IOP Conference Series: Earth and Environmental Science

Life Cycle Assessment of Cow Tanned Leather Products

To cite this article: M Ulya *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **757** 012066

Life Cycle Assessment of Cow Tanned Leather Products

M Ulya[1], A L Arifuddin[1], K Hidayat[1]

[1] Study Program of Agroindustrial Technology, Faculty of Agriculture, University of Trunojoyo Madura, Indonesia

Corresponding author's email address: millatul.utm@gmail.com

Abstract. The leather tanning industry is one of the chemical industries, which significantly impacts the environment. The raw material used for tanning is chromium (Cr), which is toxic to humans. The study aims to estimate the environmental impact of the cow tanned leather production at UD. PK X, Magetan, East Java, Indonesia. The method used is the Life Cycle Assessment (LCA) and analyzed using the "gate to gate" perspective. The results showed that the leather tanning process at UD. PK X produces several impact categories, including climate change for the entire process chain except fleshing and trimming with a total impact value of 2.03E+02 kg CO2 eq. The impact category of human toxicity potential, freshwater ecotoxicology, and marine ecotoxicology on the tanning process (Cr VI) has an impact value of 1.54E+02 kg 1.4 dichlorobenzene eq, 1.25E+03 kg 1.4 dichlorobenzene eq, and 1.55E+05 kg 1.4 dichlorobenzene eq, respectively. The last impact is photochemical oxidation in the setting out process with an impact value of 6.07E-7 kg ethylene eq.

1. Introduction

Leather is an intermediate agricultural commodity with various uses in downstream industries. It can be cut and assembled into clothing, leather goods, shoes, furniture, and several other items [1]. The raw material used in the leather industry is the hides and skins as a by-product from the meat industry. They processed and changed into a stable material that can be used to manufacture a wide variety of goods.

The leather tanning industry is one of the fastest-growing industries in the world. World production for leather with an average from 2012-2014 was 586.9 thousand tonnes/year [2]. Indonesia is the largest producer of leather in Southeast Asia [3]. In 2010-2015, the leather, leather goods, and footwear sectors' annual growth reached 5% and accounted for 0.26% of the Gross Domestic Product (GDP) of Indonesia in 2013, which was equal to $237 billion [4].

According to the Indonesian Tannery Association, 75 percent of all tanneries in Indonesia are listed as Small and Medium Enterprises (SMEs) [3]. SMEs tend to be environmentally harmful because of their inadequate methods than big companies [5]. Hu *et al.* [6] stated that on the one hand, the leather industry enhances local economic growth; on the other hand, however, it contributes to enormous environmental pollution and destruction of biological chains. One of the tanning agents is chrome metal, a chemical that is carcinogenic in grey, and there is no safe limit for its pollution [7]. Therefore, improving the environmental performance of this industry is also critical [8]. One method that can be used to improve environmental assessment is the Life Cycle Assessment (LCA) method.

LCA is a widely accepted method that has proven its efficiency as a useful decision-making tool for assessing the environmental burdens associated with production processes to move towards sustainable production practices. The LCA method has various implementations in different geographical locations in leather manufacturing, such as Spain, India, Italy, and Bangladesh [1, 9-11]. The study of LCA in the

Indonesian leather tanning industry has been studied by Kautzar *et al*. [12] in the chrome-tanned leather industry and Al Farisi *et al.* [13] in the vegetable-tanned leather industry. Kautzar *et al*. [12] reported that the production process has a most significant environmental impact than the distribution of raw materials and products. No studies have reported the environmental impact of chrome-tanned cow leather from a "gate to gate" perspective.

The research aims to estimate and minimize the environmental impact produced by the chrome-tanned cow leather industry in UD. PKX using the LCA method. It is analyzed using a "gate to gate" perspective to obtain the environmental impact at each stage of the cow leather production process. Through this research, we can find out which process produces the highest environmental impact and how to improve the environmental performance of UD PKX.

2. Materials and methods

2.1. Company description

UD PKX is a cow leather tanning industry that uses chromium as its tanning agents—placed in Ringinagung Village, Magetan District, Magetan Regency, East Java, Indonesia. This district is one of the large centers of tannery and leather handicraft industries in East Java. Thirty-four tannery industries produce liquid waste of 397.4 m^3/day [14]. The leather tanning industries in this village consist of two industry types, including industries with vegetable and chromium tanning agents. UD. PKX processes 1.5 tons of raw cowhides into 285.4 kg of cow tanned leather.

2.2. Life cycle assessment

The LCA is a decision-making tool used to identify, quantification, and evaluate a product, process, or service by estimating the associated environmental impacts throughout its life cycle [15,16]. There are four steps in the LCA method, including goal and scope definition, inventory analysis, impact assessment, and interpretation of results [17].

2.2.1. Goal and scope definition, functional unit and system boundaries

This study aimed to determine and estimate the environmental impacts in each stage of the chrome-tanning process at UD. PKX. The analysis was obtained using the "gate to gate" perspective. In this analysis, the framework boundaries were only in the tanning process. This study included all direct inputs and outputs in each step but excluded the calculation of human energy inputs.

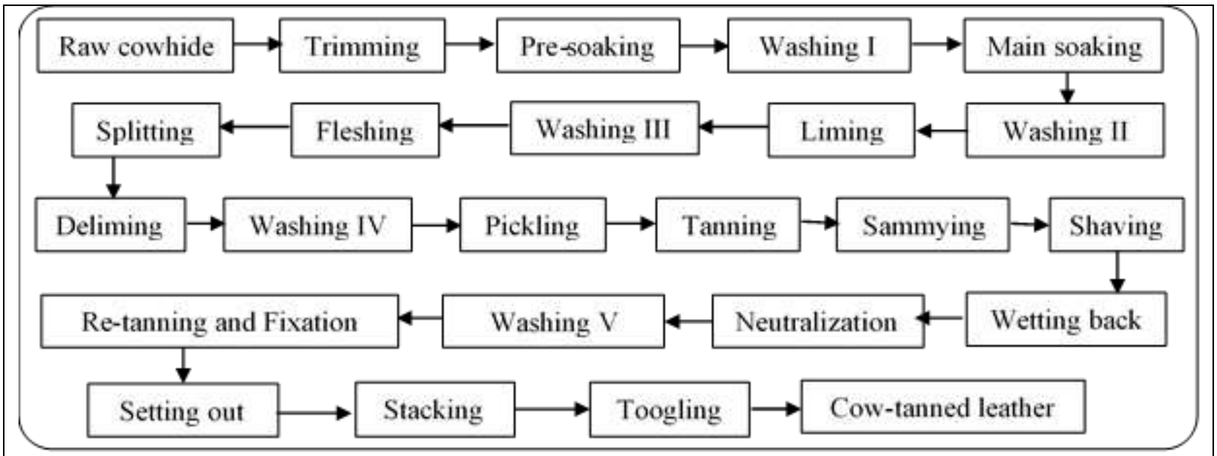

Figure 1. The system boundaries

It includes all the steps from the rawhide to the leather using chromium as the primary tanning agent. The functional unit studied is one batch production of 285.4 kg of cow-tanned leather. The boundary system can be seen in **Fig.** 1.

2.2.2. Inventory analysis (Life cycle inventory or LCI)

This analysis aims to collect data that supports the LCA analysis. All the data related to the inputs and outputs of the process were obtained from the production site. The inputs have been collected and computed, including chemicals, water demand, and energy consumption, while infrastructure was not included within the system boundaries. The Outputs have been collected and calculated, including emissions, solid, and liquid waste.

2.2.3. Impact assessment (Life Cycle Impact Assessment or LCIA)

Impact assessment is a technical, quantitative, and qualitative process to characterize and assess the effects of the environmental burdens identified in the inventory (16). Assessment and classification of the impact of waste (liquid, solid, and gas) from the tanning skin production process. The software of OpenLCA version 1.6.3 performed the impact assessment. The method used is CML (baseline) version 4.4, January 2015. The database used is open_lca_methods_1_5_6.zolca.

2.2.4. Interpretation of the results

The interpretation stage is the stage of improvement, completion, and conclusion of the solution's aspects and the impact that is analyzed from the data obtained.

3. Results and discussion

3.1. Life cycle inventory

The tanning industry UD. PKX is considered a primary source of data in this study. This secondary data obtained from Purba *et al.* [3], which is adjusted to the Life Cycle inventory stages. Data are presented in Table 1. These data have been computed to estimate environmental impact at each step of the tanning process.

Table 1. Inputs and Outputs in the tanning industry

No.	Process	Inputs and Outputs	Amount	Unit
1.	Trimming	Inputs:		
		Raw cowhide	1500	Kg
		Outputs:		
		Rejected cowhide	120	Kg
		Raw cowhide	1380	Kg
2.	Pre-Soaking	Inputs:		
		Alcohols, C12-14, ethoxylated, unspecified	2.76	Kg
		Alkylbenzenesulfonic acid, unspecified	2.76	Kg
		Electricity	8.52	kWh
		Raw cowhide	1380	Kg
		Water, ground	2415	Kg
		Outputs:		
		CO_2	6.3	Kg
		Cowhide	1380	Kg
		Water, waste	2420.52	Kg
3.	Washing I	Inputs:		
		Electricity	1.79	kWh
		Raw cowhide	1380	Kg
		Water, ground	1380	Kg
		Outputs:		
		CO_2	1.32	Kg
		Cowhide, washing I	1380	Kg
		Water, waste	1380	Kg
4.	Main Soaking	Inputs:		
		Electricity	43.51	kWh
		Raw cowhide, washing I	1380	Kg
		Sodium carbonate	4.14	Kg
		Outputs:		
		CO_2	2.54	Kg
		Cowhide, pickling	676.2	Kg
		Wastewater	748.55	Kg
13.	Tanning	Inputs:		
		Chromium VI	47.44	Kg
		Electricity	70.87	kWh
		Formic acid	3.38	Kg
		Cowhide, pickling	676.2	Kg
		Oils, unspecified	1.35	Kg
		Sodium carbonate	10.14	Kg
		Sodium chloride	67.62	Kg
		Sulfuric acid	1.35	Kg
		Water, ground	676.2	Kg
		Outputs:		
		CO_2	52.44	Kg
		Cowhide, wet blue, tanning	709.33	Kg
		Wastewater	774.24	Kg
14.	Sammying	Inputs:		
		Electricity	1.79	kWh
		Cowhide, wet blue, tanning	709.33	Kg
		Outputs:		
		CO_2	1.32	Kg
		Cowhide, sammying	425.6	Kg
		Wastewater	283.73	Kg
15.	Shaving	Inputs:		
		Electricity	4.77	kWh

		Water, ground	2760	Kg			Cowhide, sammying	425.6	Kg
		Outputs:					Outputs:		
		CO_2	32.2	Kg			CO_2	3.35	Kg
		Cowhide, main soaking	1380	Kg			Cowhide, solid waste	127.68	Kg
		Water, waste	2764	Kg			Cowhide, shaving	297.92	Kg
5.	Washing II	Inputs:			16.	Wetting back	Inputs:		
		Electricity	2.2	kWh			Alkylbenzenesolfonic acid	0.3	Kg
		Cowhide, main soaking	1380	Kg			Electricity	3.86	kWh
		Water, ground	2415	Kg			Formic acid		
		Outputs:					Cowhide, shaving	297.92	Kg
		CO_2	1.63	Kg			Water, ground	299.71	Kg
		Cowhide, washing II	1380	Kg			Outputs:		
		Water, waste	2415	Kg			CO_2	2.86	Kg
6.	Liming	Inputs:					Cowhide, wetting back	297.92	Kg
		Alcohols, C12-14, ethoxylated, unspecified	1.38	Kg			Wastewater	299.71	Kg
		Electricity	14.27	kWh	17.	Neutralization	Inputs:		
		Glucose	2.76	Kg			Electricity	2	kWh
		Cowhide, washing II	1380	Kg			Cowhide, wetting back	297.92	Kg
		Limestone, in-ground	55.2	Kg			Sodium formate	4.47	Kg
		Sodium sulfide	1.38	Kg			Water, ground	297.92	Kg
		Water, ground	4140	Kg			Outputs:		
		Outputs:					CO_2	2	Kg
		CO_2	10.56	Kg			Cowhide, neutralization	297.92	Kg
		Cowhide, liming	1380	Kg			Wastewater	302.39	Kg
		Water, waste	4200.72	Kg	18.	Washing V	Inputs:		
7.	Washing III	Inputs:					Electricity	1.24	kWh
		Electricity	2.34	kWh			Cowhide, wetting back	297.92	Kg
		Cowhide, liming	1380	Kg			Water, ground	297.92	Kg
		Water, ground	2760	Kg			Outputs:		
		Outputs:					CO_2	1.6	Kg
		CO_2	1.73	Kg			Cowhide, washing III	297.92	Kg
		Cowhide, washing III	1380	Kg			Water, waste	297.92	Kg
		Water, waste	2760	Kg	19.	Re-tanning and Fixation	Inputs:		
8.	Fleshing	Inputs:					Acrylic acid	5.96	Kg
		Cowhide, washing III	1380	Kg			Catechol	1	Kg
		Outputs:					Chestnut, pyrogallol Tannins	5.96	Kg
		Cowhide, fleshing	1352	Kg			Electricity	48.26	kWh
		Solid waste (cowhide)	27.6	Kg			Formic acid	4.47	Kg
9.	Splitting	Inputs:					Cowhide, washing V	297.92	Kg
		Electricity	9.4	kWh			Melamine	5.96	Kg
		Cowhide, fleshing	1352	Kg			Oils, unspecified	17.88	Kg
		Outputs:					Water, ground	297.92	Kg
		CO_2	6.96	Kg			Outputs:		
		Cowhide, splitting	676.2	Kg			CO_2	35.98	Kg
		Cowhide, by-product	676.2	Kg			Cowhide, re-tanning, and fixation	297.92	Kg
10.	Deliming	Inputs:					Water, waste	351.96	Kg
		Alcohols, C12-14, ethoxylated, unspecified	1.35	Kg	20.	Setting Out	Inputs:		
		Ammonium sulfate	13.52	Kg			Cowhide, re-tanning, and fixation	297.92	Kg
		Electricity	15.22	kWh			Electricity	612.99	kWh
		Protease enzyme	2.03	Kg			LPG	45	Kg
		Cowhide, splitting	676.2	Kg			Outputs:		
		Water, ground	676.2	Kg			CO_2	1.8	Kg
		Outputs:					Dinitrogen monoxide	0.0011	Kg
		CO_2	11.26	Kg			Cowhide, setting out	285.4	Kg
		Cowhide, deliming	676.2	Kg			Methane	0.0001	Kg
		Wastewater	693.11	Kg			Solid waste	15.88	Kg

11.	Washing IV	Inputs:			21.	Stacking	Inputs:		
		Electricity	3.03	kWh			Electricity	11.19	kWh
		Cowhide, deliming	676.2	Kg			Cowhide, setting out	285.4	Kg
		Water, ground	1352.4	Kg			Outputs:		
		Outputs:					CO_2	8.28	Kg
		CO_2	2.24	Kg			Cowhide, setting out	285.4	Kg
		Cowhide, washing IV	676.2	Kg	22.	Toogling	Inputs:		
		Wastewater	1352.4	Kg			Electricity	22.38	kWh
12.	Pickling	Inputs:					Cowhide, setting out	285.4	Kg
		Electricity	3.43	kWh			Outputs:		
		Formic acid	3.38	Kg			CO_2	16.56	Kg
		Cowhide, washing IV	676.2	Kg			Cowhide, setting out	285.4	Kg
		Sodium chloride	67.62	Kg					
		Sulfuric acid	1.35	Kg					
		Water, ground	676.2	Kg					

3.2. Impact assessment

The environmental impact assessment was carried out using OpenLCA software with the CML baseline version 4.4 2015 method. The environmental impacts resulting from the production process of 285.4 kg of cow-tanned leather include several impact categories, such as climate change, human toxicity, marine aquatic ecotoxicity, freshwater aquatic ecotoxicity, terrestrial ecotoxicity, and photochemical oxidation. The summary of the LCA results can be seen in Table 2.

Table 2. Summary of Life Cycle Impact Assessment UD. PKX

Impact category	Process	Amount	Unit
Climate change	Pre-soaking	6.30E+00	Kg CO_2 eq
	Washing I	1.32E+00	Kg CO_2 eq
	Main soaking	3.22E+01	Kg CO_2 eq
	Washing II	1.63E+00	Kg CO_2 eq
	Liming	1.06E+01	Kg CO_2 eq
	Washing III	1.73E+00	Kg CO_2 eq
	Splitting	6.96E+00	Kg CO_2 eq
	Deliming	1.13E+01	Kg CO_2 eq
	Washing IV	2.24E+00	Kg CO_2 eq
	Pickling	2.54E+00	Kg CO_2 eq
	Tanning	5.00E+01	Kg CO_2 eq
	Sammying	1.32E+00	Kg CO_2 eq
	Shaving	3.35E+00	Kg CO_2 eq
	Wetting back	2.86E+00	Kg CO_2 eq
	Neutralization	2.00E+00	Kg CO_2 eq
	Washing V	1.01E+00	Kg CO_2 eq
	Re-tanning and Fixation	3.60E+01	Kg CO_2 eq
	Setting out	2.86E+02	Kg CO_2 eq
	Stacking	8.28E+00	Kg CO_2 eq
	Toogling	1.66E+01	Kg CO_2 eq
Human toxicity	Tanning	9.26E+01	Kg 1,4-dichlorobenzene eq
Marine aquatic ecotoxicity	Tanning	3.88E+04	Kg 1,4-dichlorobenzene eq
Freshwater aquatic ecotoxicity	Tanning	3.12E+02	Kg 1,4-dichlorobenzene eq
Terrestrial ecotoxicity	Tanning	1.03E-17	Kg 1,4-dichlorobenzene eq
Photochemical oxidation	Setting out	6.00E-07	Kg ethylene eq

3.2.1. Climate change

Global warming cause climate change due to irregularities or anomalies in the gradual increase in earth temperature over the years. It is widely projected that as the planet warms, climate and weather variability will increase. Changes in the frequency and severity of extreme climate events and weather patterns variability will have significant consequences for human and natural systems [18]. There are three major greenhouse gases (GHG), including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) [19].

UD. PKX uses electric energy machines, causing emissions in the form of CO_2 gas with the unit used for all greenhouse gas emissions (kg CO_2 eq). Only the fleshing and trimming processes do not cause greenhouse gas emissions because of using human workers. Besides, the setting out process produces CH_4, N_2O, and CO_2 gas emissions. The combustion products of LPG produce these three gases. The highest emission produced by the tanning step is 5.00e+01 kg CO_2 eq/kg. The long duration of the tanning process, which is 9.5 hours, causes the amount of CO_2 emissions that require higher power than other processes, namely 70.87 kWh. OpenLCA software calculates the number of emissions for the impact of climate change, including CO_2 and N_2O gases.

The power, period of machinery use, and greenhouse gas pollution factors are used to calculate the amount of emissions from electricity use. Meanwhile, the LPG emissions calculation calculates the quantity of consumption, the LPG calorific value, and the greenhouse gas emission factor [20]. The amount of gas is calculated in kg unit multiplied by the impact factor in the open LCA database.

Accumulated greenhouse gas emissions from all processes at UD. PKX is 202.2929 kg CO_2 eq per 285.4 kg cow tanned leather. The setting out process produces methane gas, but it does not cause an impact because the amount is minimal.

3.2.2. Potential human toxicity (potential poisoning humans)

The chrome tanning industry does not use chromium metal in its pure form but salt form. The material used is chromium (III) sulfate ($[Cr(H_2O)_6]_2(SO_4)_3$). The chromium salt used has an ion number of 3+/ Cr3+ and will change to Cr6 + when it dissolves in water [21]. Its allergenic carcinogenic and mutagenic potential has been recognized, and the recent legislation sets the limit of 3 mg/kg based on the leather weight [6]. If chromium enters the body, it deposits in the liver, kidneys, and lymph to cause cancer [22]. The formation of Cr (VI) can cause severe allergic contact dermatitis in human skins and can elicit dermatitis at low concentrations [23].

According to the CML baseline version 4.4 2015 impact assessment method database, the IV chromium category of river water emissions is equated with 1.4 dichlorobenzenes to determine the impact comparison. The measured Cr VI is 1.543E+02 kg 1.4 dichlorobenzene eq. It is known that the environmental load for chromium metal at UD. PKX is 154.32837 kg 1.4 dichlorobenzene eq. However, liquid waste containing chromium VI is not discharged directly into the river. The wastewater treatment sector in the Magetan district processing the liquid waste from all of the tannery industries to produces safe waste. Meanwhile, activated sludge containing chromium is disposed of in the place provided and does not disturb the surrounding community. Biological processes in activated sludge can reduce Cr VI to Cr III by 30% [21].

3.2.3. Photochemical Oxidation

UD. PK X produces methane emissions in the setting out process. The setting out process uses LPG fuel to produce methane gas. Methane gas has asphyxia properties, which can replace oxygen [24]. So, humans exposed to methane gas in certain concentrations will experience symptoms of oxygen lack such as nausea, tightness, dizziness, etc. [20]. According to the CML baseline version 4.4 2015 method, methane gas has an impact factor of 0.006 kg ethylene eq/kg. The impact factor of each compound or element on ethylene gas is different. So, it is known that methane gas has a photochemical oxidation effect of 0.006 times lighter than ethylene gas. OpenLCA software performs calculations by calculating the inventory result with the impact factor to determine the impact result. The calculation showed that in one batch (1500 kg of cowhides), the photochemical oxidation of 6.00E-07 kg ethylene eq.

3.2.4. Aquatic Ecotoxicity

The tanning process in UD. PKX contributes to aquatic ecotoxicity. The material used is Cr (III) and turns into Cr (VI) when it dissolves in water. The marine and freshwater aquatic ecotoxicity were 1.5538E+05 kg 1.4 dichlorobenzene eq and 1.25E+03 kg 1.4 dichlorobenzene eq.

3.3. Interpretation of result and improving suggestion

This stage discusses the interpretation of solutions to minimize the impact of the leather production process in the tannery. The most effective way to reduce the resulting impact is to produce cow-tanned leather efficiently. The leather tanning industry is an industry that uses various types of chemicals and water as a solvent. So, the most dominant waste is a liquid waste. Several hazardous chemicals must be used appropriately so their effects can be minimized. It is also supported by proper processing, so the resulting waste does not endanger humans and the ecosystem. Until now, there have been many researchers who have studied an efficient way or method in the tannery production process without reducing the expected quality.

The first impact is the emission of greenhouse gases produced in almost the entire tannery production chain. Some solutions that can be done to reduce greenhouse gas emissions include reforestation around industrial locations to reduce CO_2 gas emissions. Efforts to plant trees around emission source locations can increase carbon stocks and reduce environmental impacts. Coutts *et al.* [25] observed that local suburban vegetation accumulates carbon substantially reduced local emissions and decreased atmospheric CO_2 concentrations in the local area. Besides, using industrial equipment machines efficiently both in the duration and capacity can minimize the emissions.

The second impact is human toxicity potential and aquatic (freshwater and marine) ecotoxicity. The source of the second impact categories is liquid waste containing heavy metal chrome. The first alternative is to use environmentally friendly tanning materials by using vegetable tannins. Many plant-based tanneries such as mimosa or acacia, mangrove, quebracho, myrobalan, valonia, gambier, chestnuts, oak, divi-divi, and sumac [26]. Usually, to get good leather results, it is necessary to have a combination of vegetable tanners. Also, chrome tanners can be combined with vegetable tanners to reduce the levels of chrome use. According to [27], mitigation steps to reduce the impact of chrome are: increase the chrome solution's temperature, so the chromium particles bind more quickly to skin collagen. However, this must be adapted to the skin's resistance; measuring chemicals to be used accurately; proper and correct handling of chemicals so as not to spill or leak either during the production process or during storage; using safer substitutes such as vegetable tanners and enzymatic processes.

4. Conclusion

The leather tanning industry (UD.PK X) produces most liquid waste and some solid waste in its production process. Each tannery production process has its characteristics and impacts categories depending on the chemicals used. Based on the results of the openLCA software assessment that the leather tanning process at UD. PK X produces several impact categories, including climate change for the entire process chain except fleshing and trimming with a total impact value of 2.023E+02 kg CO_2 eq. The impact of human toxicity potential, freshwater ecotoxicology, and marine ecotoxicology on the tanning process (Cr VI) has an impact value of 1.54E+02 kg 1.4 dichlorobenzene eq, 1.25E+03 kg 1.4 dichlorobenzene eq and 1.55E+05 kg 1.4 dichlorobenzene eq. The last impact is photochemical oxidation in the setting out process with an impact value of 6.07E-7 kg ethylene eq.

References

[1] Joseph K and Nithya N 2009 Material flows in the life cycle of leather *J. of Clean. Prod.* **17** 676-682.
[2] Food and Agriculture Organization 2015 *World Statistical Compendium for Raw Hides and Skins, Leather and Leather Footwear* 1998-2014 FAO USA.
[3] Purba F, Suparno O and Suryani A 2020 Green productivity in the Indonesian leather-tanning industry *Revista de Pielarie Incaltaminte* **20** 3 245-266.
[4] Kementerian Perindustrian Republik Indonesia. 2016. Perkembangan ekspor kelompok industry kulit, barang dari kulit, dan alas kaki [Internet]. Available at https://kemenperin.go.id/statistik/subsektor.php?kode=202015&ekspor=1.
[5] Hobbs J 2020 Promoting cleaner production in small and medium-sized enterprises, in: Ruth H *Small and Medium-sized Enterprises and The Environment: Business Imperatives* Routledge London 148-157.
[6] Hu J, Xiao Z, Zhou R, Deng W, Wang M and Ma S 2011 Ecological utilization of leather tannery waste with circular economy model *J. Clean. Prod.* **19** 221-228.
[7] Machdar I 2018 *Pengantar Pendendalian Pencemaran: Pencemaran Air, Pencemaran Udara dan Kebisingan* Deepublish Sleman.
[8] Shi J, Puig R, Sang J and Lin W 2016 A comprehensive evaluation of physical and environmental performances for wet-white leather manufacture. *J. Clean. Prod.* **139** 1512-1519.

[9] Notarnicola B, Puig R, Raggi A, Fuliana P, Tassielli G, Camillis C D and Rius A 2011 Life cycle assessment of Italian and Spanish bovine leather production system. *AFINIDAD LXVIII* **553** 167-180.

[10] Rivela B. Moreira M T. Bornhardt C. Mendez R. and Feijoo G. 2004. Life cycle assessment as a tool for the environmental improvement if the tannery industry in developing countries. *Environ. Sci. Tecnol.* **38** 1901-1909.

[11] Chowdhury Z U MD. Ahmed T. Antunes A.P.M. and Paul H.L. 2018. Environmental life cycle assessment of leather processing industry: a case study of Bangladesh *J. Society of Leather Tech. and Chem.* **102** 18-26.

[12] Kautzar G Z, Sumantri Y and Yuniarti R 2018 The analysis of environmental impact in leather's supply chain activity by using LCA and ANP *J. Rekayasa dan Man. Sist. Ind.* **3** (1) 200-211.

[13] Alfarisi S, Sutono S B and Sutopo W 2017 Evaluate the use of tanning agent in leather industry using material flow analysis, life cycle assessment and fuzzy multi-attribute decision making (FMADM). *AIP Conference Proceed.* **1902** 020053 1-5.

[14] Fatmawati N S, Hemana J and Slamet A 2016 Optimasi kinerja instalasi pengolahan air limbah industri penyamakan kulit Magetan *Jurnal Teknik ITS* **5** (2) 79-85.

[15] Tasca A L and Puccini M 2019 Leather tanning: life cycle assessment of retanning, fatliquoring and dyeing *J. of Clean. Prod.* **226** 720-729.

[16] Guinee J 2001 Handbook of Life Cycle Assessment: An Operational Guide to the ISO Standards. *Int J LCA* **6** 5 255.

[17] International Organization for Standardization 2006 UNI EN ISO 14040 Environmental management-life cycle assessment-principles and framework.

[18] Thornton P K, Ericksen P J, Herrero M and Challinor A J 2014 Climate variability and vulnerability to climate change: a review *Global Change Biology* **20** 3313-3328.

[19] Intergovernmental Panel on Climate Change 2007 *Contribution of Working Groups I, II dan III to the 4th Assessment Report of the IPCC*. Geneva Switzerland 104.

[20] Ulya M, Mu'tamar M F F and Firmansyah R A 2020 Life cycle assessment of raw and fried *tette* chips production *Advance in Food Sci., Sust. Agri. and Agroindustrial Engineer.* **3** 1 11-16.

[21] Triatmojo S and Abidin M Z 2014 *Penyamakan Kulit Ramah Lingkungan* UGM Press Yogyakarta.

[22] Murniasih S and Agus T 2013 Evaluasi Hg, Cd, Co, Cr dan As dalam Sampel Produk Agroindustri Berdasarkan Keputusan BPOM dan ADI *Jurnal Iptek Nuklir Garendra* **16** 1 26-37.

[23] Hansen M, Johansen J and Menne T 2003 Chromium allergy: significance of both Cr (III) and Cr (VI) *Contact Dermat.* **49** 209-212.

[24] Widodo S M M, Amin A, Sutrisman dan Putra, A A 2017 Rancang Bangun Alat Monitoring Kadar Udara Bersih dan Gas Berbahaya CO, CO_2 dan CH_4 di dalam Ruangan Berbasis Mikro-kontroler *Jurnal Pseudocode* **4** 2 105-119.

[25] Coutts A M, Beringer J and Tapper N J 2007 Characteristics influencing the variability of urban CO_2 fluxes in Melbourne, Australia *Atmospheric Environment* **41** 51–62.

[26] Sarkar K T 1995 *Theory and Practice of Leather Manufacture* Madras.

[27] Triatmojo S 2009 Implementasi "Produk Bersih" dalam Industri Penyamakan Kulit Guna Peningkatan Efisiensi dan Pencegahan Pencemaran Lingkungan. *Pidato pengukuhan jabatan guru besar pada fakultas peternakan*. Universitas Gadjah Mada Yogyakarta.