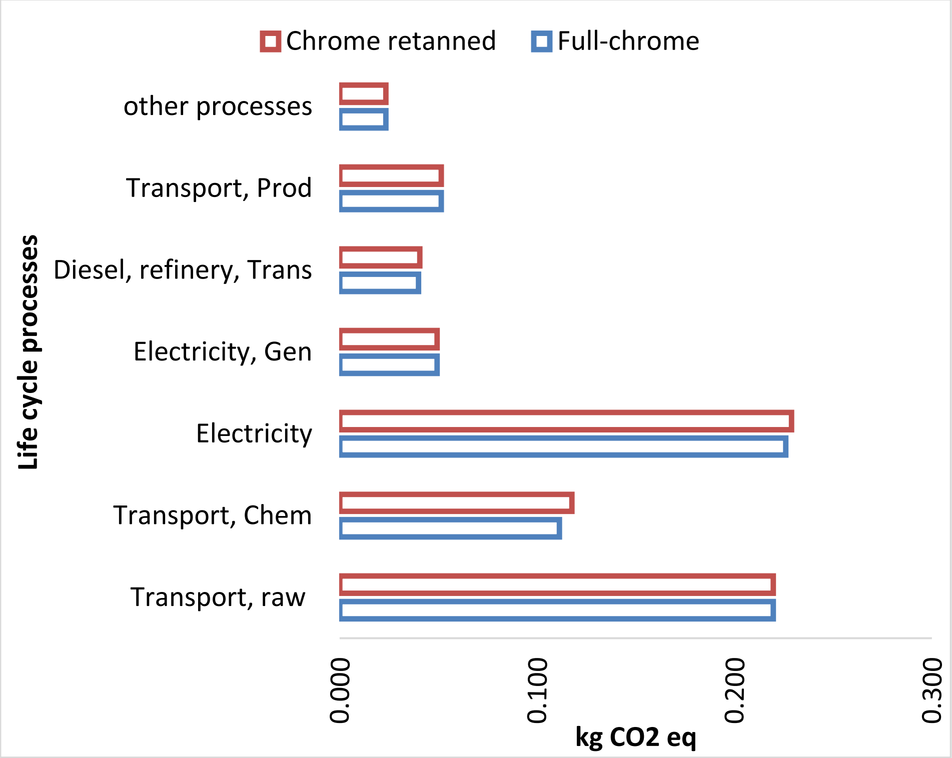

Figure 5-24: This figure shows the relative contribution of life cycle processes to the damage categories climate change between full-chrome and chrome retanned crust leather production.[7]

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[7] Impact of solid wastes excluded

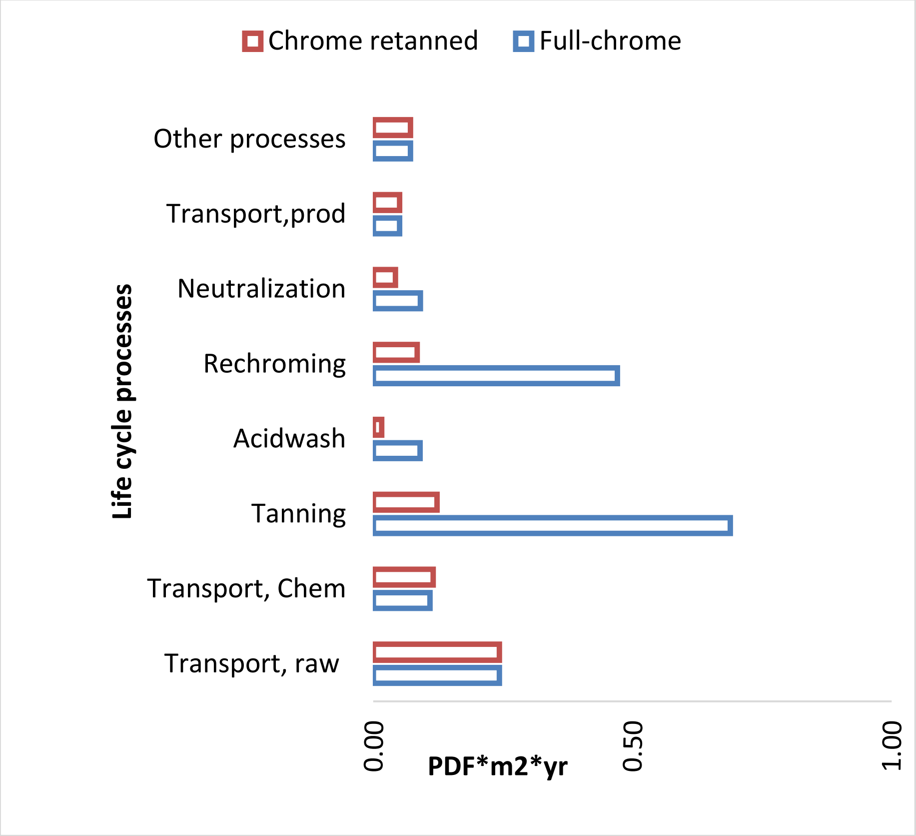

Figure 5-25: This figure shows the relative contribution of life cycle processes to the damage category ecosystem quality between full-chrome and chrome retanned crust leather production[8].

5.3.2 Ecosystem quality

The damage category ecosystem quality is the sum of the midpoint categories aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acidification/nutrification and land occupation. These impact categories have been converted into this damage category using conversion factors (Appendix A-17).Theoretically aquatic acidification and eutrophication are also contributing to this damage category though not yet considered. Fig. 5-25 shows the relative contribution of life cycle processes to the damage category ecosystem quality and this category is strongly dominated by production processes for full-chrome system and reverse for chrome retanned system. In all cases, full-chrome processes contributed much higher compared to chrome retanned leather due to increased amount of heavy metal chromium emission into water. Among these processes, tanning, rechroming and acidwash of full-chrome system are more than 5.5 times higher to corresponding

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[8] Impact of solid wastes excluded

chrome retanned system. According to 5-25, in both system, largest contribution comes from tanning followed by rechroming, neutralization and acidwash which are 0.689 and 0.123 ,0.471 and 0.0846 , 0.0905 and 0.0428 and 0.0898 and 0.0160 PDF*m^2*yr. per m^2 respectively. Other processes include electricity, electricity, gen; diesel, refinery, trans; diesel, refinery, gen.; diesel, boiler; transport, diesel; deliming-bating and packaging. Supply chain processes like transport for raw and products contributed same for both systems which are 0.243 and 0.0504 PDF*m^2*yr. per m^2.Fig. 5-26 (a) and (b) show the percent share of different life cycle processes of each system. In case of full-chrome system, tanning contributed much which is 38% followed by rechroming and transport for raw amounting 26% and 13% compared to 16% , 11% and 33% respectively of chrome retanned crust leather. Above all, total of 74% contributed by production processes of full-chrome system whereas only 35% contributed by chrome retanned system. From these figure it is clear that this damage category is dominated by production processes for full-chrome and by supply chain processes for chrome retanned system.

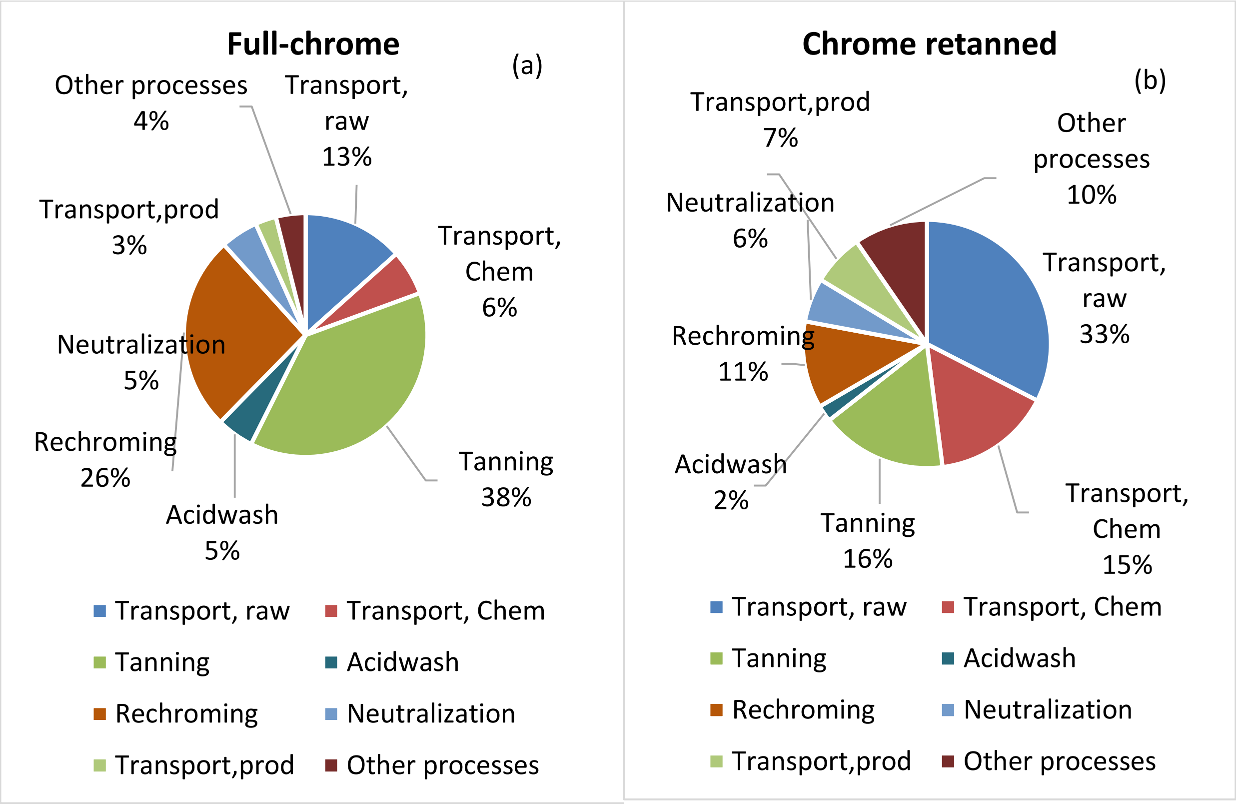

Figure 5-26 (a) and (b): These figures show the relative contribution to ecosystem quality of different life cycle processes for both systems.

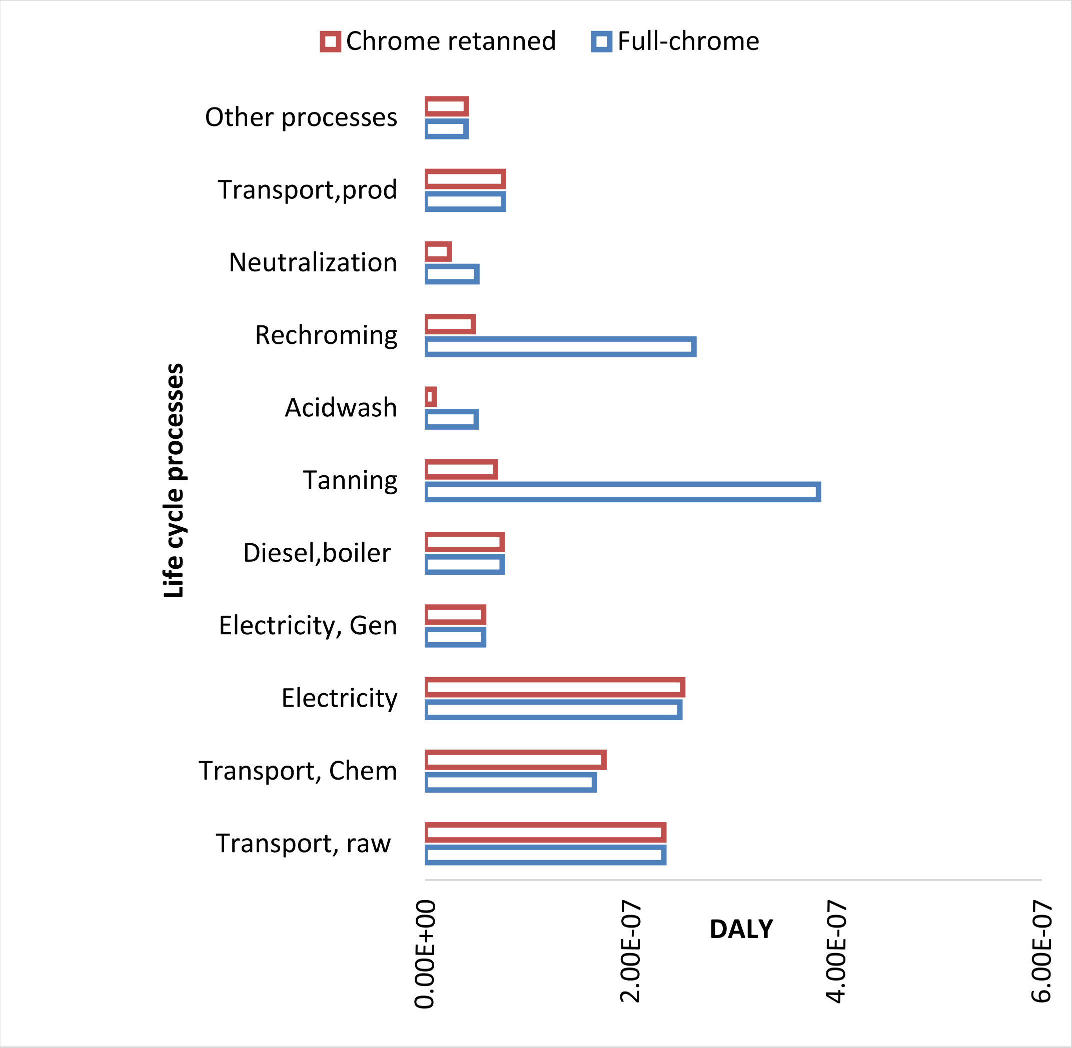

Figure 5-27: This figure shows the relative contribution of life cycle processes to the damage category human health between full-chrome and chrome retanned crust leather production[9].

5.3.3 Human health

The human health category is the sum of the midpoint categories carcinogen and non-carcinogen, respiratory organics and inorganics, ionizing radiation, ozone layer depletion. These impact categories have been converted into this damage category using defined conversion factors (Table A-18). Fig. 5-27 shows the relative contribution of different life cycle processes to the damage category human health. In case of all production processes, full-chrome processes contributed much higher compared to chrome retanned leather. Among these processes, tanning, rechroming

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[9] Impact of solid wastes excluded

and acidwash of full-chrome system are more than 5.5 times higher than corresponding chrome retanned system. According to Fig 5-27, in both system, largest contribution comes from tanning followed by rechroming, neutralization and Acidwash which are 3.83E-07 and 6.83E-08, 2.61E-07 and 4.70E-08, 5.03E-08 and 2.37E-08 and 4.99E-08 and 8.90E-09 DALY per m^2 respectively. Other processes include electricity, electricity, gen; diesel, refinery, trans; diesel, refinery, gen.; diesel, boiler; transport, diesel; deliming-bating and packaging. Among the supply chain processes, transport for raw and product contributed same for both systems which are 2.32E-07 and 7.61E-08 DALY per m^2 but transport for chemical differs slightly due to different amount of chemical consumption which are 1.65E-07 and 1.74E-07 DALY per m^2.Fig 5-28 (a) and (b) show the percent share of different life cycle processes to human health of each system. In case of full-chrome system, tanning contributed much which is 24% followed by rechroming and transport of raw amounting 17% and 15% compared to 7% , 5% and 24%respectively of chrome retanned crust leather. According to this figures, supply chain and production processes of full-chrome system contributed almost same to this category but chrome retanned system is mainly dominated by supply chain processes since supply chain processes account for more than 81% in total.

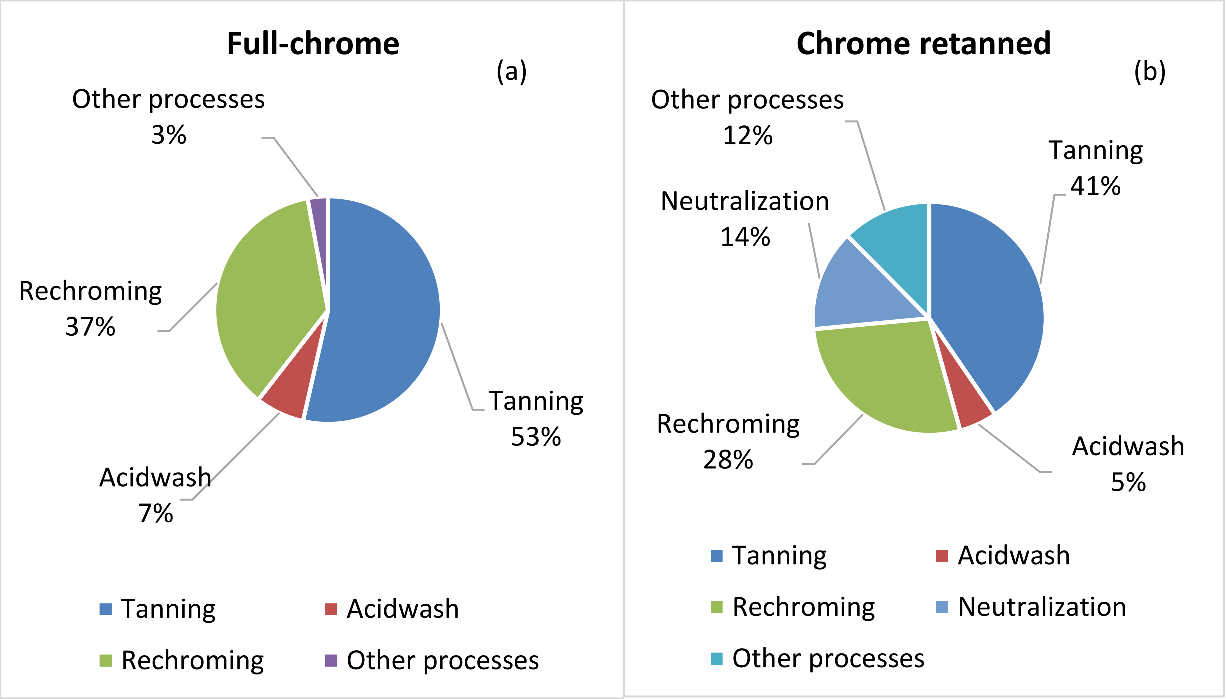

Figure 5-28 (a) and (b): These figures show the relative contribution to ecosystem quality of different life cycle processes for both systems.

5.3.4 Resources

This Fig. 5-29 shows the relative contribution of different life cycle processes to the damage category resources. This category is totally dominated by supply chain processes irrespective to any system. Diesel, refinery, transport process contributed much higher to this impact category followed by electricity, diesel, refinery for generator and packaging contributed negligible amount. Diesel, refinery, transport is more than 10 times greater than packaging and about two times than electricity. Diesel, refinery for all transport contributed much compared to diesel, refinery for generator because of greater amount of diesel consumption. According to Fig. 5-29, the amount of MJ primary by diesel, refinery, transport and electricity are 6.11 and 6.21, 3.26 and 3.29 MJ primary per m^2 for full-chrome and chrome retanned system respectively. Packaging is same for both system which is 0.615 MJ primary per m^2.

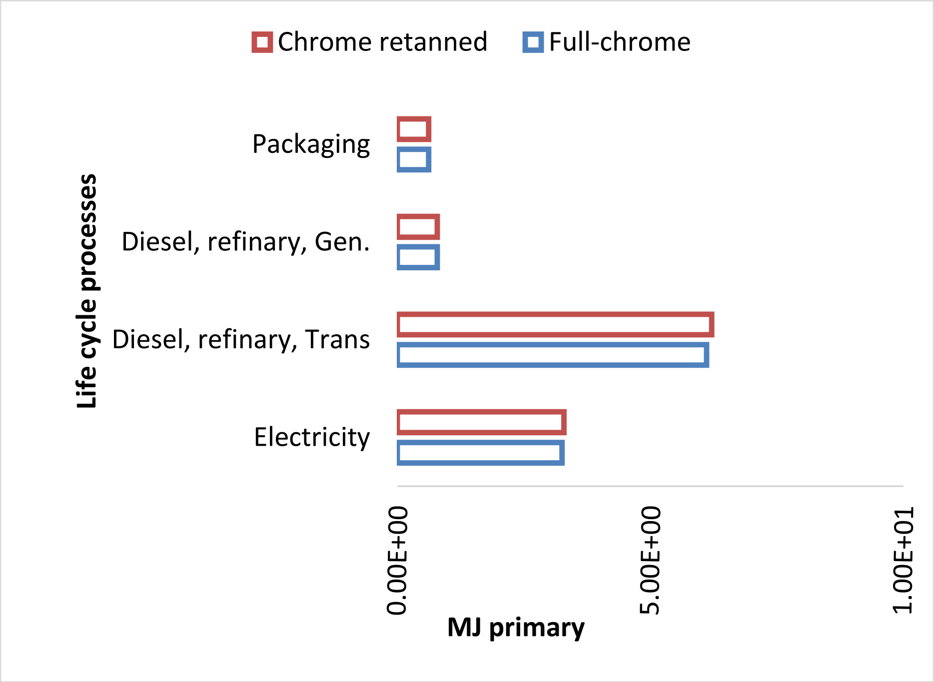

Figure 5-29: This figure shows the relative contribution of life cycle processes to the damage category resources between full-chrome and chrome retanned crust leather production[10].

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[10] Impact of solid wastes excluded

Full-chrome crust leather is one of the main products of the company under studies. It is used for shoe upper making and in few cases for bag production. It is mostly exported to Japan, South Korea and Europe. Comparing the above results, the following observation are made. Full-chrome crust leather has higher Aquatic ecotoxicity contribution. Full-chrome is more than 5 times higher than chrome retanned crust leather and the total amount of kg TEG water emitted by these two systems are 26700 and 5340 per m^2 (Appendix table: 01). In case of aquatic eutrophication, total amount of kg PO_4 P-lim emitted by chrome retanned system is marginally higher than full-chrome system and these amounts are 0.0222 and 0.0229 per m^2 respectively (Appendix table: 03). Here total amount of kg SO_2 eq emission of full-chrome system is greater than chrome retanned system and which are 0.0424 and 0.0372 per m^2respectively (Appendix table: 02). Non-carcinogens follows the trends of Aquatic ecotoxicity and here total amount of kg C_2H_3Cl eq emission of full-chrome system is 4.53 times higher than chrome retanned systems which are 0.273 and 0.0603 (Appendix table: 09). Total emission per m^2 crust leather of rest of the characterization categories are carcinogens 0.0230 and 0.0234 kg C_2H_3Cl eq (Appendix table: 04), global warming 0.721 and 0.731 kg CO_2 eq (Appendix table: 05), ionizing radiation 0.442 and 0.446 Bq C-14 eq (Appendix table: 06), land occupation 0.0012 and 0.0013 m^2org.arable (Appendix table: 07), mineral extraction 0.0011 and 0.0012 MJ surplus (Appendix table: 08), non-renewable energy 10.8 and 10.9 MJ primary (Appendix table: 10), ozone layer depletion 3.50E-09 and 3.50E-09 Kg CFC-11 (Appendix table: 11), respiratory inorganics 0.0012 and 0.0012 kg $PM_{2.5}$ eq (Appendix table: 12), respiratory organics 0.00025 and 0.00025 kg C_2H_4 eq (Appendix table: 13), terrestrial acidification/nutrification 0.0321 and 0.0326 kg SO_2 eq (Appendix table: 14) and terrestrial ecotoxicity 49.1 and 49.9 kg TEG soil for full-chrome and chrome retanned systems respectively. Damage category ecosystem quality of full-chrome system is 2.53 times higher than chrome retanned system and total amount are 1.77 and 0.698 PDF*m^2*yr. (Appendix table: 17) per m^2.In case of human health, total amount are 1.63E-06 and 1.05E-06 DALY (Appendix table: 18) per m^2 for full-chrome and chrome retanned system. It is clear that full chrome system is much higher than chrome retanned system for both categories. Total damage values per m^2 crust leather of rest of the categories are climate change 0.721 and 0.731 kg CO_2 eq (Appendix table: 16) and resources 0.615 and 0.615 MJ primary. In general, full-chrome leather has higher environmental impact. Others impact and damage categories are dominated by supply chain processes especially in most cases transports and electricity where company has little or no control.

6.1 Introduction

LCA-based tools are becoming increasingly valuable to the industry, and the industry should embrace them. But it must do so in a way that is objective, transparent and sound. They should be used as product improvement tools, rather than simply as tools to provide positive marketing support. The remedial measures recommended under this thesis are mostly substitution of chemicals, simple technological change, process modification, and input chemical reduction. Tanneries can reduce their pollution through engaging with their suppliers or transforming their business model in order to better control their supply chain (Aldaya & Hoekstra 2010). It is clearly indicated in the characterized values the company has serious impact on aquatic ecotoxicity and eutrophication which results increased contribution to ecosystem quality damage category. Non-carcinogen and acidification take the next position. Other impact categories are mainly dominated by supply chain processes. Transports dominated terrestrial ecotoxicity, terrestrial acidification/nutrification, respiratory organics and inorganics. Electricity governs mineral extraction, land occupation, ozone layer depletion and ionizing radiation. In addition, carcinogens, global warming and non-renewable energy are jointly dominated by electricity and transports. For each environmental impact the main sources and the remedial solutions will be dealt. As different supply chain processes emission and sources are out of the company's control, it is very difficult to take corrective action. However, by providing awareness program to the major suppliers and freight service provider improvement will be expected. Such as utilization of vehicle with low environmental impacts and avoiding using of old vehicles. The company may use different communication systems to raise the awareness of its staff through different means like brochure, informal discussion, e-mail or telephone. The improvement options suggested are also improving the condition of the existing boiler and trying to minimize the quantity of steam consumed. The stakeholders need to have general awareness program so as to insert life cycle thinking in the company. Life cycle thinking implies that everyone in the whole chain of a product's life cycle, from cradle to grave has a responsibility and a role to play ,taking into account all relevant external effects (PRé 2000). In relation to this the company can prepare environmental management programs (EMP) and set the environmental performance indicators that can easily be tracked.

By so doing improvement is expected on handling the environmental problems of the company. Since the implementation of the LCA not yet practiced in Bangladeshi tanneries, this thesis will serve as a tool for guiding what has to be done on LCA and on the major environmental problems of the tannery industry. However, my aim is simply to share the understanding I have developed through combining my experience of both leather and LCA in the hope that it helps the industry move forward on footprinting-related issues.

6.2 Aquatic eutrophication

Highest value of aquatic eutrophication is observed as a result of consumption of processing chemicals. When traced back to the main production process stages for such highest value of eutrophication the main source are deliming-bating, liming and presoaking processes. As mentioned earlier aquatic eutrophication results due to emission of ammonia, COD, Phosphate and phosphorus etc. to air and water. So to improve these emissions remedial solutions expected to be implemented which are suggested below.

6.2.1 Solution to aquatic eutrophication

The company is now using ammonium sulfate as the main deliming agent which is responsible for increased ammonia emission. Nitrogen free deliming agent will significantly reduce ammonia and COD load. Formic acid, sulfosalicylic acid, citrate acid, Nylon acid, gluconic acid could be used as a alternatives (Sui et al. 2012). Sulfonated phthalic magnesium salt (SPMS) can also be an alternative to nitrogenous base deliming agents (Qiang et al. 2011). In addition, carbon dioxide can be used as the replacement of ammonium salts in the deliming process and wastewater and chemicals after membrane filtration of the deliming-bating liquor can be reused (Gallego-Molina et al. 2013). Hair-save techniques can be used in liming processes where unhairing is carried out by dissolving the hair root rather than the whole hair and remaining hair is filtered out of the effluent. As a result, concentration of hair breakdown products in the effluent is reduced (Joint Research Centre 2013). Abatement of ammonia and hydrogen sulfide emission from deliming-bating process can be done by scrubbing and/or bio filtration. Lower concentrations of these substances can be abated by bio filters, but, at higher concentrations, since they poison the microorganisms which carry out the treatment so, a wet scrubber may precede. Wet scrubbing of ammonia uses an acidic solution; and that of hydrogen sulfide uses an alkaline solution, such as hydrogen peroxide or a mixture of sodium hydroxide and sodium hypochlorite (Joint Research Centre 2013). Fleshing skins in green or soaked state is a useful procedure for producing chemical-free solid residues and it allows a more rapid and uniform penetration of chemicals into the skin. Green fleshing requires a well-set machine, where blades are exactly adjusted to avoid a further fleshing step after liming (EC 2001).If green fleshing is suitably applied before the consumption of chemicals and water in the beam house are reduced by 10-20%. Consequently the wastewater volume in the unhairing/liming step will also reduce. Green fleshing allows a more rapid and uniform penetration of chemicals into the skin (EC 2001)(Clonfero 1999).Lime unhairing is the largest contributor of pollution in tanneries. Enzymes and amines can be added to facilitate the unhairing and reduce the consumption of sulfides (Clonfero 1999). When enzymes are used the water consumption increases because an additional finishing step is required to block the enzymatic activity and the saved hair is not suitable for the production of felt (Clonfero 1999).But the suspended solids, COD, BOD and nitrogen amount are expected to be reduced from the existing effluent load. During liming process the company is started to use enzymes to facilitate soaking and liming process. In the long run effort will be made to reduce the sulfide consumption. Through the use of newly developed salt-substitute non-swelling acid (such as Sulfone) (Clonfero 1999), salt-free systems, based on non-swelling polymeric sulfuric acids are available. Another reference quotes the possibility of a partial substitution of chloride by using e.g. Aromatic sulfonic acids. Use of these acids results in reduction of the chloride and sulfates in the discharge liquor (EC 2001).

6.3 Aquatic acidification

The utilization of processing chemicals is the cause of high acidification values at deliming-bating, liming, pickling and presoaking processes. The solutions suggested on aquatic eutrophication also include solution for aquatic acidification problems.

6.4 Non-carcinogens

The main source for aquatic ecotoxicity is again the chemical consumption during production processing. Tanning, rechroming, neutralization and acidwash is the main source for the severe occurrence of human toxicity since the concentration of total chromium in the polluted water is much higher than the acceptable limit. The emissions responsible for non-carcinogen are Cr (III), Cr (VI) which play significant role on maximizing toxicity potential and ammonia to a minor extent.

6.4.1 Solution

Effluent treatment plant will significantly reduce environmental load of the following parameters. Chemical modification of chromium tanning salt can be one of the options for enhancing the uptake of chromium. Synthetic tanning material based on chromium improved significantly (90%) chromium uptake (Lofrano et al. 2013). Enhancement of chromium uptake in tanning using oxazolidine and a decreasing of the chromium load in wastewater can be achieved (Sundarapandiyan et al. 2011). Modification of process such as reduction of float is another tool for improving the chromium uptake. Carrying out chrome tanning without float and increasing the temperature at the end of the tanning process brought about 91% reduction in chromium discharged (Lofrano et al. 2013). Recently CO_2 proposed as process additive for free of water tanning (Manfred et al. 2012).

6.5 Aquatic ecotoxicity

The main contributor to this category are chromium (III), chromium (VI) and ammonia. Especially both form of chromium have the same characterization conversion factor which is 453048.8189 required to convert into equivalent TEG water. Solutions to these emissions are discussed under eutrophication and non-carcinogens categories.

6.6 Water reduction

Water consumption at production level can be reduced by reducing the running washing time and practicing closed drum washing where applicable. It is found that in tannery with poor water management, only 50 % of the water consumed is actually used in the process; the other half is lost due to extensive running water losses, overflowing vessels, leakage, continuously running pipes, and over-frequent cleaning of floors and drums. Measures to be taken against inefficient use of water involve a serious worker-training program, a clearly communicated code of practice for operators, including information about cleaning cycles, and the installation of basic technical equipment such as flow-meters and relatively simple spring valves (Joint Research Centre 2013).The short float technique yields a reduction in water consumption and processing time, savings in chemical input because of a higher effective concentration and increased mechanical action. By modifying the equipment to utilize short floats, 40 – 80 % floats instead of 100 – 250 % are achieved for certain process steps. With a combination of batch washing and short floats, savings of up to 70 % can be achieved, compared with a conventional process. Attention has to be paid, however, to the consequences for the equipment and the pelts. Short floats may increase wear on the drum bodies and the drive. Water also functions as a coolant during the process. The friction and mechanical strain on the goods are increased (Joint Research Centre 2013). The installation of modern tannery machines can reduce water consumption by 50 %(compared with a conventional process) in addition to chemical savings. Depending on the cost of water, the high cost of the machines can often be justified by the water and chemical conservation and reduction of chemical input they make possible (Joint Research Centre 2013). Possible reuse of treated wastewater could be an option for washing processes in production phases.

How Effluent treatment plant will significantly reduce the environmental burdens of production processes can be examined by the following assumption. It is assumed that ETP will be capable of reducing the pollutants load to the standard discharge level. Standard values of different pollutants taken from others countries like India and Vietnam where standard value of some pollutants not yet published for Bangladesh. Standard discharge of COD, chromium taken from Paul et al. 2013. In addition, nitrate, nitrite, ammonia as N, chromium VI and phosphate taken from Indian discharge standard (Environmental protection rules 1986, schedule VI and national river conservation directorate guidelines). Standard discharge of total nitrogen taken from Vietnam discharge standard (UNIDO 2003). Standard discharge of different effluents have been converted to per m^2 of full-chrome crust leather taking average wastewater load 4.45 L per m^2.

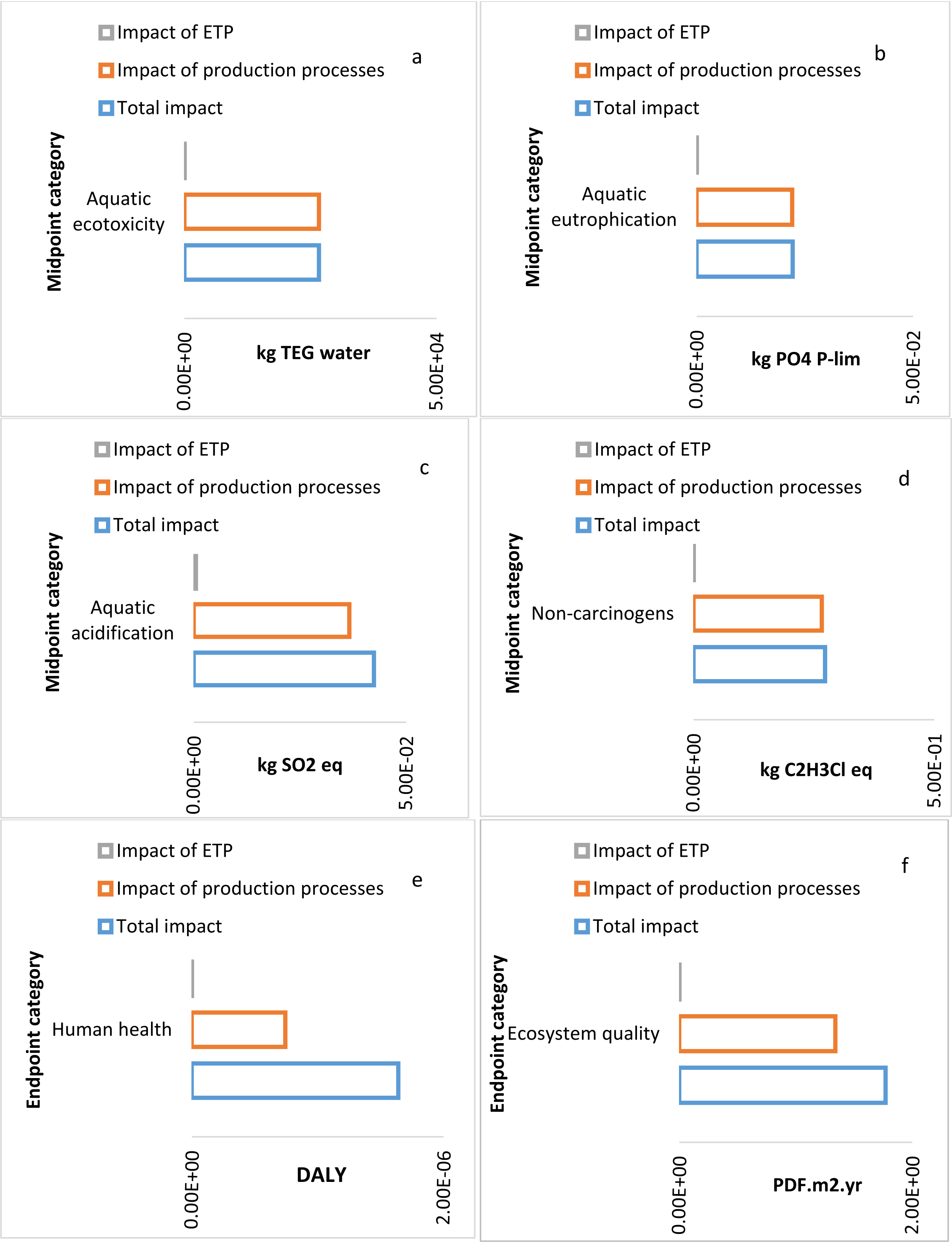

Figure 6-1: Reduction of impact by ETP. Fig. a-d show the reduction at midpoint level and fig. e-f at endpoint level.

It has been seen from the above figure 6-1 that impact of ETP processes is negligible for midpoint categories aquatic ecotoxicity, aquatic eutrophication, aquatic acidification and non-carcinogens. In addition, it is also negligible for endpoint categories human health and ecosystem quality. According to the table A-20, the percent share of impact of production processes of the above midpoint and endpoint categories are 99.88, 86.23, 99.54, 97.30, 75.93 and 45.47 (Table A-20) percent reduction of impact of production processes at the above midpoint and endpoint level by ETP processes are 99.98, 98.61, 99.81, 99.98, 99.98 and 99.98 (Table A-20) which are almost 100%. So it can be said that impacts committed by production processes to the total impacts of all life cycle processes will almost reduce if the ETP is implemented.

CHAPTER 7 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

In this study, major emissions considered by Impact 2002+ method were heavy metal chromium discharge into water, high COD, gaseous emissions (H_2S, NH_3) and ammonia as N wastes produced in the tannery. These emissions are responsible for the contribution of the tannery to significant toxicological impacts namely aquatic ecotoxicity, non-carcinogens, aquatic acidification, and aquatic eutrophication. Furthermore, energy consumption in the tannery and transportation (raw, chemical and products delivery) pose remarkable environmental burdens through emissions to atmosphere. The slaughterhouse plays a minor role in the creation of environmental impacts during the life cycle of studied leather. In this thesis the crust leather production is only considered since the company exports only crust which is then finished by the buyer itself. Also, crust leathers are the dominant articles of the company and these type of tanning (using basic chromium sulfate) cover 90% of world's leather production (Covington & Covington 2009). The assessment shows that full-chrome crust leather production system has higher environmental impact than chrome retanned crust leather. The main contributor for full-chrome crust leather's environmental impact are non-carcinogens, aquatic ecotoxicity, eutrophication and acidification. Based on the LCA method environmental improvement options from chemical substitution to technological change have been devised for the company under study. Most of the suggested improvements are low cost type and focuses on chemical substitution/process modification/chemical consumption reduction. By implementing these options the company will reduce /minimize its environmental impact to the society and may get a saving on its chemical and water consumption.

Main findings of this study are:

- Irrespective to systems the main hotspots identified are chrome tanning (full-chrome crust leather)/ pretannage (chrome retanned crust leather), rechroming, neutralization, acid wash, deliming-bating, transport for raw, transport for chemical and electricity.
- Production processes mainly contributed to non-carcinogens, aquatic ecotoxicity, aquatic acidification and aquatic eutrophication impact categories and eventually to damage categories such as human health and ecosystem quality.

- Supply chain processes like transporting of raw, chemicals and products, electricity and packaging are the main contributors for global warming, carcinogens, ionizing radiation, ozone layer depletion, terrestrial ecotoxicity, terrestrial acidification/nutrification, respiratory organics and inorganics, land occupation, mineral extraction and non-renewable energy and eventually contributed to damage categories resources, climate change and human health.
- Full-chrome crust leather has 5 times higher impact on aquatic ecotoxicity
- Full-chrome crust leather has 4.53 times higher impact on non-carcinogens
- Aquatic acidification of full-chrome system is greater than chrome retanned system
- Chrome retanned crust leather has marginally higher value of aquatic eutrophication
- Processing chemicals plays a dominant role for increased eutrophication and acidification value
- Full-chrome crust leather has 2.53 times higher impact on ecosystem quality
- Human health of full-chrome system is also greater than chrome retanned system.
- Discharge of heavy metal chromium plays a dominant role for increased impact on ecosystem quality and human health
- Full-chrome crust leather has higher environmental burden compared to chrome retanned crust leather.

7.2 Limitations of the study

- Proxy processes were derived from the data of other countries which might not be representative for our country
- Finished leather would have been more representative in terms of system boundary consideration.
- Some impacts might have spatial variability which was not considered in this study.
- Reduction of some impacts by the ETP is an idealized concept. In practice, ETP has resource and chemical consumption, pollutant emissions and the consequent environmental impacts in all impact categories which were ignored
- Solid wastes generated from different stages of production were merely identified and quantified but corresponding emissions and subsequent impact have not been analyzed and assessed

The method IMPACT 2002+ modelled different impacts which are regional or local and used generic characterization factors (CFs) representing average conditions for a specific area (country or continent). For example, the impact in DALY caused by the discharge of heavy metal chromium would be much higher in Bangladesh compared to Europe due to the higher population density. Since human health damage is simply added across individuals, that is, two people each losing 10 years of disability-free life are treated as the same loss as one person losing 20 years, the number of years lived with disability and number of years lost due to premature mortality will be much higher in higher population density areas. It is advisable to use a method that suitably fits to the production activity to be dealt. But currently no method is available to address the problems of developing countries like Bangladesh. Recently a new method name IMPACT World+ is being developed internationally to cover the whole world.

7.3 Recommendations for future work

- Some proxy processes can be developed for our country or data extrapolation methods may be used to get more robust results in bridging data gaps.
- Cradle to cradle life cycle approach would be more representative in search of greener articles
- Inclusion of finishing operations in the system boundary will be more representative
- These crust leathers can be compared with the synthetic leather to have more greener products
- The impact method having spatial variability would be more suitable which is under development by international expert team
- Inclusion of impact of solid wastes would be more representative in the LCA approach

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APPENDIX A

A.1 Life Cycle Impact Assessment Methods

SimaPro contains a number of impact assessment methods, which are used to calculate impact assessment results (PRé 2014).

- **European methods**

1. CML-IA
2. Ecological Scarcity 2013
3. EDIP 2003
4. EPD (2013)
5. EPS 2000
6. IMPACT 2002+
7. RECIPE
8. ILCD 2011 Midpoint

- **North American**

1. BEES
2. TRACI 2.1

A.2 the basic structure of impact assessment methods in SimaPro is

- Characterization
- Damage assessment
- Normalization
- Weighting

The last steps are optional according to the ISO standards. This means it is not always available in all methods. In SimaPro one can switch the optional steps on or off when edit a method.

- **Characterization**

The substances that contribute to an impact category are multiplied with a characterization factor that expresses the relative contribution of the substance. For example, the characterization factor for CO_2 in the impact category Climate change can be equal to 1, while the characterization factor of methane can be 25. This means the release of 1 kg methane causes the same amount of climate change as 25 kg CO_2. The total result is expressed as impact category indicators (formerly characterization result). In SimaPro, sub-compartments can be specified for each substance. For example, one can define and emission to water having a sub-compartment Ocean. This allows one to create detailed impact assessment methods, with specific characterization factors for each sub-compartment. Some impact assessment methods are not as detailed as the inventory in terms of specification of sub-compartments. In this case SimaPro will choose the "unspecified" characterization factor as the default factor for a substance that has a sub-compartment specified in the inventory but has no specific characterization factor in the chosen impact assessment method.

- **Damage assessment**

Damage assessment is a relatively new step in impact assessment. It is added to make use of endpoint methods, such as the Eco-indicator 99 and the EPS 2000 method. The purpose of damage assessment is to combine a number of impact category indicators into a damage category (also called area of protection). In the damage assessment step, impact category indicators with a common unit can be added. For example, in the Eco-indicator 99 method, all impact categories that refer to human health are expressed in DALY (disability adjusted life years). In this method it is allowed to add DALYs caused by carcinogenic substances to DALYs caused by climate change.

- **Normalization**

Many methods allow the impact category indicator results to be compared by a reference (or normal)value. This means, the impact category is divided by the reference. A commonly used reference is the average yearly environmental load in a country or continent, divided by the number of inhabitants. However, the reference may be chosen freely. One could also choose the environmental load of lighting a 60W bulb for one hour, 100 km of transport by car or 1 liter of milk. This can be useful to communicate the results to non LCA experts, as benchmark one's own LCA against something everybody can imagine.

- **Weighting**

Some methods allow weighting across impact categories. This means the impact (or damage) category indicator results are multiplied by weighting factors, and are added to create a total or single score. Weighting can be applied on normalized or non-normalized scores, as some methods like EPS do not have a normalization step. In SimaPro, there are often alternative weighting sets available, always in combination with a normalization set.

Table A-1: Characterization value of aquatic ecotoxicity impact category in kg TEG water

Processes name	**Full-chrome (kg TEG water)**	**Chrome retanned (kg TEG water)**
Transport, raw	1.50E+01	1.50E+01
Transport, chem	7.00E+00	7.00E+00
Electricity	7.00E+00	7.00E+00
Electricity, gen	1.00E-06	1.00E-06
Diesel, refinery, trans	8.70E-02	8.80E-02
Diesel, refinery, gen.	1.10E-02	1.10E-02
Diesel, boiler	1.49E-01	1.49E-01
Transport, diesel	9.00E-03	9.00E-03
Deliming-bating	1.00E-06	1.00E-06
Tanning	1.37E+04	2.45E+03
Acidwash	1.79E+03	3.19E+02
Rechroming	9.38E+03	1.69E+03
Neutralization	1.80E+03	8.52E+02
Packaging	4.77E-01	4.77E-01
Transport, prod	3.00E+00	3.00E+00
Other processes	3.20E+01	3.30E+01
Total of all processes	2.67E+04	5.34E+03

Table A-2: Characterization value of aquatic acidification impact category in kg SO_2 eq

Processes name	**Full-chrome kg SO_2 eq**	**Chrome retanned kg SO_2 eq**
Transport, raw	0.00161	0.00161
Transport, chem	0.00101	0.00107
Electricity	0.00085	0.00086
Electricity, gen	0.00033	0.00033
Diesel, refinery, trans	0.00029	0.00030
Diesel, refinery, gen.	0.00004	0.00004
Diesel, boiler	0.00116	0.00116
Transport, diesel	0.000001	0.000001
Presoaking	0.00283	0.00283
Main soaking	0.00057	0.00057
Liming	0.00488	0.00488
Deliming-bating	0.01270	0.01270
Pickling	0.00451	0.00451
Tanning	0.00969	0.00312
Acidwash	0.00015	0.00003
Rechroming	0.00013	0.00002
Neutralization	0.00002	0.00002
Retanning	0.00029	0.00228
Fatliquoring	0.00033	0.00024
Topfat	0.00050	0.00007
Packaging	0.00009	0.00009
Transport, prod	0.00047	0.00047
Other processes	0.00353	0.00330
Total of all processes	0.04240	0.03720

Table A-3: Characterization value of aquatic eutrophication impact category in kg PO_4 P-lim

Processes name	**Full-chrome (kg PO4 P-lim)**	**Chrome retanned (kg PO4 P-lim)**
Slaughtering	0.00007	0.00007
Electricity	0.00003	0.00003
Diesel, refinery, trans	0.000005	0.000005

Diesel, refinery, gen.	0.000001	0.000001
Presoaking	0.00305	0.00305
Main soaking	0.00126	0.00126
Liming	0.00432	0.00432
Deliming-bating	0.00916	0.00916
Pickling	0.00051	0.00051
Tanning	0.00127	0.00092
Acidwash	0.00028	0.00009
Rechroming	0.00027	0.00005
Neutralization	0.00026	0.00014
Retanning	0.00050	0.00169
Fatliquoring	0.00044	0.00131
Topfat	0.00079	0.00035
Packaging	0.000001	0.000001
Other processes	0.00268	0.00214
Total of all processes	0.0222	0.0229

Table A-4: Characterization value of carcinogen impact category in kg C_2H_3Cl eq

Processes name	**Full-chrome (kg C2H3Cl eq)**	**Chrome retanned (kg C2H3Cl eq)**
Transport, raw	0.00477	0.00477
Transport, chem	0.00425	0.00449
Electricity	0.00948	0.00959
Diesel, refinery, trans	0.000109	0.000111
Diesel, refinery, gen.	0.00001	0.00001
Diesel, boiler	0.00141	0.00141
Transport, diesel	0.00000	0.00000
Packaging	0.001	0.001
Transport, prod	0.00196	0.00196

Other processes	0.00113	0.00113
Total of all processes	0.0230	0.0234

Table A-5: Characterization value of Global warming impact category in kg CO_2 eq

Processes name	**Full-chrome (kg CO_2 eq)**	**Chrome retanned (kg CO_2 eq)**
Transport, raw	0.22	0.22
Transport, chem	0.111	0.118
Electricity	0.226	0.229
Electricity, gen	0.0494	0.0494
Diesel, refinery, trans	0.0399	0.0406
Diesel, refinery, gen.	0.00513	0.00513
Diesel, boiler	0.00007	0.00007
Transport, diesel	0.00024	0.00024
Packaging	0.017	0.017
Prod. transport	0.0515	0.0514
other processes	0.023	0.023
Total of all processes	0.721	0.731

Table A-6: Characterization value of ionizing radiation impact category in Bq C-14 eq

Processes name	**Full-chrome (Bq C-14 eq)**	**Chrome retanned (Bq C-14 eq)**
Electricity	0.214	0.217
Diesel, refinery, trans	0.103	0.105
Diesel, refinery, gen.	0.013	0.013
Packaging	0.11	0.11
Total of all processes	0.442	0.446

Table A-7: Characterization value of land occupation impact category in m^2org.arable

Processes name	**Full-chrome (m^2org.arable)**	**Chrome retanned (m^2org.arable)**
Electricity	0.00099	0.00101
Packaging	0.00025	0.00025
Total of all processes	0.00124	0.00125

Table A-8: Characterization value of mineral extraction impact category in MJ surplus

Processes name	**Full-chrome (MJ surplus)**	**Chrome retanned (MJ surplus)**
Electricity	9.30E-04	1.02E-03
Diesel, refinery, trans	3.00E-05	3.00E-05
Diesel, refinery, gen.	4.00E-06	4.00E-06
Packaging	1.44E-04	1.44E-04
Total of all processes	1.10E-03	1.20E-03

Table A-9: Characterization value of non-carcinogens impact category in kg C_2H_3Cl eq

Processes name	**Full-chrome (kg C_2H_3Cl eq)**	**Chrome retanned (kg C_2H_3Cl eq)**
Transport, raw	0.00363	0.00363
Transport, chem	0.00163	0.00172
Electricity	0.00101	0.00103
Diesel, refinery, trans	0.00003	0.00003
Diesel, boiler	0.00022	0.00022
Transport, diesel	0.000002	0.000002
Deliming-bating	0.0000001	0.0000001
Tanning	0.137	0.024

Acidwash	0.01780	0.00318
Rechroming	0.0934	0.0168
Neutralization	0.01800	0.00848
Packaging	0.00012	0.00012
Transport, prod	0.00075	0.00075
Other processes	0.00739	0.00750
Total of all processes	0.2730	0.0603

Table A-10: Characterization value of non-renewable energy impact category in MJ primary

Processes name	**Full-chrome (MJ primary)**	**Chrome retanned (MJ primary)**
Electricity	3.25	3.29
Diesel, refinery, trans	6.11	6.21
Diesel, refinery, gen.	0.786	0.786
Packaging	0.615	0.615
Total of all processes	10.80	10.90

Table A-11: Characterization value of ozone layer depletion impact category in kg CFC-11 eq

Processes name	**Full-chrome (kg CFC-11 eq)**	**Chrome retanned (kg CFC-11 eq)**
Electricity	2.20E-09	2.20E-09
Diesel, refinery, trans	9.00E-10	9.00E-10
Diesel, refinery, gen.	1.00E-10	1.00E-10
Packaging	3.00E-10	3.00E-10
Total of all processes	3.50E-09	3.50E-09

Table A-12: Characterization value of respiratory inorganics impact category in kg $PM_{2.5}$ eq

Processes name	**Full-chrome (kg PM2.5 eq)**	**Chrome retanned (kg PM2.5 eq)**
Transport, raw	3.00E-04	3.00E-04
Transport, chem	2.10E-04	2.20E-04
Electricity	3.12E-04	3.16E-04
Electricity, gen	8.13E-05	8.13E-05
Diesel, refinery, trans	3.00E-05	3.00E-05
Diesel, boiler	1.00E-04	1.00E-04
Transport, diesel	2.00E-07	2.00E-07
Deliming-bating	0.00E+00	0.00E+00
Packaging	1.00E-05	1.00E-05
Transport, prod	1.00E-04	1.00E-04
Other processes	1.30E-04	1.30E-04
Total of all processes	1.15E-03	1.17E-03

Table A-13: Characterization value of respiratory organics impact category in kg C_2H_4 eq

Processes name	**Full-chrome (kg C_2H_4 eq)**	**Chrome retanned (kg C_2H_4 eq)**
Transport, raw	5.00E-05	5.00E-05
Transport, chem	4.00E-05	5.00E-05
Electricity	3.60E-05	3.70E-05
Electricity, gen	2.60E-05	2.60E-05
Diesel, refinery, trans	4.00E-05	4.00E-05
Diesel, refinery, gen.	5.00E-06	5.00E-06
Diesel, boiler	1.00E-05	1.00E-05
Transport, diesel	0.00E+00	0.00E+00
Packaging	2.14E-05	2.14E-05

Transport, prod	2.00E-05	2.00E-05
other processes	5.00E-06	5.00E-06
Total of all processes	2.50E-04	2.50E-04

Table A-14: Characterization value of terrestrial acid-nutrification impact category in kg SO_2 eq

Processes name	**Full-chrome (kg SO_2 eq)**	**Chrome retanned (kg SO_2 eq)**
Transport, raw	0.0126	0.0126
Transport, chem	0.00795	0.00840
Electricity	0.00225	0.00228
Electricity, gen	0.002	0.002
Diesel, refinery, trans	0.00080	0.00082
Diesel, refinery, gen.	0.0001	0.0001
Diesel, boiler	0.001	0.001
Transport, diesel	0.000008	0.000008
Deliming-bating	0.000005	0.000005
Packaging	0.0002	0.0002
Transport, prod	0.003	0.003
Other processes	0.00121	0.00123
Total of all processes	0.0321	0.0326

Table A-15: Characterization value of terrestrial ecotoxicity impact category in kg TEG soil

Processes name	**Full-chrome (kg TEG soil)**	**Chrome retanned (kg TEG soil)**
Transport, raw	29	29
Transport, chem	12.70	13.40
Electricity	1.070	1.090
Electricity, gen	0.000001	0.000001

Diesel, refinery, trans	0.103	0.104
Diesel, refinery, gen.	0.01	0.01
Diesel, boiler	0.28	0.28
Transport, diesel	0.018	0.018
Deliming-bating	0.000003	0.000003
Packaging	0.08	0.08
Transport, prod	5.87	5.87
Other processes	0.505	0.506
Total of all processes	49.10	49.90

Table A-16: Damage assessment value of climate change category in kg CO_2 eq

Processes name	**Full-chrome (kg CO_2 eq)**	**Chrome retanned (kg CO_2 eq)**
Transport, raw	0.22	0.22
Transport, chem	0.111	0.118
Electricity	0.226	0.229
Electricity, gen	0.049	0.049
Diesel, refinery, trans	0.0399	0.0406
Diesel, refinery, gen.	0.005	0.005
Diesel, boiler	0.00007	0.00007
Transport, diesel	0.0002	0.0002
Packaging	0.0179	0.0179
Transport, prod	0.0514	0.0514
Other processes	0.0233	0.0233
Total of all processes	0.721	0.731

Table A-17: Damage assessment value of ecosystem quality category in PDF*m^2*yr.

Processes name	**Full-chrome**	**Chrome retanned**
Transport, raw	0.24	0.24
Transport, chem	0.109	0.115
Electricity	0.0122	0.0124
Electricity, gen	0.002	0.002
Diesel, refinery, trans	0.00165	0.00168
Diesel, refinery, gen.	0.0002	0.0002
Diesel, boiler	0.004	0.004
Transport, diesel	0.0001	0.0001
Deliming-bating	0.000005	0.000005
Tanning	0.689	0.123
Acidwash	0.089	0.016
Rechroming	0.471	0.084
Neutralization	0.0905	0.0428
Packaging	0.001	0.001
Transport, prod	0.05	0.05
Other processes	0.0715	0.0717
Total of all processes	1.77	0.69

Table A-18: Damage assessment value of human health category in DALY.

Processes name	**Full-chrome (DALY)**	**Chrome retanned (DALY)**
Transport, raw	2.32E-07	2.32E-07
Transport, chem	1.65E-07	1.74E-07
Electricity	2.48E-07	2.51E-07
Electricity, gen	5.69E-08	5.69E-08
Diesel, refinery, trans	2.37E-08	2.40E-08

Diesel, refinery, gen.	3.00E-09	3.00E-09
Diesel, boiler	7.00E-08	7.00E-08
Transport, diesel	2.00E-10	2.00E-10
Deliming-bating	0.00E+00	0.00E+00
Tanning	3.83E-07	6.83E-08
Acidwash	4.99E-08	8.90E-09
Rechroming	2.61E-07	4.70E-08
Neutralization	5.03E-08	2.37E-08
Packaging	1.00E-08	1.00E-08
Transport, prod	7.00E-08	7.00E-08
Other processes	3.97E-08	4.01E-08
Total of all processes	1.64E-06	1.05E-06

Table A-19: Damage assessment value of resources category in MJ primary.

Processes name	**Full-chrome (MJ primary)**	**Chrome retanned (MJ primary)**
Electricity	3.26E+00	3.29E+00
Diesel, refinery, trans	6.11E+00	6.21E+00
Diesel, refinery, gen.	7.86E-01	7.86E-01
Packaging	6.15E-01	6.15E-01
Total of all processes	1.08E+01	1.09E+01

Table A-20: reduction of environmental burden by ETP

Impact category (Midpointand Endpoint category)	Total impact	Impact of production processes	Percent share of impact of production processes	Impact of ETP discharge	Percent reduction of impact of production processes by ETP
Aquatic ecotoxicity, kg TEG water	26700	26700	99.88	4.23 kg TEG water	99.98
Aquatic acidification, kg SO_2 eq	0.0424	0.0366	86.23	0.000507 kg SO_2 eq	98.61
Aquatic eutrophication, kg PO_4 P-lim	0.0222	0.0221	99.54	0.00004 kg PO_4 P-lim	99.81
Non-carcinogens, kg C_2H_3Cl eq	0.273	0.266	97.30	0.00004 kg C_2H_3Cl eq	99.98
Ecosystem quality, PDF.m^2.yr	1.77	1.34	75.93	0.000213 PDF.m^2.yr	99.98
Human health, DALY	0.000002	0.000001	45.47	0.0000000001 DALY	99.98

APPENDIX B

Table B-1: Normalization factors (NF) for the four damage categories for Western Europe, for versions 1.0, 1.1, 2.0 and 2.1.

Damage categories	**Normalization factors for damage categories (NF)**			**Unit**
	in version 1.0 and 1.1	**in version 2.0**	**in version 2.1**	
Human health	0.0077	0.0068	0.0071	DALY/point
Ecosystem quality	4’650	13’700	13’700	PDF.m^2.yr/point
Climate change	9’950	9’950	9’950	kg $CO_{2\text{-eq}}$/point
Resources	152’000	152’000	152’000	MJ/point

Table B-2: European population used for modeling and normalization in the different versions.

	EU_{pop}	
	in version 1.0 and 1.1	**in version 2.0 and 2.1**
IMPACT 2002 human toxicity and ecotoxicity modeling	431'000'000 pers	431’000’000 pers
IMPACT 2002+ normalization (except global warming and non-renewable energy consumption)	380’000’000 pers	431’000’000 pers
IMPACT 2002+ normalization (global warming and non-renewable energy consumption)	380’000’000 pers	380’000’000 pers

Table B-3: Characterization damage factors for the considered reference substance (DF)

Midpoint categories	**Characterization damage factors for the considered reference substance (DF) refsub**		**Unit**
	in version 1.0 and 1.1	**in version 2.0 and 2.1**	
Human toxicity (carcinogens + non-carcinogens)	1.45E-6	v2.0: 1.45E-6 v2.1: 2.80E-6	DALY/ kg Chloroethylene-eq into air
Respiratory (inorganics)	7.00E-4	7.00E-4	DALY/kg $PM_{2.5}$-eq into air
Ionizing radiations	2.10E-10	2.10E-10	DALY/Bq Carbon-14-eq into air
Ozone layer depletion	1.05E-3	1.05E-3	DALY/kg CFC-11-eq into air
Photochemical oxidation (= respiratory (organics) for human health)	2.13E-6	2.13E-6	DALY/kg Ethylene-eq into air
Aquatic ecotoxicity	8.86E-5	5.02E-5	PDF·m^2·yr/kg Triethyleneglycol-eqinto water
Terrestrial ecotoxicity	(v1.0: 8.86E-5 PDF·m^2·yr/kg Triethylene glycol-eq into water) 43 v1.1: 1.39E-2	7.91E-3	PDF·m^2·yr/kg Triethylene glycol-eqinto soil
Terrestrial acidification/nutrification	1.04	1.04	PDF·m^2·yr/kg SO_2-eq into air
Aquatic acidification	n/a	n/a	PDF·m^2·yr /kg SO_2-eq into air
Aquatic eutrophication	n/a	n/a	PDF·m^2·yr/kg PO_4^{3-}-eq into water
Land occupation	1.09	1.09	PDF·m^2·yr/m^2 Organic arable land- eq ·year

Midpoint categories	**Characterization damage factors for the considered reference substance (DF) refsub**		**Unit**
	in version 1.0 and 1.1	**in version 2.0 and 2.1**	
Global warming	1	1	kg CO_2-eq into air/kg CO_2-eq into air
Non-renewable energy	45.6	45.8	MJ total primary non-renewable energy/kg Crude oil-eq (860 kg/m3)
Mineral extraction	5.10E-2	5.10E-2	MJ surplus energy/kg Iron-eq (in ore)

Table B-4: Normalization factors for the fourteen midpoint categories

	Normalization factors		**Unit**
	version 1.0 and 1.1	**version 2.0 and 2.1**	
Midpoint categories			
Human toxicity (carcinogens + non-carcinogens)	218	219	kg Chloroethylene-eq into air
Respiratory (inorganics)	9.98	8.80	kg $PM_{2.5}$-eq into air
Ionizing radiations	6.04E+5	5.33E+5	Bq Carbon-14-eq into air
Ozone layer depletion	0.225	0.204	kg CFC-11-eq into air
Photochemical oxidation (= respiratory (organics) for human health)	14.1	12.4	kg Ethylene-eq into air
Aquatic ecotoxicity	3.02E+4	1.36E+6	kg Triethylene glycol-eq into water

Terrestrial ecotoxicity	7’160 kg Triethylene glycol-eq into water (v1.0) 1.68E+4 (v1.1)	1.20E+6	kg Triethylene glycol-eq into soil
Terrestrial acidification/nutrification	358	315	kg SO_2-eq into air
Aquatic acidification	75.1	66.2	kg SO_2-eq into air
Aquatic eutrophication	13.4	11.8	kg PO_4^{3-}-eq into water
Land occupation	3’930	3’460	m^2 Organic arable land-eq ·year
Global warming	9’950	9’950	kg CO_2-eq into air
Non-renewable energy	152’000	152’000	MJ Total primary non-renewable energy
	1’770	3’330	kg Crude oil-eq (860 kg/m3)
Mineral extraction	24.7	292	MJ Surplus energy
	485	5’730	kg Iron-eq (in ore)

APPENDIX C

LCA only accounts for anthropogenic emissions in air, water and soil, thus excluding unhealthy conditions at workplaces and homes, traffic accidents, drinking or smoking. LCA also does not deal with health problems caused by natural disasters, climate, micro-organisms or volcanic eruptions. In general, it does not address economic aspects; thus the consequences of low income are not taken into account.

C.1. Damages to Human Health

Damages to human health are expressed as DALY (Disability Adjusted Life Years).This health-indicator, expressed as the number of Disability-Adjusted Life Years (DALYs), measures the total amount of ill health, due to disability and premature death, attributable to specific diseases and injuries. The DALY concept thus compares time lived with disability (YLD: Years Lived Disabled) and time lost due to premature mortality (YLL: Years of Life Lost). Health is simply added across individuals. That is, two people each losing 10 years of disability-free life are treated as the same loss as one person losing 20 years. The core of the DALY system is a disability weighting scale. This scale has been developed in a number of panel sessions. The scale lists many different disabilities on a scale between 0 and 1 (0 meaning being perfectly healthy and 1 meaning death). carcinogenic substances cause a number of deaths each year. In the DALY health scale, death has a disability rating of 1. If a type of cancer is (on average) fatal ten years prior to the normal life expectancy, we would count 10 lost life years for each case. This means that each case has a value of 10 DALYs.

Models have been developed for respiratory and carcinogenic effects, the effects of ozone layer depletion and ionizing radiation. In these models for human Health four sub steps are used:

- Fate analysis, linking an emission (expressed as mass) to a temporary change in concentration.
- Exposure analysis, linking this temporary concentration to a dose.
- Effect analysis, linking the dose to a number of health effects, like the number and types of cancers.
- Damage analysis, links health effects to DALYs, using estimates of the number of Years Lived Disabled (YLD) and Years of Life Lost (YLL).

C.1.1 Damage to human health caused by carcinogenic substances

Providing evidence of a causal link between agent and tumor incidence is a complex task and needs the consideration of all kinds of experimental results and epidemiological studies.

- **Fate analysis**

The result of the fate analysis is a fate factor that provides the link between an emission in Europe(kg/yr.) and the steady state concentration in air, drinking water and food resulting from this emission. For the emission in the form of a mass load (1 kg) the resulting concentration can be allocated to the emission during a certain period of time.

- **Effect analysis: estimation of cancer incidence**

The cancer incidence is estimated using the Unit-Risk concept. The unit risk factor for inhalation is an estimate of the probability that an average individual will develop cancer when exposed to a pollution at an ambient concentration of one microgram per cubic meter for the individual's life (70 years) [UR in cases per g/m^3]. In case more unit risk factors are available the most recent factors are preferred. In case the unit risk factor for only one exposure pathway is known, the unit risk factors for the other pathways have been extrapolated by calculating an equal intake, using data on inhalation rate, consumption of drinking water and food. The population density determines the number of people exposed. Since pollutants with long atmospheric residence times are blown to rural areas, the effect of these substances is mostly on lower population densities. Long range distribution of substances is mostly via air, regardless where the emission takes place. Therefore the population density is modelled per substance dependent on their atmospheric residence times.

- **Damage analysis**

Estimation of the Years of Life Lost (YLL) and Years Lived Disabled per cancer incidence resulting from the effect factors are estimated from:

1. The type of cancer that is expected.
2. Which share of tumor patients will die?
3. How many potential life years are lost (depending on age)?
4. How long is the illness?

5. What is the severity of the disability?

C.1.2 Damage to Human Health caused by respiratory effects

In epidemiological studies it has been shown that several non-organic substances and dust are related to respiratory effects in humans. According to Pilkington the following substances cause respiratory effects:

- Particulate matter PM10 and PM2.5
- Nitrate and sulfate
- SO_3
- O_3
- CO and probably
- NO_x

The primary emissions that cause exposure to these substances are PM_{10}, $PM_{2.5}$, TSP, NO_x, NH_3, CO,VOCs, and SO_x. These substances are considered as primary pollutants in the fate analysis.

- **Fate analysis**

Hofstetter calculated fate factors for particles with a simple model using assumptions on residence time and dilution height. These fate factors are compared to literature data. For all primary emissions the results of several statistical methods using empirical and modelled data are compared. Best estimates have been made for the fate factors based on three main principles:

1. The fate factors should be appropriate for European conditions.
2. Preference is given to fate factors for which the underlying assumptions are known.
3. Average fate factors that assume a proportional relation between emissions and concentration have been used for all but ozone creation. In this case the marginal factor was considered most appropriate in order to reflect the non-linear atmospheric chemistry of ozone formation.

- **Estimation of dose-response relations**

For the damage analysis of emissions that cause respiratory effects the epidemiological approach is used. Toxicological experiments do not produce effects at ambient concentrations, because test populations used are not representative and the substance is not equal to the substances in the environment. For this reason and the reason that the slope factor for the dose-response curve is not constant, toxicological data are difficult to extrapolate to effects at ambient concentrations. On the other hand the epidemiological approach suffers from limited possibilities to prove causalities, to show correlation with several dozens of substances and to attribute health risks among pollutants with identical emissions sources. On the other hand the epidemiological approach can profit from a large body of literature and has already been used in several externality studies. Therefore this approach is used to estimate DALYs for respiratory diseases caused by environmental pollutants.

- Particles: epidemiological evidence on adverse acute health effects of air polluted with particles is very substantial. There is strong but much less widespread epidemiological evidence on chronic health effects. Sulfates are assumed to result in very small particles ($PM_{2,5}$), whereas nitrates result in PM_{10}. A conversion factor is used to calculate the relationship for $PM_{2,5}$.
- Ozone: The overall evidence strongly supports the view that the acute effects of ozone can be quantified and that they should be added to those of particles.
- Sulfur dioxide: Some study results establish a clear association between SO^2 and mortality, but causality is not proven yet.
- CO: there is little epidemiological evidence concerning CO. The relationship between CO and acute mortality is used in the calculations.
- Nitrous dioxide: a positive association between NO^2 and mortality and respiratory hospital admissions is reported.

Exposure-response functions are determined using the information on ambient concentrations, population density in the study area, daily hospital admissions for respiratory causes and the relative risk. The calculated exposure-response slopes have a background similar to the one of the Unit Risk factors for carcinogenicity.

- **Damage analysis**

To calculate final results in DALYs the seriousness and duration of the diseases had to be estimated. The disability weights are estimated using the weights from Murray as a starting point, because no disability weights have been established for all endpoints. Also the duration of illness has been estimated. Literature values sometimes have a large variation. Poor data for life years lost due to premature death caused by respiratory effects had to be used.

C.1.3 Damage to Human Health caused by ionizing radiation

- **Fate analysis**

The fate model has been based on Dreiceret Al 1995, who described the routine14 atmospheric and liquid discharges in the French nuclear fuel cycle.

- **Exposure analysis**

In the exposure analysis, what dose human actually absorb, given the radiation levels that are calculated in the fate analysis. The measure for the effective dose is the Sievert (Sv), based on human body equivalence factors for the different ionizing radiation types. Data expressed in Sievert contain physical data on energy doses and biological data on the sensitivities of different body tissues. An intermediate stage in the calculations of doses is often expressed as Gray (Gy). This is the measure of absorbed dose without considering the different reaction types of body tissues.

- **Effect and damage analysis**

In the damage analysis, concentration is on carcinogenic and hereditary effects, as these appear to be the most significant.

Two issues are important:

- Establishing the number of cases that occur as a result of the calculated exposure.
- Establishing the number of DALYs per case.

C.1.4 Damage to human health caused by ozone layer depletion

The most important reason is the increase of the chlorine and bromine levels, due to the release of substances such as CFCs with a long atmospheric residence time. This low level has resulted in increased UV radiation levels.

- **Fate and exposure model**

Chlorine containing substances are diluted in the troposphere. In an average of 4 years they also drift into the stratosphere, where they contribute to chemical processes that result in the depletion of the ozone layer. Substances that have a significantly lower residence time than 4 years do not reach the stratosphere in substantial amounts. This means the damage created by a substance is depending on the time horizon. If the time horizon is just 100 years, part of the damage created by substances with a residence time of more than 100 year is neglected.

- **Effect analysis**

UV radiation can cause both beneficial and adverse effects on humans. A direct beneficial effect of exposure is the formation of vitamin D. Adverse effects are among others: sunburn, ageing of the skin, and snow blindness. Health risks associated with ozone depletion are increased damage to skin, eyes, and immune system [UNEP 1994].In light-skinned populations, exposure to solar UVR appears to be the most important environmental risk factor for skin cancer (basal and squamous cell carcinomas and cutaneous melanoma). In the cases of both basal cell carcinoma (BCC) and melanoma (MSC), increases in risk are tied to early exposures (before about age 15), particularly those leading to severe sunburns. There is reasonably good evidence that such immuno-suppression plays a role in human carcinogenesis. Ocular damage from UV exposures includes chronic eye conditions like cataract [UNEP 1998]. Cataracts may be a more widespread health effect than skin cancers.

- **Damage assessment**

Based on the AF and the world-wide incidence of skin cancer and cataract in 1990 [Murray, 1996], the excess incidence as a result of 1% ozone depletion during 1 year is calculated. Mortality is calculated on base of lethal fraction of the disease and the incidence. Incidences and mortality are translated to DALYs using the approach of Hofstetter 1998 and data from Murray et al., 1996 for age at onset of the disease, average duration of the disease and disability weighting. Three-quarters of all DALYs per percentage of ozone layer decrease are caused by disabled years as a result of cataracts. Most DALYs caused by early death (years of life lost) result from increased mortality due to SCC and MSC.

C.2 Damage to ecosystem quality

Damages to ecosystem quality are expressed as the percentage of species that have disappeared in a certain area due to the environmental load. This definition is not as homogeneous as the definition of human health. Ecosystems are heterogeneous and very complex to monitor. One way to describe ecosystem quality is in terms of energy, matter and information flows. If we want to characterize ecosystem quality in terms of these flows, we could say that a high ecosystem quality is the condition in which the flows are not noticeably disrupted by anthropogenic activities. In contrast, a low ecosystem quality is the condition in which these flows are disrupted by anthropogenic activities. The level of disruption is thus the most important parameter to monitor ecosystem quality. To complicate things further these flows can exist on many different levels. For instance the information flow can be described on the level of ecosystems, species and genes. The material and energy flow can be described in terms of free biomass production. It is clear we cannot model all these attributes on all these levels and dimensions. For our purpose, we concentrate on the information flow, on the species level. This means we assume the diversity of species is an adequate representative for the quality of ecosystems. Practically all species groups can be affected by anthropogenic influence. It is impossible to monitor them all. We had to make a choice for the species groups that can be used as an appropriate representative for the total ecosystem quality. Furthermore it is important to choose between the complete and irreversible extinction of species and the reversible or irreversible disappearance or stress on a species in a certain region during a certain time.

The damage to ecosystem quality now can be expressed as:

the relative decrease of the number of species (fraction)* area * time

C.2.1modelling the effect on species groups

The crucial parameter in the model for ecosystem quality is the parameter that represents the effect on a species group. Unfortunately it has not been able to find a uniform parameter for this purpose, such as the DALY. For acidification, eutrophication and land-use the PDF of species is used, the Potentially Disappeared Fraction. The PDF is used to express the effects on vascular plant populations in an area. The PDF can be interpreted as the fraction of species that has a high probability of no occurrence in a region due to unfavorable conditions. The PDF is based on the POO, the Probability of Occurrence. The PDF is in fact represented by 1-POO. This means the fraction of species that does not occur can also be described as the fraction of the species that has disappeared. For this project the PDF concept is also used for land-use. This means there is no uniform damage unit for the damage category ecosystem quality, as in the damage category human health. There are two problems. First, it uses different species groups as representatives for the total ecosystem. Vascular plants for acidification, eutrophication and land-use and a broad range of (mostly lower) aquatic and benthic organisms for toxic effects. Secondly, it uses different levels to determine the effects, the level at which species are affected and the level at which species disappear.

The procedure to calculate damage to ecosystem quality resulting from an emission can be described as follows:

- Determination of the temporary, marginal increase of the concentration in a specific environmental compartment from the fate model, for each specific substance
- Determination of the increase in standardized toxicity units (hazard units) from the concentration increase of the substance for each emitted substance that may cause an impact on ecosystem quality using the average NOEC of each substance. Add up the total increase in hazard units.
- Choosing a reference value for the slope of the combi-PAF curve for substance mixtures representing the present ambient level of toxic stress (working point).
- Determination of the temporary marginal damage (in the environmental compartment considered) from the total increase in hazard units using the slope of the combi-PAF function at the work point. Then multiplying the calculated increase in combi-PAF with the total area of the environmental compartment.

For one specific emission, this procedure is repeated for the concentrations in all relevant environmental receiving compartments separately (water, agricultural soil, industrial soil, natural soil).

C.2.2Damage to ecosystem quality caused by ecotoxic substances

- **Fate analysis**

The fate analysis for ecotoxic substances included in the Eco-indicator 99 methodology is carried out with EUSES. The result of the fate analysis is a link between an emission to air, water, agricultural soil and industrial soil and concentrations in water, and pore water of agricultural, industrial and natural soil.

- **Effect analysis**

The method used to calculate damage to ecosystem quality is the elaboration of the concept by Hamers et al 1996, providing an algorithm to calculate the toxic stress on ecosystems denoted as a potentially affected fraction (PAF) of species. Secondary poisoning is not incorporated into the PAF calculations. The main exposure route is assumed to be water for aquatic ecosystems and pore water for terrestrial ecosystems. The exposure route through food is considered not to be important. A substance specific dose-effect curve, which is representative for the naturally occurring organisms has to be calculated. It is assumed that the dose-effect curve can be described by the log logistic distribution function of NOECs. The log logistic distribution function is estimated from single species toxicity data. The distribution function is based on chronic NOECs. PAF is calculated from the combination of the estimated distribution function and the calculated field concentration.

- **Damage analysis**

For LCA purposes , a specific way to add up damages from combined emissions of a product system, which is a combination of concentration and effect addition. Since spatial and temporal information is not included in LCA, an average background concentration for all substances, equal in all areas of Europe, has to be assumed. A marginal increase of the concentration of one single substance, resulting from a product system, has only a very small influence on the average situation in Europe. According to Meent et al.,1999, the marginal damage to ecosystems from a marginal increase of the concentration of a single substance depends on the present level of damage from the mixture of substances already present in the environment. This means that the slope of the single substance PAF curve is not relevant, but the slope of the overall PAF curve, based on mixtures of substances, which are present in the European environment, must be determined to assess the marginal damage from an emission.

C.2.3Damage to ecosystem quality caused by land-use

The impact of land-cover changes on ecosystems is very significant. In most parts of Europe this influence is perhaps more significant than the effects of many other impact categories. As it is seen, land-cover changes do not only have effects on a specific local area, also the surrounding region can be affected. Furthermore, it needs to distinguish land occupation and land transformation. This means the damage model must be developed in four different versions. Unlike other damage models, the data required for the land-use model is based on empirical data, such as observations of species numbers in different types of land-cover, instead of extrapolations of laboratory data and computer models.

C.2.2.4 Land conversion and land occupation

There is a distinct difference between the following two cases:

1. Land that is being converted from one state to another.
2. Land that has been converted earlier and is occupied for a number of years. It is useful to distinguish these two cases.

A typical example is the production of corn in an old agricultural area. In LCA, this activity cannot be held responsible for the fact that once the area was converted from a natural area long ago. However, each year a certain area remains occupied and cannot return to its original natural stage. For this reason the damage due to land occupation is seen as the damage caused by preventing the occupied area from returning into its natural condition. A typical example of land conversion is the mining activity in a pristine natural area. For each ton of extracted metal, a small additional area is converted from its natural conditions into a mining pit. After the mineral has been extracted, it will take a considerable amount of restoration time before the area returns to a situation that has the same diversity as the original situation. If the mining operation occurs in an agricultural area, the change in species numbers will be smaller, and it may take less time before the area returns to a situation that has the same diversity as the original condition.

C.2.2.5The general principle for the damage model

The concept of PDF can be rather easily applied to model the regional and local damage caused by land occupation and conversion. The potentially disappeared fraction of vascular plant species is expressed as the relative difference between the number of species S on the reference conditions and the conditions created by the conversion, or maintained by the occupation.

C.3 The damage category resources

In the Eco-indicator 99 methodology, it only models mineral resources and fossil fuels. The use of agricultural and silvicultural biotic resources and the mining of resources such as sand or gravel, are considered to be adequately covered by the effects on land use. Biotic resources which are extracted directly from nature, like fish and game or wild plants, are not modelled in Eco-indicator 99 so far. In the case of non-renewable resources (minerals and fossil fuels), it is obvious that there is a limit on the human use of these resources, but it is rather arbitrary to give figures on the total quantity per resource existing in the accessible part of the earth crust. Market forces assure that the deposits with the highest concentrations of a given resource are depleted first, leaving future generations to deal with lower concentrations. Thus in theory, the average ore grade available for future generations will be reduced with the extraction of every kilo. This decreasing concentration is the basis for the resource analysis. The resource analysis is very comparable to the fate analysis, instead of modelling the increase of the concentration of pollutants, we model the decrease of the concentration of mineral resources. The unit of the Resources damage category is the surplus energy in MJ per kg extracted material, this is the expected increase of extraction energy per kg extracted material, when mankind has extracted an amount that is N times the cumulative extracted materials since the beginning of extraction until 1990. A value of 5 is chosen for N. As the surplus energy is dependent on the choice of N, the absolute value of the surplus energy has no real meaning. Surplus energy is used to add the damages from extracting different resources.

C. 3.1 Description of the problem

The first part of the model, the resource Analysis can be compared with a kind of inverse fate modelling: The decrease in resource concentration due to extractions is modelled; the second part is the actual damage model, where decreased concentrations are translated into the concept of surplus energy.

There are different ways to group resources:

- Mineral resources, like metals
- Bulk materials such as sand, gravel and lime
- Energy resources, such as fossil fuels
- Flow resources, such as solar energy, hydropower etc.
- Environmental resources, like soil, water and air
- Biotic resources, such as biodiversity and silvicultural products (wood, fish, etc.)

This rather wide definition of resources partially overlaps with the other damage categories, especially in the field of environmental resources. The availability of clean water and air as well as biodiversity are covered in the other damage categories. In the Eco-indicator 99 methodology, it only models mineral resources and fossil fuels. The use of agricultural and silvicultural biotic resources and the mining of bulk resources such as sand or gravel are considered to be adequately covered by the effects on land-use.

- **Minerals**

In geostatistical models for minerals, it is generally accepted that the distribution of concentrations of mineral resources is lognormal if we plot quantities against grade. This phenomenon has been described, for single deposits, as Laski's law. There is a wide agreement amongst resource geologists that the lognormal ore grade distribution is a reasonable approximation also for the world-wide ore occurrences of a large part of minerals.

- **Fossil fuels**

The formation of fossil resources has occurred on a completely different time scale, trough completely different processes. For fossil fuels the term concentration is not a very good indicator for the resource quality. The processes that have produced and distributed the fossil fuels are quite different from the processes that have caused the lognormal distribution in the earth crust. This means that the log normal distribution of resource concentration is not directly applicable to fossil fuels. Basically three types of fossil fuels
can be distinguished.

C.3.2 Damage to Resources caused by depletion of minerals and fossil fuels

Unlike the damage categories human health and ecosystem quality it has not found a more or less accepted unit to express damages to resources. If the resource quality decreases, economic factors and environmental burdens associated with mining low grade ores will become the real problem. The latter includes the land-use for the mining operation and the amount of energy to extract the resource from the low-grade ore. The availability of land and energy could thus form the real limitations and land-use and energy use will probably be the most important factors. When look at alternative energy resources, another additional option is to translate increased energy consumption into increased future land use, as most non-fossil energy sources use a relatively large area. The surplus energy is defined as the difference between the energy needed to extract a resource now and at some point in the future. He calculates the future surplus energy at Q*N, in which Q represents the total amount that has been extracted by mankind before 1990 and N represents the number of times this amount is extracted. The choice of the factor 5 is arbitrary, we could also have selected the point on the damage curve at10*Q or 2*Q, as assume the damage curve is linear. The consequence of this arbitrary choice is that the absolute value of the surplus energy has no significance. The only purpose of the surplus energy concept is to have a relative measure for the damage the depletion of a mineral or fossil resources creates. In a way the surplus energy is used as a characterization method, since the choice of N is only used as a reference. As will see later in the damage assessment, the lack of absolute meaning of the damage to resources does create some problems in the presentation of questions to the panel.

- **Surplus energy for minerals**

Chapman states there are three effects:

1. The amount of energy needed to change the chemical bonds in which the mineral is found is by definition constant. It is not possible to reduce this energy requirement by efficiency improvements or technological developments.
2. The energy requirements needed to extract, grind and purify an ore goes up as the grade goes down
3. The energy requirements needed to extract, grind and purify an ore goes down with efficiency increases and technological developments.

- **Surplus energy for fossil fuels**

With the descriptions of the typical characteristics of the fossil resources in the resource analysis and with the data on the increased extraction energy for non-conventional resources, we can begin to construct the model for the surplus energy. However, in the case of fossil fuels, it needs to discuss two specific problems. First, the discontinuous or stepwise character of the quality decrease for fossil resources and then the possibility of substitution between fossil resources. In the case of minerals, it is assumed that the decrease of mineral resource concentrations is almost a straight and continuous line. In the case of oil and gas extraction, extraction will cause rather abrupt steps in the resource quality, when the marginal production of oil and gas switches from conventional to unconventional resources. In mineral resource analysis, it did not take substitution between resources into account, as stated that the possibilities for substitution are dependent on future changes in demand and technology development. In the case of fossil fuels the possibility for substitution are much more logical to assume, as all the fossil fuels share the same essential property, that is that they supply energy. It is even possible to produce an oil replacement from coal.