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An overview on the environmental impacts of synthetic leather made of hemp fiber with preliminary life cycle assessment

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Abstract

This report covers a preliminary life cycle assessment (LCA) on imitation leather made from hemp fiber (hemp leather) and a comparison to bovine leather, to examine whether hemp leather is an environmentally sustainable alternative. The bovine leather industry is responsible for heavy chemical use and emissions, detrimental effects to the environment as well as to human health. The United Nations (UN) and other organizations call for immediate action against the animal product industry sector to greatly reduce emissions and protect the environment. Hemp is a versatile plant that can be used for many things, including paper, composites, textiles, food and medicine, and is probably a suitable material for imitation leather. The hemp plant requires little inputs, grows fast and without pesticides, has positive effects on the environment and can be cultivated on every inhabited continent. The preliminary LCA was based on a patent describing the manufacturing process of hemp leather completed with data from literature and a few assumptions made. LCA-results for bovine leather were collected from literature and the two leather fabrics were then compared. The comparison showed that hemp leather is superior to bovine leather in all compared categories except for water consumption and hazardous waste. Bovine leather had 99% more energy use, 78% higher acidification potential (AP), 99,9% higher eutrophication potential (EP) and 83% higher global warming potential (GWP) than hemp leather. The large water consumption in the manufacturing phase of hemp leather is possible to be explained by over dimensioning of inputs. The report concludes that hemp leather would be the environmentally and ethically admirable choice between the two leathers and that more research on more modern methods of manufacturing it should be performed.

Sammanfattning

Denna rapport omfattar en preliminär livscykelanalys (LCA) på syntetiskt läder gjort av hampfiber (hampläder) och en jämförelse med nötskinn, för att undersöka om hampläder är ett miljövänligt alternativ. Nötskinnsindustrin är ansvarig för stor kemikalieanvändning och tunga utsläpp, skadlig inverkan på miljö samt människors hälsa. Förenta nationerna och andra organisationer fordrar till omedelbar handling mot djurindustrisektorn för att drastiskt minska utsläpp och skydda miljön. Hampa är en mångsidig växt som kan användas inom många olika applikationer, såsom till papper, kompositer, textiler, mat och medicin, och är förmodligen ett passande material till imitationsläder. Hampan behöver liten mängd tillförd energi, växer fort och utan bekämpningsmedel, har positiva effekter på miljön och kan odlas på alla bebodda kontinenter. Den preliminära LCA:n är baserad på ett patent beskrivande hampläders produktionsprocess, kompletterat med data från litteratur samt några antaganden. LCA-resultat från nötskinnsproduktion samlades från litteratur och resultaten från de två lädertyperna jämfördes sedan. Jämförelsen visade att hampläder är överlägset nötskinn i alla jämförda kategorier utom vattenkonsumtion och farligt avfall. Nötskinn har 99% högre energianvändning, 78% högre försurningspotential (AP), 99,9% högre övergödningspotential (EP) och 83% högre potential till global uppvärmning (GWP) än hampläder, enligt resultaten. Hampläders produktionsprocess stora vattenkonsumtion kan troligtvis förklaras av en överdimensionering av indata. Denna rapport drar slutsatsen att hampläder skulle vara det mest miljövänliga och etiskt försvarbara valet mellan de två lädertyperna och att modernare produktionsmetoder för hampläder bör studeras.

Content

Abbreviations

AP – Acidification potential

EF – Ecological footprint

EP – Eutrophication potential

FAO – Food and Agriculture Organization of the United Nations

GHG – Greenhouse gases

GWP – Global warming potential

HRW – Human Rights Watch

LCA – Life cycle assessment

Nr – Nitrogen

UN – United Nations

WF – Water footprint

WFP – World Food Programme

1. Introduction

1.1 Subject and aims of this report

The purpose of this report is to perform a preliminary LCA on and examine an imitation leather sheet made of industrial hemp (*Cannabis Sativa*) and the possible environmental impacts of one of hemp's many industrial applications. This will be compared to other LCA results from literature based on the manufacturing of bovine leather to examine if hemp is a sustainable alternative material, with respect to environmental factors. This because the leather industry has many known negative impacts on the environment and the health of workers, being a chemical heavy production, often in developing countries (Rastogi et al., 2008, Worst Polluted, 2013, Human Rights Watch (HRW), 2012), as well as there being a lot of emissions associated with the raising of animals needed to retrieve the hides (Steinfeld et al., 2006). Hemp is an interesting plant from a sustainable point of view, generating fiber, hurds (woody core), dust/waste fiber (tow) and seeds, which all have industrial as well as other applications. It is relatively low maintenance in cultivation and grows annually, is capable of growing in climates ranging from the Arctic to the equator (Cherrett et al., 2005) and has been grown on every continent except for Antarctica, requires no herbicides or pesticides and purifies soil by absorbing heavy metal contaminants (Kozlowski et al., 2005). Hemp played an important role in meeting demand for rope, textiles and paper before production reduced greatly as a result of the World Wars and was shortly thereafter made illegal due to its association with narcotics (Kozlowski et al., 2005). Today there exist many low narcotic varieties and the cultivation of hemp has grown, although not gained close to its popularity from the early 20th century (Cherrett et al., 2005). Hemp is now cultivated on all continents and most of the cultivation takes place in Asia and Europe, with China as main producer of hemp fiber (yielding 17930 ton in 2016) followed by The Netherlands (17417 ton in 2016) (FAOSTAT, 2018). There is a growing popularity for hemp cultivation (Cherrett et al., 2005) and probably would be even more so if hemp farming did not require a license as it does today because of legislation due to its association with narcotics. This report also aims to present how hemp potentially could be utilized industrially in a sustainable perspective.

1.2 Bovine leather and livestock production

Bovine leather is the product of the by-product, hides, from the animal food product sector. It is a sector that employs at least 1.3 billion people worldwide (figure from 2006) (Steinfeld et al., 2006), that has many known environmentally heavy impacts and emissions, which the hides or leather can be allocated to 14% of (Joseph & Nithya, 2009). In their report from 2006, '*Livestock's long shadow – Environmental Issues and Options'*, Food and Agriculture Organization of the UN (FAO) claim that climate change is the most serious environmental challenge facing the human race and encourage decisive efforts at both technical and political levels for mitigation of the damage caused by this sector and emphasizes that it needs to be addressed with urgency as there is a rising demand in animal food products, putting an increasing pressure on Earth's natural resources. They state that the livestock sector is one of the top three most significant contributors to the most severe environmental problems and just the production of meat is expected to double until 2050 (predicted in 2006). This means that the environmental impacts must be cut in half by 2050, to not increase the level of damage beyond the current level, the current level being one of the highest from all contributing sectors. It is also estimated that more people, 40% of the world's population as estimated in 2005, will adopt a diet consisting of more meat (demand for meat will increase by 68%

by 2030) as an effect of global income increase and consequently a 60-120% global increase for crop demands by 2050 as well (Cassidy et al., 2013).

FAO states that the livestock sector occupies 26% of Earth's ice-free surface, making it the single largest anthropogenic land user, by far. The feedcrop production takes up 33% of total arable land, leading to the livestock sector to account for 70% of all agricultural land. The livestock sector is accountable for more than 70% of deforestation in the Amazon (Margulis reports, in the work from 2004, that 91% of deforestation of the Amazon is due to livestock raising and that that land has been converted just for cattle ranching (Margulis, 2004)), making way for pastures and feedcrops. 20% of the world's pastures have deteriorated through overgrazing and erosion due to keeping of livestock. In the USA, livestock is responsible for 55% of erosion and sediment (Steinfeld et al., 2006).

FAO states that the livestock sector is responsible for 18% of all greenhouse gas (GHG) emissions measured in CO_2-equivalent, which is higher than that for the entire transport sector. This is a lot, especially since this sector is not a major global player economically. It emits 37% of all anthropogenic methane and 65% of anthropogenic nitrous oxide, which have 23 and 296 times the GWP of CO_2 respectively. Goodland and Anhang (2009) calculated that the methane emissions from the livestock sector in 2004 were responsible for 7416 million ton CO_2-eq. or 11,6% of worldwide GHG emissions. It also emits 64% of anthropogenic ammonia, which is the greatest contributor to acidification of ecosystems (Steinfeld et al., 2006).

FAO states that the livestock sector consumes 8% of the water globally, mostly through the irrigation of feedcrops. It is "probably" the largest sectoral source of water pollution, eutrophication, dead zones in coastal areas and deterioration of coral reefs, human health problems and antibiotic resistance (50% of antibiotics in the USA are used on livestock), the major sources for this being animal waste, antibiotics and hormones, chemicals from tanneries, fertilizers and pesticides and sediments from eroded pastures.

Livestock might be the leader in reduction of biodiversity with 15/24 important ecosystem services said to be in decline as a result of livestock raising (Steinfeld et al., 2006). It is the major influence in deforestation, land degradation, pollution, climate change, overfishing, sedimentation of coastal areas and facilitation of alien species, taking up 20% of the Earth's total animal biomass and 30% of what was once wildlife habitat (Eshel et al., 2014).

Eshel et al. (2014) found that beef production requires and produces 28, 11, 5, and 6 times more land, irrigation water, GHG emissions, and reactive nitrogen (Nr), respectively, than the average of the other livestock categories examined in their work and that preliminary analysis of three staple plant foods shows two-to six fold lower land, GHG, and Nr requirements than those of the non-beef animal-derived ones.

Research also shows that slaughterhouse workers have higher levels of psychological disorders (Emhan et al., 2012, Victor et al., 2016) as well as extraordinarily high levels of physical injury (HRW, 2005, Leibler et al., 2017) and higher levels of arrests for violent crimes compared to those of other industries (Fitzgerald et al., 2009).

It is also known that meat consumption can increase the risk for cancer (Willett W.C. et al., 1990; Giovannucci et al., 1994, González et al., 2006), heart disease (Snowdon et al., 1984) and type 2 diabetes (Song et al., 2004; Pan et al., 2011)

Leather production itself uses a lot of hazardous chemicals, one of which is the highly hazardous chromium. A big part of the leather industry has in the recent years moved to developing countries because of the environmental regulations in industrialized ones and slaughterhouses in for example India, where the leather industry employs 15 million direct and 5 million indirect (numbers from 2009), usually discharge their waste water without any treatment and disposes of solid waste at dumpsites releasing a lot of solids and adds to methane emissions to the environment (Joseph and Nithya, 2009). The effluents from the tanneries, loaded with chemicals, are often also disposed of without having been treated beforehand, posing a serious risk to human health (Khwaja, 2000). Health risks of tannery workers is significantly higher than those of other industries (Rastogi et al., 2008). Muhammad and Haque (2012) also found that physical and mental health among tannery workers (in Dhaka City, Bangladesh) are related and that it was worse for the tannery workers than for people living nearby the tannery area (Muhammad & Haque, 2012).

In the work of Joseph and Nithya, 2009, an Indian tannery was examined and revealed that, to make $100\mathrm{m}^2$ bovine leather, 750kg of hides is needed which corresponds to 60 cows having to be raised and slaughtered beforehand, also meaning that a substantial amount of feed and consequently water is needed. Mekonnen and Hoekstras work from 2012 shows that leather has at least twice the green water footprint (WF), related to rainwater consumption, that of any of the ten animal derived food products it was compared to, except for beef and was in the top six for grey WF, related to pollution, is the volume of freshwater needed to assimilate it (Mekonnen and Hoekstra, 2012).

Clearly, bovine leather is not a sustainable product and to meet the environmental challenges of today and the future there needs to be a serious decrease in the consumption of all animal products, which also means there should consequently be fewer hides to produce leather from. Consumers are concerned about environmentally friendly products (Ghvanidze et al., 2016), ethical factors, such as animal welfare and right to life (Beardsworth and Keil, 1991; Forum for the Future, 2016) as well as the health of workers (Andorfer and Liebe, 2012). According to FAO, more than 27 million cows were bred for meat in Europe alone in 2016 (FAOSTAT, 2018).

1.3 Hemp

Hemp (*Cannabis Sativa*) is an ancient crop, native to Central Asia. It can grow on every inhabited continent and there are many different cultivars suitable for different climates (Kozlowski et al., 2005). Hemp is cultivated for its fiber, hurds and seeds that have several industrial and other applications (Kozlowski et al., 2005). Hemp is an annual crop and takes about 110 days to grow, usually to somewhere between 2-5m tall (Robinson, 1995). Since the plant grows at this rate, it shades out its own weeds and there is therefore no need for herbicides or pesticides (Kozlowski et al., 2005), making organic cultivation advantageous and crop rotation the common practice. The hemp plant has long roots that can reach deep down in the soil and thereby prevent erosion and absorbs heavy metal contaminants which leaves the soil in very good condition for the following crop. Hemp is often considered as a pathogen free crop (Kozlowski et al., 2005). It also contributes to phytodepuration and high root biomass accumulation, making it suitable as a biomass crop (Amaducci and Gusovius, 2010).

Hemp's fiber, the most important part of the plant, yielding four times more per acre than trees (Robinson, 1995) and three times as much as cotton (Cherrett et al., 2005), can be used for textiles, rope, composites (Pervaiz and Sain, 2003) and paper (van der Werf et al., 1995) among other things. The fibers are up to 4,6m, compared to cotton fibers that are about 23cm, and have eight times the tensile strength (Robinson, 1995). The hurds can be used for hempcrete, a lightweight and non-toxic bio-composite building material made with lime (Stevulova et al., 2013), transport fuel in the form of ethanol (González-Garcia et al., 2012), cellulose "plastics" and other specialty papers (Kozlowski et al., 2005) and briquettes that can be used as a feedstock for energy production (Papadopoulou et al., 2014). The seeds, or the hempseed oil, is used as lamp oil and can be polymerized or made into polyurethane (Robinson, 1995), paint and varnish (McKendry, 2002), biodiesel (Li et al., 2010) and contains all the essential amino and fatty acids (McKendry, 2002; Kozlowski et al., 2005), making it suitable for food and personal care products (Robinson, 1995).

There has since a long time been numerous medical applications in various fields of the Cannabis Sativa plant, such as for anxiety, sleeplessness, pain, Parkinson, gout, burns, tumors, colic in horses, MS, Tourette, tinnitus and Delirium tremens to name a few (Russo, 2014). There have also been reports of supranormal development in infants born to mothers smoking during pregnancy, it can prevent miscarriage, it was often prescribed as a sedative because doctors of the time deemed it safer than opium and its derivatives and can even relieve opiate and cocaine abuse. THC has 20 times the anti-inflammatory powers of Aspirin and twice that of Hydrocortisone. Hemp is also important in religious rituals (Russo, 2014).
It's been an important industrial crop, used for textiles, rope and paper, until legislation was established at the time of the World Wars due to concerns about the plants psychoactive properties (Kozlowski et al., 2005) (THC-content in the plant), which led to legislation (Müssig, 2010). However, there are only trace amounts of this compound in industrial hemp, yet this has led to the forgetting of hemp as a valuable industrial crop (McKendry, 2002). Hemp cultivation requires less water (no irrigation at all according to Zatta et al. (2012)) and energy than many other common crops (Canakci et al., 2004; Brouwer & Heibloem, 1986), especially cotton (for example 11,24MJ/kg for cotton in the work of Canakci et al. (2004) compared to 0,76MJ/kg for hemp in the work of van der Werf, 2004) which would be the competing crop for fabric manufacturing, and its ecological footprint (EF) is therefore also much lower (Cherrett et al., 2005).

Making synthetic leather out of hemp is not a widespread practice and any information about it was difficult to find. It seems however to be a suitable material, as it produces (a lot of) fiber, and as a sustainable material because all parts of the plant can be used, as well as its relatively low impacts on the environment. This makes hemp an interesting possible material for synthetic leather production.

2. Methods

This report will cover an LCA on hemp leather from raw fiber to product and the comparison with LCA results on bovine leather production to see if hemp as material for synthetic leather is a sustainable alternative and to identify potential for improvement of the manufacturing process of hemp leather.

First, research in literature and through contact with dealers in the hemp trade was conducted, following with data collection for the LCA performed in this report. The LCA was mainly based on the patent '*US5000822 Process for the preparation of imitation leather from natural hemp and the product thereof*' by Hwang and Kyung (1991) and a few assumptions about quantities were made to complete the given information. The cultivation and preparation of hemp fiber has previously been studied and the data in this report will be based on various previous works to complete the analysis.

The assessment on bovine leather will mainly be based on the work by Joseph and Nithya (2009) completed with data on EF (97,8m^2/kg live weight) from the work of Pelletier et al. (2010), energy consumption (3,5MJ/kg live weight), EP (30g $\mathrm{PO_4}$-eq/kg live weight) and GWP (14kg $\mathrm{CO_2}$-eq/kg live weight) from the work of Ogino et al. (2015), waste produced (10% of live weight (only carcass waste)) from the work of Huerta et al. (2016) and land use (42m^2/kg hot standard carcass weight (50% of live weight)) from Dick et al. (2014) as the work by Joseph and Nithya (2009) does not include the cattle raising phase which is the most environmentally significant in the bovine leather life cycle. In the work by Joseph and Nithya (2009) based on data from India, the average live weight of a cow is 275kg. This weight has been used to calculate other values needed for the assessment. The average weight of a hide in the same work is 12,5kg and 750kg is needed to make 100m^2 of leather, which means 60 animals are needed. As the hides are a by-product of the beef industry, the leather industry can be economically allocated to 14% of its environmental impacts (Joseph and Nithya, 2009). It is assumed that the livestock were raised on pasture and "finished" on feedlots, because this seems to be the most common practice (Pelletier et al., 2010; Ogino et al., 2015).

The subheadings 2.1 Goals and scoping, 2.2 Life cycle inventory, 3.1 Impact analysis and 4.1 Improvement analysis will be dedicated to the preliminary LCA on hemp leather and the information therein regards only hemp leather.

2.1 Goals and scoping

The functional unit for this report will be 100m^2 of finished hemp leather sheet, with a thickness of 1,5mm. The system boundaries are as shown in Figure 1; the fertilizer, chemical and machine production will be taken into account by assumptions in the life cycle of hemp leather with data from the Ecoinvent 2.3 and GaBi 6 databases using the GaBi 6 software. The part of the hemp plant used for hemp leather is the fiber, or waste fiber (tow), and this report will examine the retrieving of the raw material and on to the manufacturing of the hemp leather, but not end-of-life. This LCA will be of the "cradle-to-gate" type and end at distribution. Transports will also be accounted for. It is unclear whether buildings are included in the results from Bajpai (2016), where this data is collected from, assumably they are.

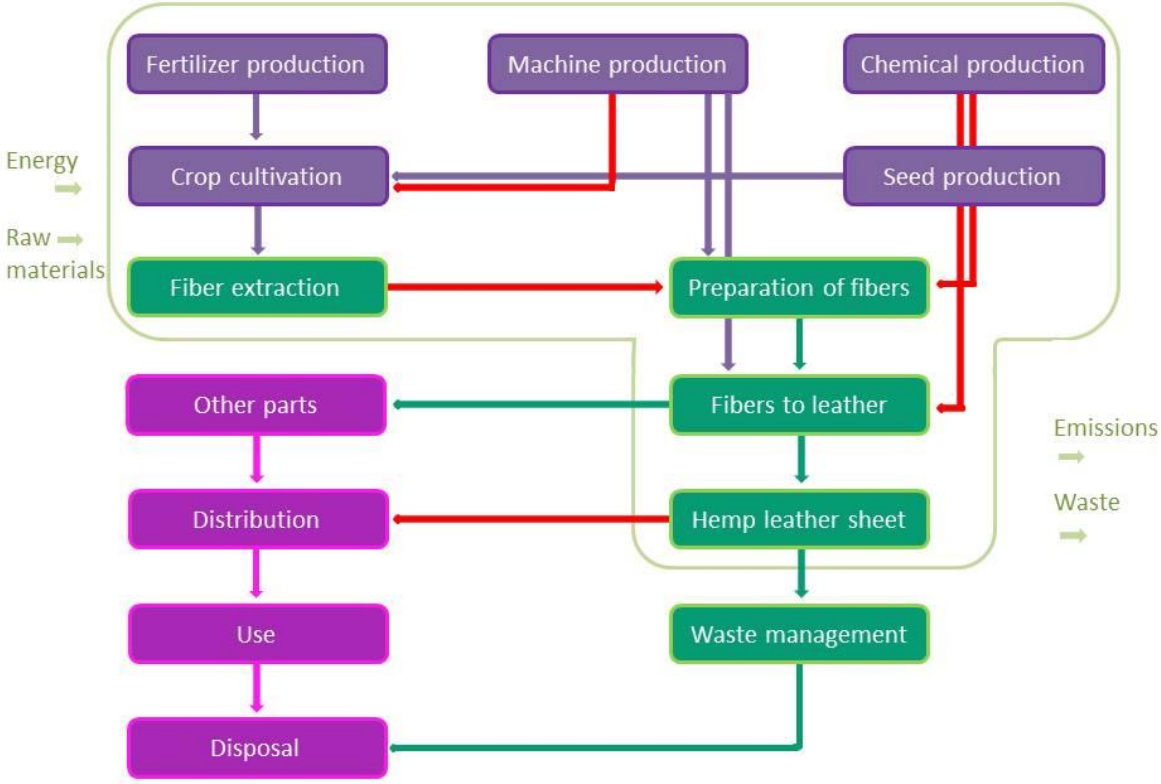

Figure 1 – Inputs, outputs and system boundary for the life cycle of hemp leather. Red arrows indicate where transports have been accounted for.

Since there lacks information in the patent by Hwang & Kyung (1991) about the quantity of raw hemp fiber needed for the manufacturing to produce a certain amount of hemp leather, the assumption that it will require 40kg for $100\mathrm{m}^2$ of hemp leather with a thickness of 1,5mm is made. This is the amount needed for a woven hemp fabric thick as cardboard (Ellis, 2018), to not underestimate the process. However, the patent states that the raw hemp fiber has been ground prior to the process, which means that the fiber used for hemp leather could as well as fiber be the tow, for example obtained as a by-product of the hemp textile industry where long fibers are mainly used (Cherrett et al., 2005).

The process for making the hemp leather is in accordance with the work of Hwang and Kyung (1991) with certain assumptions made where necessary. It includes seven steps, the first one being a bath in an alkali solution with 10-11 pH made of water and sodium bicarbonate. Next, the fiber is washed with water, then put in a pressure tank for digesting in diluted ammonia gas under $30\mathrm{kg/cm}^2$pressure at -35° to -5°C for about 20 hours. Next, the pressure on the tank is adjusted to atmospheric pressure, sodium chromate and sulphuric acid (or ammonium phosphate and methylol urea) is added to the tank and it should digest for 12-20 hours at 105-160°. After this, the temperature is adjusted to 35-40°C and the treated fiber digests for 1-2 hours. Next, ammonia is added to adhere to amino radicals in the fiber and the product obtained from this step should have the same structure and properties as conventional protein fiber. After, the fiber is washed and then dehydrated. There are no details about the dehydration process. After this the fiber mix is put in a Hollander beater and purified by adding SBR resin and when the fiber is coated in it, cyclohexylcarboxyl dephenylamino thiazolyl sulphonamide is added. This compound was not found in either the Ecoinvent or GaBi database so cyclohexylamine was used to imitate this. The fiber mix is filtered through a screen and then transferred to a fiber jetting device that forms the mixture into a sheet to a desired thickness utilizing water pressure. Then the sheet is passed through a high-pressure roller to make a non-woven sheet. It is then soaked in a mixture of water, methylphenol (cresol) and SBR resin with a pH of 7-7,5 and then dried. The sheet is then passed through a calender to produce a smooth surface.

The processes referred to in the patent are similar to those in the production of paper. Paper pulp is first dispersed in water, then goes on to a beating process and then refining which can include use of resins and waxes as additives and dyes. It is then put through a paper machine, which consists of a headbox, or fiber jetting device, a wire section where the sheets are formed, a press section that drains the paper of water, a dryer section that includes a calender section if extra smoothness is desired and lastly a reel that collects the finished paper. It can also, after coating, be passed through a “supercalender”, which consists of rollers of varying hardness and material that gives the paper smoothness and gloss (Bajpai, 2016). The energy consumption (2784kWh/ton of paper) of the process of making hemp leather was based on data from the work on pulp and paper production of Bajpai (2016) and the water usage (26900m^3/day producing 250ton paper) completed with the work of Karthik et al. (2011) on water conservation in a paper mill. It is assumed that, as in the paper mill, some water will be recycled in the process. Heat produced by the manufacturing process has not been accounted for, which will be produced.

Two cases were examined, one with the manufacturing of machines such as paper machine and air compressor included and one without. This because the inclusion of the paper machine resulted in taking up a very large portion of the output flows, which can be assumed to be because of the size and capacity of the paper machine, which was not specified in the database. Allocation was made according to the assumption that the capacity of the paper machine was 500ton/day of fiber and thereby assuming that it takes one day to manufacture 100m^2 hemp leather. To get a clearer view on the other flows, both scenarios are included in the report.

The next step is the manufacturing of a product from the hemp leather sheet. This has been excluded from this report, as it depends on the product manufactured; it may for example be sold as a piece of fabric sheet. A comparison of the hemp leather with conventional imitation leather was performed by the authors of the patent that concluded that hemp leather had improved properties. Table 1 shows the results from the patent. The hemp leather is said to have an excellent stiffness, flexibility and hydroscopic properties (Hwang and Kyung, 1991). The conventional product that the hemp leather was compared to is not specified.

Leather properties	Conventional product	Product of the present invention
Tensile strentgh [kg/cm^2]	Lateral: 143 Longitudinal: 196	143 220
Tearing strentgh [kg/cm^2]	Lateral: 24 Longitudinal: 28	60 73
Rupturing strentgh [kg/cm^2]	-	33,5
Anti-bending capacity (times)	Lateral: 5000 Longitudinal: 5000	4900 5000

Table 1 – "Comparison of imitation leather properties of the present invention with that of conventional product" from the patent by Hwang and Kyung (1991).

2.2 Life cycle inventory

Apart from the data collected from the various works and the assumptions made, life cycle inventory was obtained from the Ecoinvent 2.3 and GaBi 6 database, using the GaBi 6 software. The inputs were based on data from Europe and mostly Italy, because most of the data required for this LCA in the databases are from Europe and because the preliminary data for the assessment of the cultivation phase was from Italy, where a lot of hemp cultivation and significant research on hemp cultivation is performed (Zatta et al., 2012). Analysis was based on the input and output results and on CML 2001 impact assessment method results presented by the GaBi software, some of the result categories being GWP 100 years, EP and AP.

Because the process of manufacturing hemp leather in this report is hypothetical, the process as a whole was examined, meaning it cannot be defined how the impacts portion to the different parts of the process. Only four of the chemicals' life cycles in the process were available in the databases and thereby the only ones included in the analysis; ammonia, sodium dichromate (instead of sodium chromate, as stated in the patent), sulfuric acid and SBR resin. Six of the nine chemicals used are classified as hazardous in literature. Chemicals cover ca 85% of the assumed weight of the inputs.

A transport distance of 50km was used for both transports, because this value is arbitrary, since hemp can be cultivated close to anywhere and the processing plants can also be located nearby, and therefore its impact is not so relevant in this case.

To get comparable results to the LCA results on bovine leather manufacturing, the hemp leather assessment was completed with results from various works for the impacts of cultivation of the plant. Values for GWP (2330kg CO_2-eq/ha), AP (9,8kg SO_2-eq/ha), EP (20,5kg PO_4-eq/ha), energy use (11,4GJ/ha), fertilizers (N: 75kg/ha, P_2O_5: 38kg/ha, K_2O: 113kg/ha, CaO: 333kg/ha), diesel (65kg/ha) and seed amount (55kg/ha) were collected from the work of van der Werf (2004) and water consumption (120m^3/ha) and biogenic GWP (-1,73 kg CO_2-eq/kg hemp) were collected from the work of Zampori et al. (2013). It was assumed that 1ha yields an average of 15ton hemp.

Table 2 shows inputs and outputs of the process examined as well as for the cultivation of 40kg of hemp.

Inputs/raw materials	Units	Amount needed, manufacturing process	Amount needed, cultivation of hemp
Raw hemp fiber	[kg]	40	40
Electrical power	[MJ]	401	30,4
Water	[m^3]	15,3	0,32
Diesel	[kg]	4,64	0,17
Chemicals	[kg]		
Sodium bicarbonate		0,94	
Ammonia gas		0,14	
Sodium chromate (sodium dichromate)		4,72	
Sulfuric acid		3,22	
Cyclohexylcarboxyl diphenylamino thiazolyl sulfonamide (cyclohexylamine)		1,73	
Cresol		74	
SBR resin		121,8	
Fertilizers	[kg]		
Ammonium nitrate			0,2
Triple superphosphate			0,1
Potassium chloride			0,3
Calcium oxide			0,89
Seed for sowing	[kg]		0,15
Outputs			
Hemp leather sheet	[m^2]	100	100
Waste water and sludge	[kg]	11540	0
Hazardous waste	[kg]	109,6	0
Other waste	[kg]	466	0

Table 2 – Inputs and outputs for the manufacturing of 100 m^2 hemp leather sheet. Manufacturing process only to the left and cultivation process/raw material extraction to the right.

2.3 Uncertainties

There are quite a few uncertainties in this report and it should not be viewed as a complete assessment, but rather as an overview of the potential life cycle of hemp leather, or as a preliminary LCA, and an introduction to the idea of using hemp (or hemp waste) for imitation leather.

The various works that the results are collected from are conducted with data from different countries, as there was a lack of compatible data with a geographical limitation. Therefore, data from India, USA, Italy, France, UK, Brazil, Mexico, Thailand, Sweden and Spain has been collected for the assessment on hemp cultivation and bovine leather.

Uncertainties will be discussed in relation to interpretation of the results under 4. Discussion.

3. Results

3.1 Impact analysis

The most relevant and comparable LCA results; energy resources, water use, CO_2 emissions, global warming potential (GWP) over 100 years, acidification potential (AP) and eutrophication potential (EP), are shown in table 3.

Hemp has the ability to store carbon, it is biogenic, which means the carbon footprint will be lower with this in consideration. Biogenic carbon should only be taken into account if the use or end-of-life phase takes place after more than 10 years (Zampori et al., 2013). Both leathers should have a life span of at least 10 years, hemp fibers being very durable (Robinson, 1995), so it is suitable to account for biogenic carbon, but since it is unsure whether it has in the LCA for bovine leather, the results for biogenic carbon for hemp leather will only be presented and not considered in the assessment.
The carbon footprint for the cultivation of 40kg of hemp, according to Zampori et al. (2013) amounts to –69,2kg CO_2-eq. The distribution of GWP between indicators is easier to visualize when the machines, paper machine and air compressor, have been excluded from the analysis, as seen when comparing figure 2 and 3.

Resources/emissions	**Units**	**Manufacturing phase of hemp leather**
Energy resources	[kg]	3750
Water	[m^3]	104000
CO_2 emissions	[kg]	147
GWP 100 years	[kg CO_2-eq]	8180
AP	[kg SO_2-eq]	37,4
EP	[kg PO4-eq]	23,9

Table 3 – Resource and emission results for the manufacturing phase of hemp leather.

The following bar diagrams are the CML results from GaBi 6. They represent the LCA results of making 1000m^2 hemp leather from 400kg of hemp fiber. The assessment and the results presented in the tables represent the results of making 100m^2, the functional unit in this report, of 40kg of hemp fiber. Diagrams of the results are from the case with machines included and excluded respectively, as stated, so the impacts of the different indicators can be visualized more clearly.

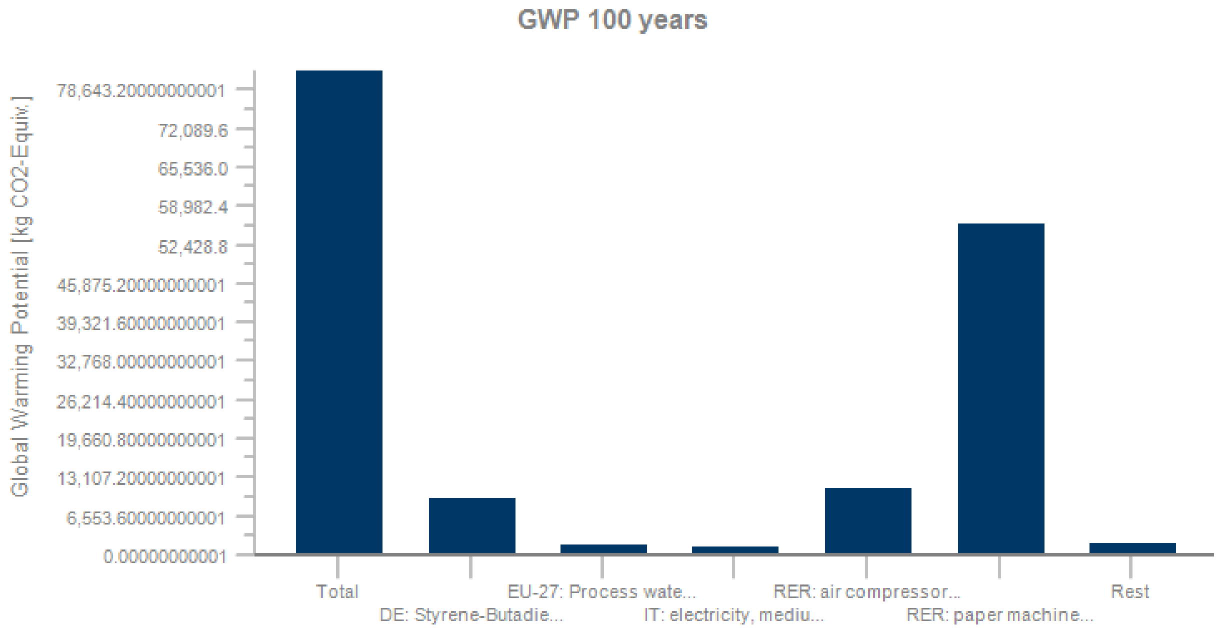

Figure 2 - GWP 100 years of the manufacturing process with machines, paper machine and air compressor, included. Bars from the left: total, SBR-resin, process water, electricity, air compressor, paper machine, rest.

This GWP-diagram clearly shows that the paper machine has the greatest impact. The impact from the SBR-resin and the air compressor are similar which could indicate that the impact from the paper machine is over dimensioned, that the air compressor has a relatively small impact or that the manufacturing of SBR-resin has almost as great an impact as the manufacturing and the usage of the air compressor. There is however a large amount of SBR-resin used. The impacts of all the chemicals involved in the process have not been assessed in this LCA which is an important factor as well.

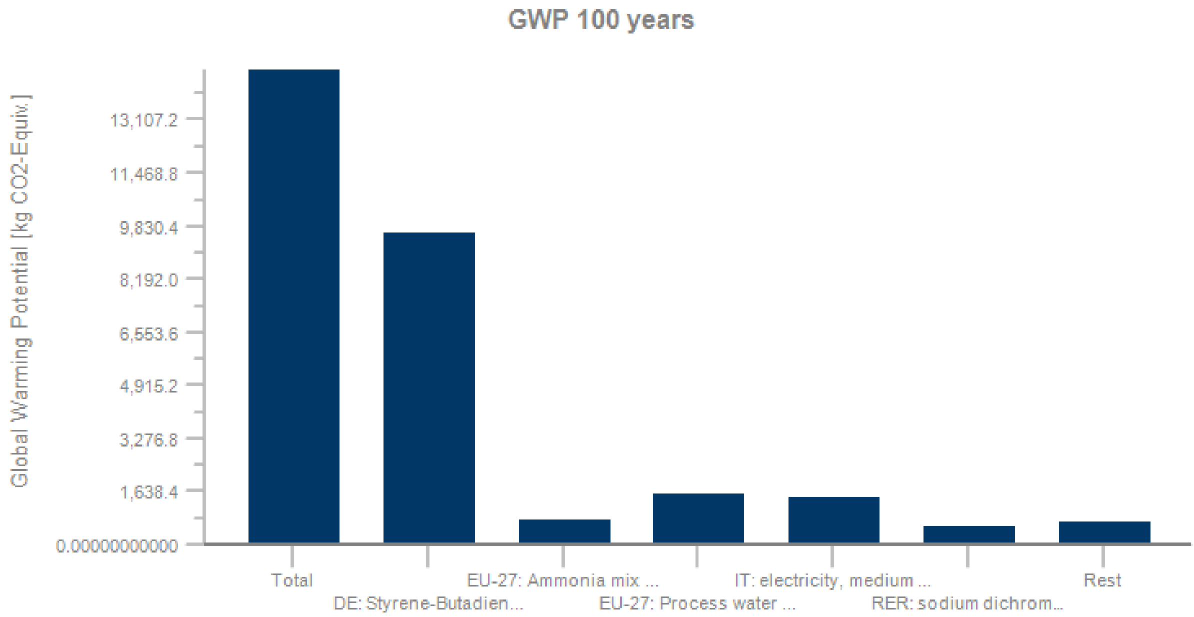

Figure 3 – GWP 100 years of the manufacturing process with machines excluded. Bars from the left: total, SBR-resin, ammonia, process water, electricity, sodium dichromate, rest.

In this GWP diagram it is clear that the SBR-resin has a large impact on the process, which is in accordance with the amount used, though there are large differences between the SBR-resin and the rest of the indicator categories. The process uses a lot of water and energy, which explains why the water and energy bar are the next highest. If all the chemicals could have been tracked in the LCA, this bar diagram would probably look different, especially since the process uses a lot of cresol.

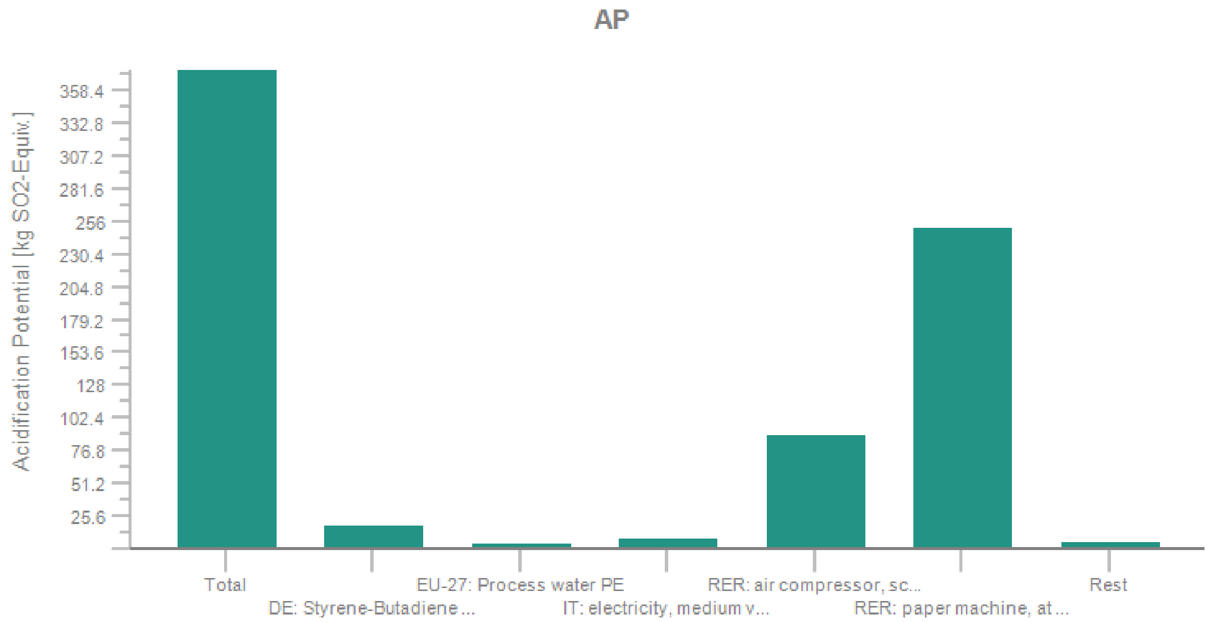

Figure 4 – Acidification potential of the manufacturing process with machines included. Bars from the left: total, SBR-resin, process water, electricity, air compressor, paper machine, rest.

The AP-results also show the greatest impact being from the paper machine and the next from the air compressor. Here, the SBR-bar is much lower and the difference between the air compressor and paper machine bars is smaller which does not support that the paper machine impact would be over dimensioned, but it does not necessarily argue either.

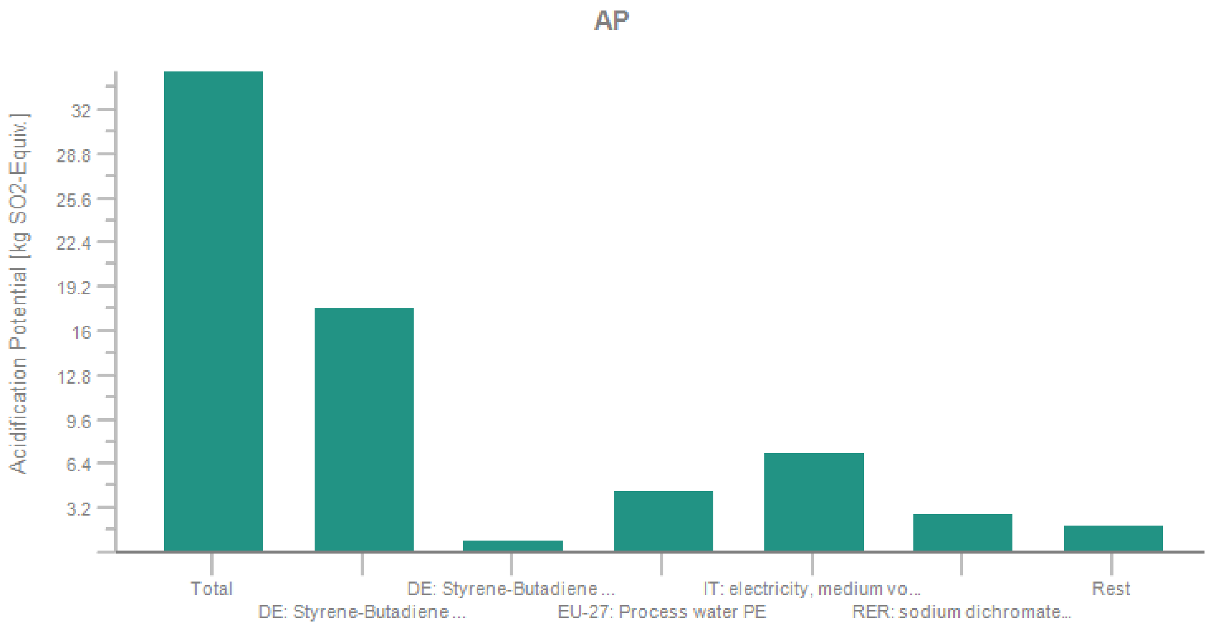

Figure 5 – Acidification potential of the manufacturing process with machines included. Bars from the left: total, SBR-resin, SBR-resin, process water, electricity, sodium dichromate, rest.

The SBR-resin occurs twice in the second AP-diagram because two phases of the process require it. The same pattern follows, with the greatest impacts caused by the SBR-resin, water and electricity consumption. The impact from sodium dichromate shows a greater one than that of the remaining, which is a large impact in comparison. Sodium dichromate is highly acidic and corrosive (PubChem, 2018) which explains this.

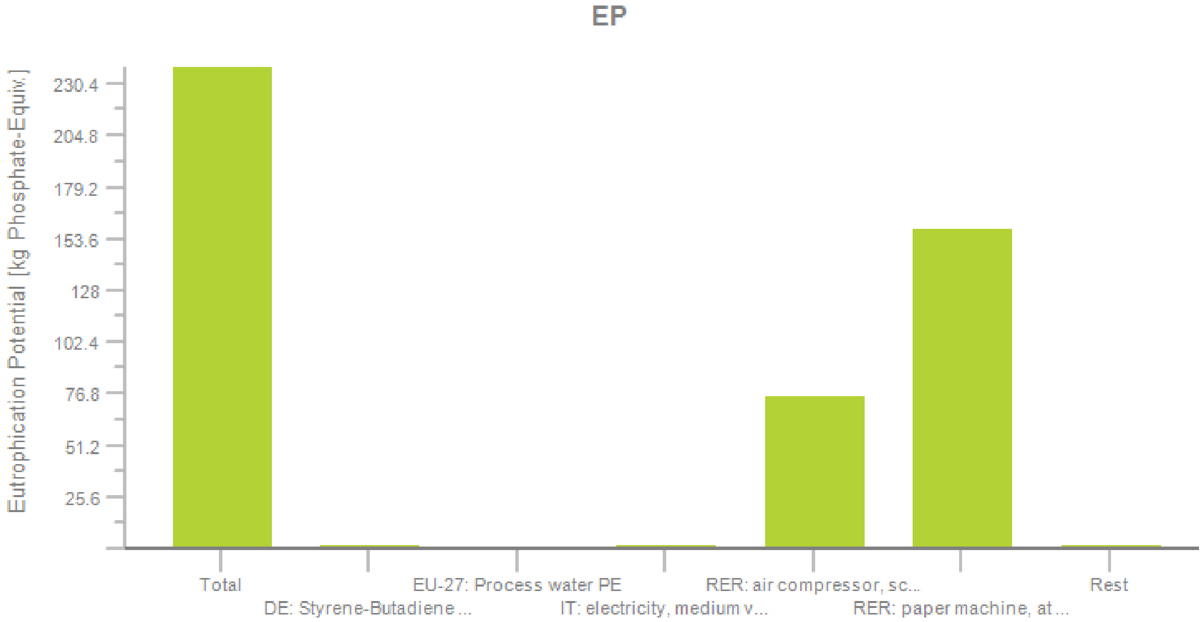

Figure 6 – Eutrophication potential of the manufacturing process with machines included. Bars from the left: total, SBR-resin, process water, electricity, air compressor, paper machine, rest.

Here is it clear that the machines used have the greatest EP out of all the indicators. This might be explained by the manufacturing processes of them and the resources used therein.

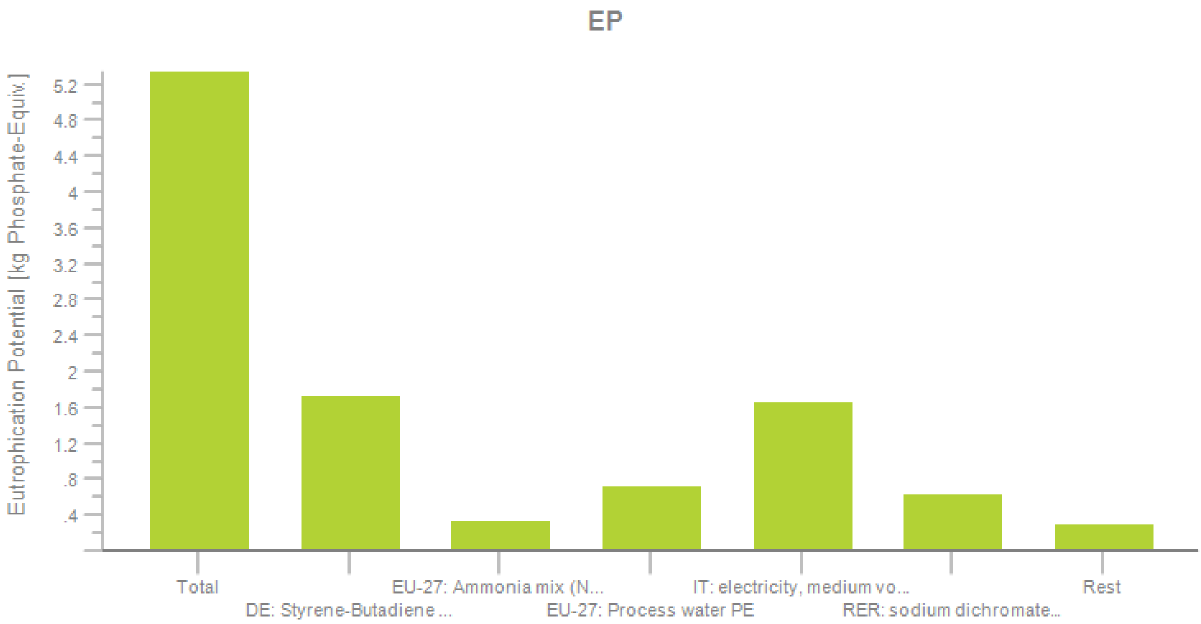

Figure 7 – Eutrophication potential of the manufacturing process, machines excluded. Bars from the left: total, SBR-resin, ammonia, process water, electricity, sodium dichromate, rest.

The SBR-resin, water and electricity usage have the largest impacts on the process in all categories when the machines are excluded. It can also be assumed that the cresol would have a large impact.

The transports do not appear on any of the diagrams, which is also expected since the distances were not very long. Apart from perhaps the paper machine, the distribution of the impacts does not otherwise suggest much irregularities and the results are as could be expected.

For a complete assessment of hemp leather, the LCA results from the assessment in GaBi 6 are combined with LCA-results from hemp cultivation and the results can be seen in table 4.

Inputs	**Unit**	**Hemp leather, total**
Water	$[m^3]$	15,6
Energy	[kWh]	119,8
Chemicals	[kg]	221,3
Hazardous chemicals	[kg]	103,6
Outputs		
Water use	$[m^3]$	
Solid waste	[kg]	466
Wastewater	$[m^3]$	11,5
Hazardous waste	[kg]	109,6
GWP 100 years	[kg CO_2-eq]	8186,2
AP	[kg SO_2-eq]	37,43
EP	[kg PO_4-eq]	24,0

Table 4 – Inputs and outputs in the complete life cycle of hemp leather from cradle-to-gate.

A value for EF was not available as it was for leather, see table 5. The same table shows the complete life cycle of hemp leather compared to the life cycle of bovine leather.

3.2 Hemp leather compared to bovine leather

Inputs/outputs	**Units**	**Hemp leather, total**	**Hemp cultivation**	**Bovine leather**
Water	$[m^3]$	15,6	0,32	16,7
Energy	[kWh]	33,3	8,44	2668,8
Chemicals	[kg]	221,3		647,7
Hazardous chemicals	[kg]	103,6		240
Solid waste	[kg]	466		1548
Water use	$[m^3]$	104000,3	0,32 (irrigation)	17804,4
Wastewater	$[m^3]$	11,5		17*
Hazardous waste	[kg]	109,6		95
Land use	[ha]		0,0027	34,7
GWP 100 years	[kg CO_2-eq]	8186,2 or 8110,8 (biogenic)	6,2 or -69,2 (biogenic)	47530
AP	[kg SO_2-eq]	37,43	0,03	182,5
EP	[kg PO_4-eq]	24,0	0,05	69,3**
EF	[ha]			22,6**

Table 5 – Inputs and outputs in the life cycle of hemp leather and bovine leather. GWP and AP values in first column set to new approximated values. Where empty is due to lack of data. *From tannery. **Based on cattle raising only.

It is distinguishable from table 5 that leather has substantially larger impacts in every category except for hazardous waste and water usage. The water usage for hemp leather is surprisingly high, especially since the greatest water use in the hemp leather life cycle is during manufacturing and in the raw material extraction phase, i.e. the raising of cattle, for bovine leather. The greatest difference is seen for energy use and EP, with hemp using 99% less energy and having a 100% smaller EP impact. It is harder to distinguish land use and EF because of lack of data. The EF-result presented includes the emissions of methane.

It is known that cattle raising is heavy on the environment, therefore this outcome, except for the water use, was expected but that the differences would be so great was not. To better demonstrate the differences, table 6 shows them in percent between the two leather types, where the right column demonstrates in how many more or less percent bovine leather makes an impact in the different categories.

Inputs/outputs in %	Bovine leather margin
Water	6,6
Energy	99
Chemicals	66
Hazardous chemicals	57
Solid waste	70
Water use	-17
Wastewater	32 (from tannery)
Hazardous waste	-13
GWP	83
GWP, material production	100
GWP, manufacturing	46
AP	78
EP, material production	99,9

Table 6 – Inputs and outputs in percent, demonstrating the difference between the two leather types. 'GWP, material production" refers to the extraction of the central raw material, i.e. hemp fiber or bovine hides, and 'GWP, manufacturing' to the respective manufacturing process.

Hazardous waste is 13% more from hemp leather than bovine, which can be understood from the large amount of cresol and sodium chromate (or sodium dichromate) used.

Since the data collected correlates to places on different continents, the energy mix, natural gas, coal and oil use in comparison cannot be assessed.

4. Discussion

The environmental impacts and health concerns of bovine leather, as well as the main product, beef, are well known today. As FAO argues, this issue must be addressed with urgency which is why this report aims to examine if hemp is a suitable and sustainable alternative to bovine hides. Cassidy et al. state in their work from 2013, that 36% of calories produced by the world's crops is used as feed for livestock and only 12% of those calories contribute to the human diet. If the world's crop lands were to grow food exclusively for human consumption, the available food calories would increase as much as 70%, which represents the ability to feed another four billion people. According to the World Food Programme (WFP), hunger is the leading cause of death in the world and as many as 815 million people are without food daily, which is still only 20% of four billion. The burden on the world's crop lands is great and will only become greater which means measures must be taken immediately.

The bovine hides used for leather production are recovered from the beef cattle industry as a by-product with economical value and can therefore be allocated to 14% of its impacts (Joseph and Nithya, 2009). Close to a third of the total agricultural global water footprint (WF) is related to the production of animal products and the average WF per calorie of beef is 20 times that of cereals and starchy roots (Mekonnen and Hoekstra, 2012).

4.1 Improvement analysis

The manufacturing process for hemp leather has its greatest impacts in water, energy and chemical use. Improvement in water usage should be attainable through more water recycling within the plant and the sludge therefrom, if not hazardous, could be burned for heat and thereby improve the use of energy resources at the same time. It is also possible that the process would use less water, because it seems unlikely that the manufacturing phase of hemp leather would consume more water than 8,4 (14% of 60) cows who each has a life span of 36 months.

Another way to minimize energy consumption could be to lower the consumption of chemicals, which has been proven to be successful by the company Hemp Bio Leather (Hemp Bio Leather, 2018) who don't use any chemicals in the manufacturing of their hemp leather. They also claim that water and energy usage are kept to a minimum and that their hemp leather is biodegradable. Hemp Bio Leather is manufactured in a lab at the moment, and the future will show how their process will face production on a big scale and an LCA should be done on a similar process, to get an overview over how the material flows and impacts of more modern methods look, seeing as the patent used in this report is 27 years old (from 1991). For this particular manufacturing process, assessed in this report, it is difficult to say which chemicals could be reduced. The SBR-resin has quite a large impact on the process, but it is an important part of the process, essentially what would make the non-woven sheet appear leather-like, which makes it unlikely that the amount of it could be reduced. It could however be replaced with natural rubber, though the toughness might decrease (SBR tends to harden over time, whereas natural rubber softens (Encyclopædia Britannica, 2018)), which in turn might require the change of chemicals from cresol to something that better suits natural rubber. A change from cresol to a less hazardous chemical would be favorable for the environment and health of workers. As the patent the manufacturing process is based upon does not specify the functions of the cresol, it is difficult to assess with what and if it could be replaced. The same can be said about sodium chromate, however, the patent states that, either sodium chromate and sulfuric acid or ammonium phosphate and methylol urea can be used. Methylol urea is a formaldehyde derivative, which suggests that it also should be highly toxic, but there is a lack of data covering the toxicity of this compound. Ammonium phosphate is less toxic than both sodium chromate and sulfuric acid, which are both carcinogens according to literature, so perhaps the choice to use ammonium phosphate and methylol urea instead of sodium dichromate and sulfuric acid could have less heavy environmental impacts.

Waste from the cultivation phase of hemp leather production has been assumed to be zero, since the tow is the "waste" itself. However, there might be other waste, though it is assumed to be compostable on sight.

The amounts of water and fiber, and thereby the chemicals, needed for the process are not based on any existing data (except for the water used in the paper mill) and are probably not exact. The results in this report should be seen as a preliminary assessment and give an insight to what this process could imply. The weights of the different leathers might not be the same.

4.2 Hemp leather and bovine leather

The water usage of the hemp leather manufacturing process seems very high which is surprising since the whole life cycle of cattle raising has been taken into consideration and it is known that cattle raising consumes a lot of water (Mekonnen and Hoekstra, 2012). Especially since the production of feed should consume a lot of water and a cow in its life time as livestock consumes around 1.6% or more of its body weight in forage per day, which suggests an amount of 5,4 ton forage during its life time on an average of 36 months, which amounts to a water consumption of about 1800000 m^3 of water per cow if the forage consists of only alfalfa (other types of feed fed to livestock generally have larger footprints (Mekonnen and Hoekstra, 2012, Steinfeld et al., 2006)) hay - and 100 m^2 of leather requires 60 animals. 275kg for a cow is also quite small when compared to other countries (420-500kg in Brazil (Dick et al., 2014), 505-727kg in the USA (Pelletier et al., 2010) and 421-653 in Thailand (Ogino et al., 2015)), so it is possible that the water use can be even greater. Water consumption also differs geographically with different factors, for example the Netherlands show lower total WFs for most animal products they produce if compared to the USA and the USA shows lower WFs in comparison to India. This because, in the Netherlands, the animal production is dominated by the industrial production system, which has a smaller footprint than grazing and mixed systems that are more common in the USA and India (Mekonnen and Hoekstra, 2012), but then means that the animals will not be able to go outside or feed on hay. It is also due to the different climates and the poor agricultural practices in India. It still seems unlikely that the manufacturing process of hemp leather should consume more water than the life cycle of the livestock for bovine leather.

The great amount of water used could likely be explained by the paper machine's impact on the LCA and that it likely has an even larger capacity than 500ton/day. There is a very large difference between the GWP, AP and EP between the air compressor and the paper machine, which could also point to this. It is also possible that the paper machine in the database takes account for the water used and that it thereby has been over dimensioned in this LCA. More information about the paper machine was not included in the database.

Methane warms up the atmosphere more powerfully than CO_2 but its half-life is only 8 years, compared to 100 for CO_2 and since the livestock industry is responsible for 37% of anthropogenic methane emissions, it means that the positive effects of a reduction in livestock would happen relatively fast (Goodland and Anhang, 2009).

The leather industry uses quite a lot of chromium, or chrome sulphate, among other toxic chemicals, which is listed as one of the most noxious heavy metals by the Environmental Protection Agency and can result in various health issues, such as digestive and dermatological issues (Sharma et al., 2012) and has shown decreased skeleton density in rats (Bieńko et al., 2017). The use of any chromium in the manufacturing process of hemp leather should therefore also be avoided.

The use of fertilizers and pesticides in the livestock production has not been taken into account, but it can be assumed that the use of both is larger than that for hemp production since livestock production requires many yields of crops and because no pesticides are used in hemp production.

A switch from the use of bovine hides to hemp fiber would economically injure the beef producers, as 14% of their earnings would be lost which in turn might urge them to consider other types of farming, and maybe hemp farming. As the hemp plant has the ability to restore soil and the tops and leaves add fertility to the soil (Robinson, 1995), it would be a healthy opportunity to alleviate eroded land due to livestock raising. And if the beef industry narrows down due to measures being taken for the environment, the bovine hides need a replacement for the leather industry to be able to continue. It could be argued that contemporary petroleum based synthetic leathers would take over after bovine leather, but this would probably not be as favorable for the environment (Steinfeld et al., 2006) as a switch to hemp leather would be, especially if the hemp leather manufacturing process would first be refined. An environmentally friendly product is also attractive for consumers today (Ghvanidze et al., 2016) and the high durability fibers (and also the hemp leather itself, as suggested by Hwang & Kyung (1991), see table 1) should add to its value. Since hemp has so many applications, there are many sectors apart from the leather industry that could employ a lot of people, and especially those who work in the leather industry sector today, so there should not be concerns about jobs being lost to the potential dismantling of the beef/leather industry. The health risks of working in the leather industry, both in the slaughterhouses and tanneries, should also make the hemp leather (or just hemp) industry more attractive to workers if they were presented with the option.
Because of the high yields from hemp, it demands less land and should be economically attractive. There is also a large demand for crop land by the biofuel industry (Cassidy et al., 2013) and hemp can provide both feedstock for biofuel (hurds) as well as fiber and/or seeds at the same time.

It could be argued that, to produce $100\mathrm{m}^2$ hemp leather instead of bovine leather, in this case 60 lives would be saved, though this would require for the beef industry to narrow down or end as well. This moral argument (considering also the conditions the animals are being kept in and that they are being kept just for human purposes) is one that more people identify with (Beardsworth and Keil, 1991; Forum for the Future, 2016), which suggests that there is a market for products that can be labelled at "cruelty free" and "vegan" as well as "Fairtrade", as the health of workers is also important to consumers (Andorfer and Liebe, 2012), all labels that hemp leather could possess. Though other factors such as price and convenience can play a big part for consumers (Ghvanidze et al., 2016), so there would have to be a change in the animal derived food industry for this to happen on a big scale. Czarnezki (2011) suggests “Eco-Labeling”, a labeling that lets consumers know the environmental cost of products which could lead to them choosing more consciously (Czarnezki, 2011).

It should be remembered that the energy mix is not the same in different countries and therefore results in this report and it is hard to assess how much of an impact that would have, though the energy use is still the same.

Comparing hemp leather to bovine leather makes it clear that hemp leather is superior environmentally, and probably economically considering the inputs and yield. With so many factors pointing to the grave environmental effects animal products have and that they actually contribute to world hunger and starvation, it is strange that not more measures against them are being taken by larger organizations. The second of the UN 17 Global Goals is “Zero Hunger” and none of its target points mentions the need to decrease the consumption of animal products (WFP, 2018), for example. As we can grow food for another four billion people if the livestock industry were to end, there should not be a need for genetically modified crops, as the UN suggests as part of the solution to world hunger, as it is clear what has the most severe impacts and what should be done to prevent them.

5. Conclusions

After this assessment on the manufacturing of hemp leather and the comparison with bovine leather, the following conclusions can be drawn;

- The manufacturing of bovine leather is largely detrimental to the environment and human health.
- The manufacturing of hemp leather according to the work of Hwang & Kyung (1991) and similarly to paper has much lower environmental impacts in most categories examined but consumes large amounts of water and produces large amounts of hazardous waste.
- There are ways to manufacture hemp leather without the use of chemicals and with minimal energy and water use that need to be further studied.
- The animal industry, and therefore the leather industry, sector is the one of the world's largest contributors to climate change, land use, deforestation, acidification, water use, human health problems and biodiversity reduction.
- The hemp plant has negative CO_2-eq., purifies soil, has lower water, energy and fertilizer use compared to other crops, can be cultivated on a large area of the planet and requires no pesticides.
- The consumption of animal food products, especially beef, must decrease largely for the sake of the environment, which means that the supply of hides needed for the manufacturing of bovine leather must decrease largely as well.
- The manufacturing process of hemp leather needs to be further studied.
- Hemp leather has great potential to become an attractive product, with respect to environmental, functional as well as ethical factors.

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