GREEN PRODUCTIVITY IN THE INDONESIAN LEATHER-TANNING INDUSTRY

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ABSTRACT. Green productivity (GP) is a strategy by which production processes are improved by efficiently using resources and materials and adverse impacts on the environment are reduced. This study aims to measure GP of an Indonesian leather-tanning industry and develop alternatives to current processes that would improve its environmental and economic impacts. Two small to medium tanneries (Tanneries A and B) in two provinces were used as a case study. Data were collected through direct observation, measurements, in-depth interviews, and activity documentation. Material flow was analyzed using a green material flow map to determine the six sources of green wastes and the environmental indicators. The GP Index (GPI) was used to measure GP. The best method by which to improve GP was determined using GPI to a ratio of GP along with expert analysis using an analytical hierarchy process. GPI at Tannery A, located in West Java, was 0.14 with economic and environmental indicators of 1.44 and 10.41, respectively. GPI at Tannery B, located in Central Java, was 0.16 with economic and environmental indicators of 1.60 and 9.99, respectively. GP in both tanneries was low because of their suboptimal use of water. High water consumption can lead to a high discharge of liquid waste. Six alternatives for Tannery A and four for Tannery B were created. According to GPI, GP ratio, and expert opinion, the best strategy by which to improve GP was water recycling in the soaking and liming processes. This strategy increased GPI at Tannery A to 0.18 and at Tannery B to 0.20.

KEY WORDS: Green productivity, Green productivity index, Green productivity ratio, Indonesian leather-tanning industry

PRODUCTIVITATEA ECOLOGICĂ ÎN INDUSTRIA DE PIELĂRIE DIN INDONEZIA

REZUMAT. Productivitatea ecologică (GP) este o strategie prin care procesele de producție sunt îmbunătățite prin utilizarea eficientă a resurselor și a materialelor, reducând impactul advers asupra mediului. Acest studiu își propune să măsoare GP a industriei de pielărie din Indonezia și să dezvolte alternative la procesele actuale care ar îmbunătăți impactul asupra mediului și economiei. S-au utilizat două tăbăcării mici spre medii (Tăbăcăriile A și B) din două provincii ca studiu de caz. Datele au fost colectate prin observație directă, măsurători, interviuri detaliate și documentarea activității. Fluxul de materiale a fost analizat folosind o hartă a fluxului ecologic de materiale pentru a determina cele șase surse de deșeuri ecologice și indicatorii de mediu. Indicele GP (GPI) a fost utilizat pentru a măsura productivitatea ecologică. Cea mai bună metodă prin care s-a îmbunătățit GP a fost determinată folosind GPI raportat la GP împreună cu analiza experților folosind un proces de ierarhie analitică. GPI al Tăbăcăriei A, situat în Java de Vest, a fost 0,14; indicatorii economici și de mediu fiind de 1,44, respectiv 10,41. GPI al Tăbăcăriei B, situat în Java Centrală, a fost 0,16, indicatorii economici și de mediu fiind de 1,60 și, respectiv, 9,99. În ambele tăbăcării GP a fost scăzută din cauza utilizării apei sub nivelul optim. Consumul mare de apă poate duce la eliminarea unei cantități mari de deșeuri lichide. Au fost create șase alternative pentru Tăbăcăria A și patru pentru Tăbăcăria B. În conformitate cu GPI, raportul GP și opinia experților, cea mai bună strategie pentru a îmbunătăți GP a fost reciclarea apei în procesele de înmuiere și cenușărire. Această strategie a crescut GPI în cazul Tăbăcăriei A la 0,18, iar în cazul Tăbăcăriei B la 0,20.

CUVINTE CHEIE: productivitate ecologică, indice de productivitate ecologică, raport de productivitate ecologică, industria de pielărie din Indonezia

PRODUCTIVITÉ ÉCOLOGIQUE DANS L'INDUSTRIE INDONÉSIENNE DU TANNAGE DU CUIR

RÉSUMÉ. La productivité écologique (GP) est une stratégie par laquelle les processus de production sont améliorés en utilisant efficacement les ressources et les matériaux et en réduisant l'impact négatif sur l'environnement. Cette étude vise à mesurer la GP de l'industrie indonésienne de tannage du cuir et à développer des alternatives aux procédés actuels pour améliorer l'impact sur l'environnement et l'économie. Deux petites et moyennes tanneries (Tanneries A et B) dans deux provinces ont été utilisées comme étude de cas. Les données ont été collectées par observation directe, mesures, entretiens approfondis et documentation des activités. Les flux de matières ont été analysé à l'aide d'une carte des flux de matières vertes pour déterminer les six sources de déchets verts et les indicateurs environnementaux. L'indice GP (GPI) a été utilisé pour mesurer la productivité écologique. La meilleure méthode pour améliorer GP a été déterminée en utilisant GPI sur un ratio de GP avec une analyse d'experts utilisant un processus de hiérarchie analytique. Le GPI de la Tannerie A, située dans la province de Java occidental, était de 0,14 avec des indicateurs économiques et environnementaux de 1,44 et 10,41, respectivement. Le GPI de la Tannerie B, située dans la province de Java central, était de 0,16 avec des indicateurs économiques et environnementaux de 1,60 et 9,99, respectivement. La GP dans les deux tanneries était faible en raison de leur utilisation sous-optimale de l'eau. Une consommation d'eau élevée peut entraîner un rejet élevé de déchets liquides. Six alternatives pour la Tannerie A et quatre pour la Tannerie B ont été créées. Selon le GPI, le ratio GP et l'opinion d'experts, la meilleure stratégie pour améliorer la GP était le recyclage de l'eau dans les processus de trempage et de chaulage. Cette stratégie a augmenté le GPI de la Tannerie A à 0,18 et de la Tannerie B à 0,20.

MOTS CLÉS : productivité écologique, indice de productivité écologique, ratio de productivité écologique, industrie indonésienne du tannage du cuir

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INTRODUCTION

Indonesia is the largest leather producer in Southeast Asia, and leather and footwear products are some of its main exports. Figure 1 compares annual leather production from several countries and clearly indicates Indonesia's rank as top producer from 1999 to 2015 [1]. The average growth of leather, leather product and footwear industries in 2010–2015 reached 5% and accounted for 0.26% of Indonesia's Gross Domestic Product (GDP) in 2013, which was equivalent to $237 billion [2].

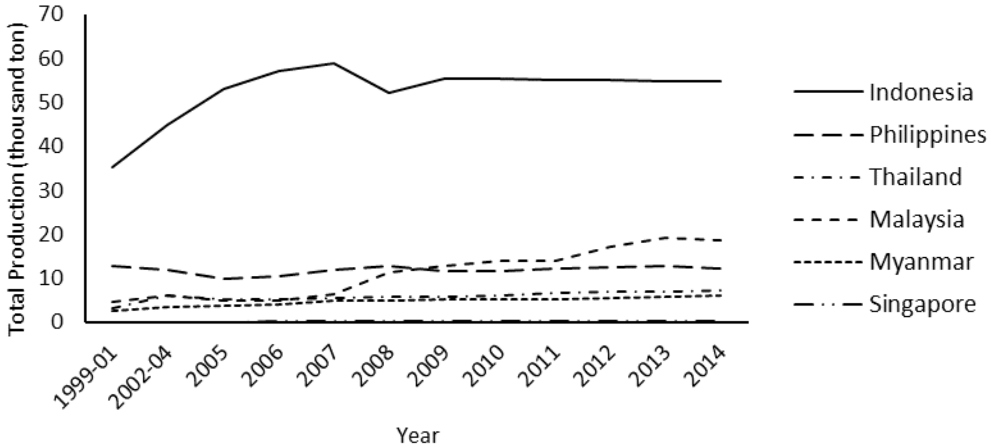

Figure 1. Total production of bovine heavy leather and bovine light leather

The Indonesian leather-tanning industry has experienced considerable growth. Data from Statistics Indonesia showed that the annual growth of leather, leather and footwear production for a large- to medium-scale industry was 6.6% and for a small-scale industry was 7.7% during 2010–2017 [3]. The export volume was growing as well by nearly 12.84% in 2013–2015 [2]. The agreement by the Association of Southeast Asian Nations Free Trade Area since 2015 has continued to incite competition in the global leather market. To thrive among the competition, a company must have business advantages and imperatives, such as maximum productivity in its operation management system. The challenges for the industrial world are dynamically increasing following various types of pressure, such as market globalization, standardization, regulations, and policy [4]. If the first operating system focuses only on low-cost production, the world would expect the industry to consider sustainable developments, including environmental impacts, ecofriendly technology, and renewable resources.

The leather-tanning industry is widely known as non-ecofriendly [5]. The tanning process results in various wastes, both solid and liquid, that can seriously damage the environment if not properly handled [6, 7]. The amount of solid waste from a tannery varies depending on the technology and type of end product. Some sources have estimated that 1 tonne of raw skin could result in 439–600 kg solid waste, of which 25% contained chrome and the remaining 75% was chrome-free solid waste or became a suspended solid in liquid waste, and that only 250–300 kg was converted into leather [8, 9].

According to the Indonesian Tanners Association, 75% of all tanneries in Indonesia are classified as small and medium enterprises (SMEs). These SMEs have limitations that hinder their environmental management efforts. SMEs tend to be more harmful to the environment than the larger enterprises because of their poor production techniques [10]. SME tanneries in developing countries face serious waste management problems and many are being shut down because they are not able to meet the required waste management standards [11]. This situation is similar in Indonesia, where there is a lower rate of adoption of green tanning practices [12]. This contradicts a recognition by the industry of the importance of building an ecofriendly tannery to thrive in the global market. An approach to green productivity (GP) must surface to achieve that objective.

GP is a strategy by which to improve productivity as well as the economic aspects, environmental quality, and socioeconomic development of an industry. This approach improves production processes by more efficiently utilizing resources and materials to reduce negative impacts on the environment. A GP strategy maintains that a healthy environment and competitive economic factors are mutually influential [13]. To design a productivity-improvement strategy in Indonesia's tanneries, it is essential to first measure their GP index (GPI). This value aids a business in gaining a better understanding of the factors involved, such the costs and benefits of the actions taken and the limitations and opportunities that surround them. This would help the industry to better understand its GP goals and assist it in formulating its objectives and ways by which to achieve them [14].

The GP strategy applied in various industries has improved product quality; reduced scrap, pollution, and risk; reduced materials and costs; and increased yield without sacrificing the environment [15, 16]. In addition, GP promotes systematic assessment by reporting on and planning for environmental protection efforts [17]. The aim of this research was to map and analyze GP in the Indonesian leather-tanning industry and examine efforts by which to increase GP in these industries using case studies in two SME tanneries.

EXPERIMENTAL

Framework

GP in the Indonesian leather-tanning industry was measured using a systems approach that began with collecting data through direct observation, measurements, in-depth interviews, activity documentation, and analyses of solid and liquid waste samples by an accredited test laboratory. System identification was conducted using mass balance analysis and six green wastes at each stage of the production process. In the next stage, the environmental and economic indicators were used to calculate GP. GP is increased by minimizing or eliminating the use of resources that have an impact on environmental conditions. The best alternatives for increasing productivity are created using the GPI method, GP ratio, and analytical hierarchy process (AHP) technique.

The best GP improvement strategy is determined in two ways. First, a GPI calculation is simulated for each of the proposed alternatives, with the highest GPI being the alternative that provides the best improvement in GP. Second, the most applicative alternative is determined using AHP, which involves three expert opinions from academic, industry practice, and business sectors.

Data Collection and Analyses

Qualitative and quantitative data in the form of primary and secondary data were used in the analyses. Primary data were obtained through direct observation, measurements, in-depth interviews, activity documentation, and analyses of solid and liquid waste samples by an accredited test laboratory. Secondary data were obtained from the opinions of experts who were academics, practitioners, and businesspeople. Secondary data were also obtained from related studies published in scientific articles, scientific journals, and reference books and on the Internet. GP data together with influential indicators were calculated and analyzed using Microsoft Excel 2010. The best alternatives by which to increase GP were analyzed using Expert Choice 11. A summary of the data, characteristics of the data, data sources, collection procedures, and data analyses are presented in Table 1.

Table 1: Data, data characteristics, data sources, and data collection sources

No.	Data	Data Characteristics	Data Sources	Data Collection Source
1	Production process flow	Secondary	Tannery A and B	Field survey, interview and literature review
2	Economic: total production costs; total production; selling price;	Secondary	Tannery A and B	Field survey, interview and literature review
3	Six green waste generated	Secondary	Tannery A and B	Field survey, and literature review
4	Solid and liquid waste quality in Tannery A and B	Primary	Accredited laboratory	Testing in laboratory
5	Alternative solution to increase green productivity	Primary	Experts (academic, practitioner, and businessman)	Interview and questionnaire

Identification of Production Process and Material Requirements

The production process was analyzed using mass balance analysis and Green Value Stream Mapping (GVSM). Mass balance analyses identified the amount of waste generated in the production system; GVSM identified seven sources of green waste. The seven sources of green waste were defined as an excessive use of energy, water, material, waste, transport, emissions, and damage to biodiversity [18]. In this study, biodiversity loss was not calculated because of the limited information available from the tanneries.

Green Productivity Index

GPI is the ratio of economic benefits to environmental impacts and is represented by the following equation [19]:

$$GPI = \frac{Economic\ Indicator}{Environmental\ Indicator} = \frac{SP/PC}{EI} \quad (1)$$

where GPI = green productivity index, SP = selling price, PC = production cost, and EI = environmental impact.

Economic Indicator

An economic indicator is the ratio of the selling price to production cost for producing a one-unit of product. In this research, the production cost was based on the cost to process 1.5 tons salted-hide. The total costs were the sum of the fixed and variable costs.

$$Economic\ Indicator = \frac{Revenue}{Total\ Cost} \quad (2)$$

$$Total\ Cost = Fixed\ Cost + Variable\ Cost \quad (3)$$

$$TC = \frac{FC}{X} + VC \quad (4)$$

where TC = total cost (IDR/h), FC = fixed cost (IDR/year), VC = variable cost (IDR/h), and x = estimated working hours per year (h/year).

Environmental Impact Indicator

The value of the environmental impact indicator depends on multiplying the sum of the weight of the GP indicator and the amount of waste produced during the production process for each type of indicator. A high environmental impact value indicates poor environmental management. The indicator weight was derived from the 2005 Environmental Sustainability Index (ESI) [17] using the weight equalization aggregation method. ESI measures a country's ability to protect the environment for decades to come and integrates 76 sets of data into 21 indicators of environmental sustainability [20]. Table 2 shows an important ESI indicator used in this study. The 2005 ESI water quality indicators include variables such as of dissolved oxygen value, phosphorus concentration, electronic conductivity, and suspended solids. Phosphorus is important because it plays a role in the eutrophication process in waterbodies [21, 22].

GPI comprises three indicators as follows: gaseous waste generation (GWG), water consumption (WC), and solid waste generation (SWG). Table 2 presents the derivation of six weighted ESI indicators into the three GPI environmental variables. GWG, WC, and SWG are weighted as 0.33, 0.5, and 0.17, respectively; therefore, the environmental impact during the tanning production process is presented in Equation 5.

$$EI = 0.33\, GWG + 0.5\, WC + 0.17\, SWG \tag{5}$$

Table 2: Derivation of three environmental indicators of the green production index (GPI) in the leather-tanning process

GPI Indicators	Equivalent with ESI Indicators	Wight in ESI	Weight merging (x)	Weight (x) in GPI (x/0.30)
Gaseous wastes generation (GWG)	Reducing air pollution	0.05	0.10	0.33
	Greenhouse gas emission	0.05		
Water consumption (WC)	Water quality	0.05	0.15	0.5
	Water quantity	0.05		
	Reducing water stress	0.05		
Solid wastes generation (SWG)	Reducing waste & consumption pressure	0.05	0.05	0.17
Total			0.30	1

Emissions from Liquid and Solid Wastes

Liquid waste emissions were calculated based on chemical oxygen demand (COD) values. The methane value was then converted to a carbon dioxide (CO_2) equivalent. Solid waste emissions from the open dumping/landfill area were calculated using the Landfill Gas Emissions Model (LandGEM) v.3.02. LandGEM is an automated approximating tool with a Microsoft Excel interface that can be used to estimate emission levels for total landfill gas, CH_4, CO_2, non-CH_4 organic compounds, and other air pollutants from the landfill. This tool was issued by the United States Environmental Protection Agency's (USEPA) Clean Air Technology Center. Solid waste emissions from open burning were calculated following the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories chapter on waste incineration and open burning. IPCC is an international body created to scientifically assess climate change. IPCC was established in 1988 by the World Meteorological Organization and the United Nations Environment Program. The calculation of CO_2 gas emissions from combustion of shaving scraps is as follows:

$$CO_2\ Emission = (SW \times dm \times CF \times FCF \times OF) \times \frac{44}{12} \tag{6}$$

where SW = total amount of solid waste (kg), dm = dry matter content in the waste (%), CF = fraction of carbon in the dry matter/total carbon (%), FCF = fraction of fossil carbon in the total carbon (%), OF = oxidation factor (%), and 44/22 = conversion factor from C to CO_2. The dm value was obtained from the analysis of the sample used in the laboratory, while CF, FCF, and OF values were derived from the default data for CO_2 emission factors according to IPCC Guidelines for National Greenhouse Gas Inventories [23].

Selection of Alternatives

The selection of alternatives was based on the future GPI and then expanded using AHP to determine those most applicable. The GPI value in GP were obtained from the ratio of the GPI alternative (GP_{alt}) to the GPI initial condition (GP_{cur}) [19]. The GPI ratio formula is presented as follows:

$$GP_{ratio} = \frac{GP_{alt}}{GP_{cur}} = \frac{(SP_{alt}/PC_{alt})/EI_{alt}}{(SP_{cur}/PC_{cur})/EI_{cur}} = \frac{(Sp_{alt} \times PC_{cur})}{(SP_{cur} \times PC_{alt})} \times \frac{EI_{cur}}{EI_{alt}} \tag{7}$$

where GP_{ratio} = GPI ratio; SP_{alt} = selling price of the alternative; PC_{alt} = production costs of the alternative; SP_{cur} = the selling price of the initial condition; PC_{cur} = production cost of initial conditions; EI_{alt} = environmental impacts of the alternative; and EI_{cur} = environmental impact of the initial conditions.

AHP is an analytical method used in decision making to determine the best decisions from various alternatives. There are four basic principles of AHP according to Marimin *et al*. (2014) [24]. First, problems should be identified to compile a hierarchy. The preparation begins with deconstructing a complex problem into its main components. Then, the main components are further broken down and the process continues to form a hierarchy. Second, each level in the hierarchy is assessed through pairwise comparisons. Scales 1–9 are best for expressing opinions [25]. Third, pairwise comparisons are made at each level in the hierarchy to determine priorities. A pair of elements is compared based on specific rules, and the intensity of preferences between the elements is considered. Each hierarchical level, either quantitative or qualitative, can be compared according to a predetermined protocol for judgment so that weights and priorities are generated. Fourth, a logical consistency must be ensured. Assessments that are highly consistent are necessary for accurate decision making. The consistency ratio should be ≤10%. If not, the assessment is considered to be random and must be corrected.

RESULTS AND DISCUSSIONS

Industries Profile

The GP measurement for the Indonesian leather-tanning industry was conducted at two sites located in different provinces—Tannery A in Bogor, West Java, and Tannery B in Magetan, East Java. Both are SMEs. Tannery B is located in a specialized area for small-medium-sized tanneries called Lingkungan Industri Kulit (LIK), which is supervised by the Magetan Industry and Trade Office. Tannery A is not located in a specifically industrial area. Both Tanneries A and B produce custom products according to customer specifications. Some of the final products are gloves, upper shoes, and leather articles for bags. Tannery A uses salted goatskin for the raw material and Tannery B uses salted bovine hide.

Production Process

There are four main processes in both tanneries—beamhouse, tanning, post-tanning, and finishing. Beamhouse and tanning consume large amounts of water. The beamhouse process consists of soaking, liming, fleshing, deliming, and pickling. Fleshing at both tanneries was done manually. The tanning process consists of tanning and retanning. Post-tanning processes include dyeing, fatliquoring, and fixation. Finishing includes vacuum drying and toggling.

Calculation of Environmental Impact Indicators

We calculated the value of the environmental impact indicator from the accumulation of waste generated from the production process. GVSM was used to analyze the amount of waste generated from each stage of the process. There were seven sources of green waste found for each stage of the production process [18]; however, only six of these were taken into account for this study. Biodiversity loss was not calculated because of the limited amount of data available at the observed tanneries. The six sources of green waste were energy consumption, water consumption, material consumption, solid waste generation, transportation, and emissions, and their measured results from the tanning process at both Tanneries A and B are presented in the current state of GVSM in Figure 2 and

Figure 3, respectively. Water consumption was the highest among all sources of green waste at both tanneries, with washing (40%) and soaking (28%) being the biggest contributors.

Each tannery produced two types of waste—solid waste from liquids and liquid waste from solids. Green waste in the transportation category was zero because, at each tannery, materials and goods were moved manually. Emissions were derived from only liquid and solid wastes. Solid waste and wastewater management at Tannery A was poor. There is a simple wastewater treatment plant separates sludge using chemical coagulated materials and treats biowastes using bacteria; however, these practices do not meet the requirement standards for wastewater treatment plant (WWTP) effluent. Solid waste from fleshing was discharged into an open-dumping area and scraps from the shaving process were open burned behind the facility.

Waste management at Tannery B was relatively good. Liquid waste was treated in a communal WWTP managed by a government-owned agency before being discharged to the local waterbody. WWTP operational costs came from government subsidies and fees paid by each tannery in the area. The tariff was calculated based on raw hide.

Four types of solid waste were also generated from the tanneries. Waste from Tannery B came namely from scraps after trimming, fat and meat residues, scraps from splitting, and scraps from shaving. Very little of this waste has any economic value. Scraps from trimming are used in kikil (traditional food), scraps from splitting are made into skin cracker (food), and scraps from shaving were used as filler in footwear production. The remaining fat and meat residues are deposited into the landfill.

Scraps from shaving contributed 64% to total emissions generated from Tannery A. An interview with the owner revealed that the current waste management methods were used because they were cheap and easy. The owner of Tannery A was conscious of violating the regulations; however, there were not many alternative methods based on economics. Tannery A's strategic location, which is adjacent to a waterbody, made it extremely easy to directly dispose of the wastewater. The wastewater was discharged during rainy days because the high volume of rain and flow rate dissolved and moved the wastewater very quickly. Similar problems were encountered in tanneries in other countries, such as Bangladesh [26], Albania [27], Pakistan [28], and India [29].

Based on the analysis of six sources of green waste, Tannery A generated 0.42 tons GWG, 19.97 tons WC, and 1.68 tons SWG; Tannery B generated 0.02 tons GWG, 19.77 tons WC, and 0.58 tons SWG. Using Equation (5), the EI value for the production process in Tanneries A and B were 10.41 and 9.99, respectively. The amounts of GWG and SWG in Tannery B was were smaller than in Tannery A because the former had good liquid waste management and solid waste utilization management protocols.

Calculation of Economic Indicators

The production cost for 1500 kg raw hide was used as a basis to calculate the economic indicators. Calculations of production costs for Tanneries A and B are presented in Table 3 and Table 4. Using the Equation (2), the current economic indicator for Tanneries A and B were 1.44 and 1.60, respectively. The value of the economic indicator for Tannery B was higher than that for Tannery A because of several factors, such as cheaper labor wages, shorter production times, and income from the sale of the by-products (scraps from trimming and splitting).

Table 3: Calculation of production costs and acceptance at Tannery A

	Item	Amount (IDR)
Production cost		
Fixed cost	Labor wages	23,534,259
	Depreciation of machinery and equipment	10,533,930
	Maintenance of machinery and equipment	526,697
Variable cost	Raw materials and auxiliary	32,697,168
	Utilities	615,313
Total production cost		67,907,367

Item	Amount (IDR)
Acceptance	
Product (sq ft)	4,900
Price per sqft	20,000
Total acceptance	98,000,000

Table 4: Calculation of production costs and acceptance at Tannery B

	Item		Amount (IDR)
Production cost			
Fixed cost	Labor wages		6,420,000
	Depreciation of machinery and equipment		1,410,000
	Maintenance of machinery and equipment		70,500
Variable cost	Raw materials and auxiliary		35,331,651
	Utilities		421,094
	WWTP fee		225,000
Total production cost			43,653,242
Acceptance			
Item	Weight	Price (IDR/unit)	Amount (IDR)
Product	2700 sqft	17,500	47,250,000
Scraps from trimming	120 kg	9,500	1,140,000
Scraps from splitting	561.06 kg	38,000	21,321,040
Total acceptance			69,711,040

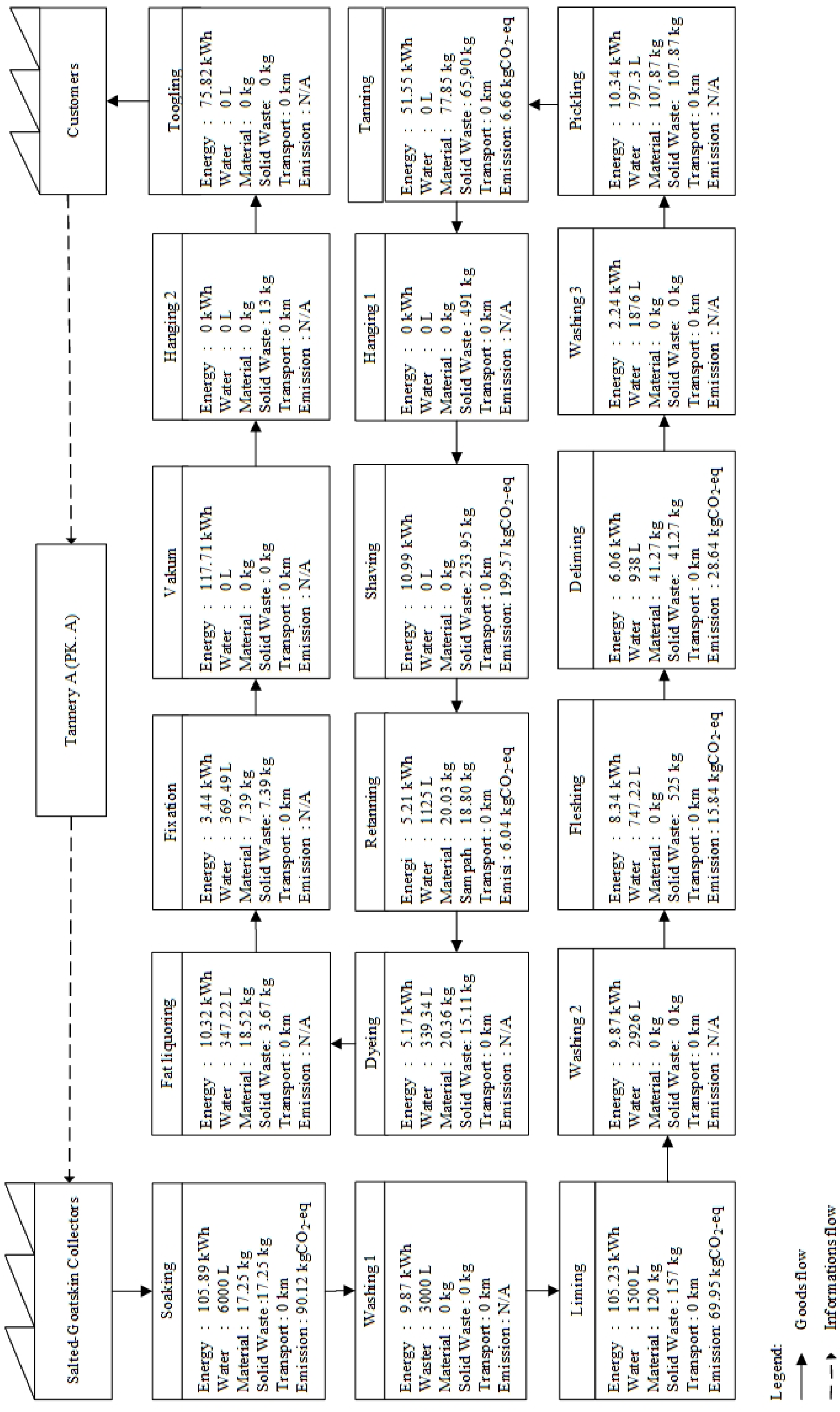

Figure 2. Current Green Value Stream Mapping (GVSM) at Tannery A

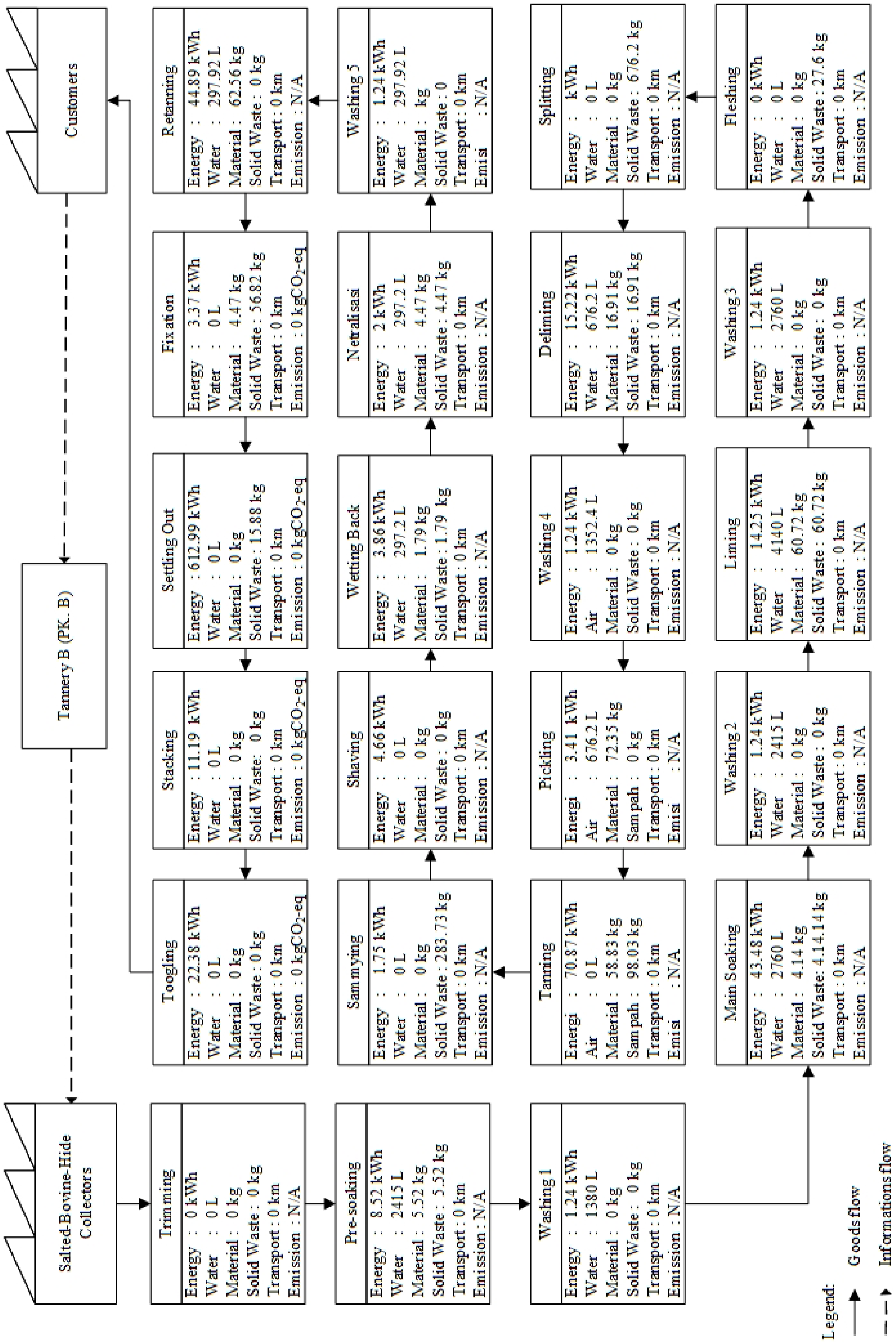

Figure 3. Current Green Value Stream Mapping (GVSM) at Tannery B

Calculation of Green Productivity Index

GPI was derived from the ratio of economic to environmental indicators. By using Equation (1), we obtained an initial GPI value at Tannery A of 0.14 and at Tannery B of 0.16, which indicated that Tannery B had a greater GP value. Good environmental management practices at Tannery B were the reasons behind its higher value. In addition, the communal WWTP in LIK helped small tanneries to properly manage their wastewater. The existence of government support through advice from experts in management systems followed by subsidized operational costs helped Tannery B to become more environmentally friendly.

Based on Figure 4, the environmental impact values at both tanneries were significantly higher than the economic indicator, which means that the environmental impacts exceeded the economic impacts. This suggests that poor management of factory performance has hindered the achievement of GP in Tanneries A and B. Based on the histogram, Tannery A had the highest environmental impact value (10.41) with an economic impact value of 1.44. Tannery A was at the same level of GPI as another tannery studied. The measurements taken by Hasanah *et al*. (2016) [30] at Tannery XYZ had a GPI value of 0.204 with an environmental indicator of 8.78 and an economic indicator of 1.79. Nevertheless, the environmental indicators in both research findings are still far above the economic impacts.

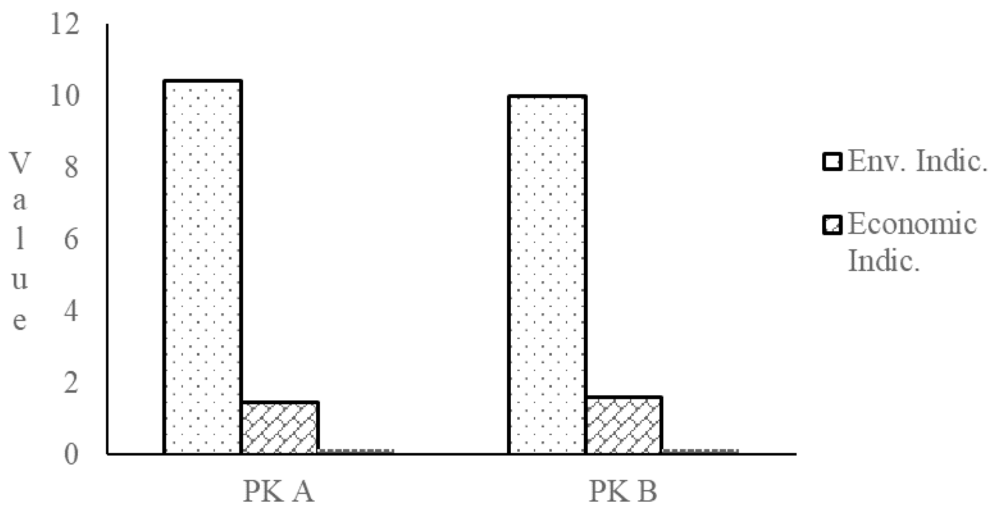

Figure 4. Environmental indicator, economic indicator, and green productivity index (GPI) of Tanneries A and B

Alternative Strategies for Green Productivity Improvement

A GP improvement strategy is derived from chosen alternatives to waste management based on the GPI value. Based on the literature study, five such alternatives that would improve the GPI value in Tanneries A and B were formulated. The alternatives are described in the following sections.

Alternative 1: Water Recycling

Water consumption in the beamhouse and during the tanning process comprises ~50% of total tannery water consumption [31]. Soaking and liming processes are the highest water consumers and accounted for 37% in Tannery A and 47% in Tannery B; therefore water-recycling techniques must be implemented to rationalize total water consumption by the tannery. In addition, reducing water consumption will reduce the volume of liquid waste. Countercurrent recycling techniques at the soaking stage can decrease water usage by up to 67% of its total water consumption. The physical properties of the leather produced using this method are proportional to the leather processed using the current processes [31, 32]. Hides move in a direction opposite that of the water. Counter-soaking schemes at Tanneries A and B are presented in Figure 5. Water recycling during the liming process also promotes a decrease in water consumption. Money and Adminis (1974) [33] conducted a study in which they reused water containing lime and sodium sulfite from the liming process more than 20 times and showed that there was a 20-fold overall reduction in water consumption. Nazer *et al.* (2006) [34] used the same technique with four cycles and reduced COD emissions by 24%, and saved water, sulfite, and sulfate by 50%, 46–76%, and 26–73%, respectively.

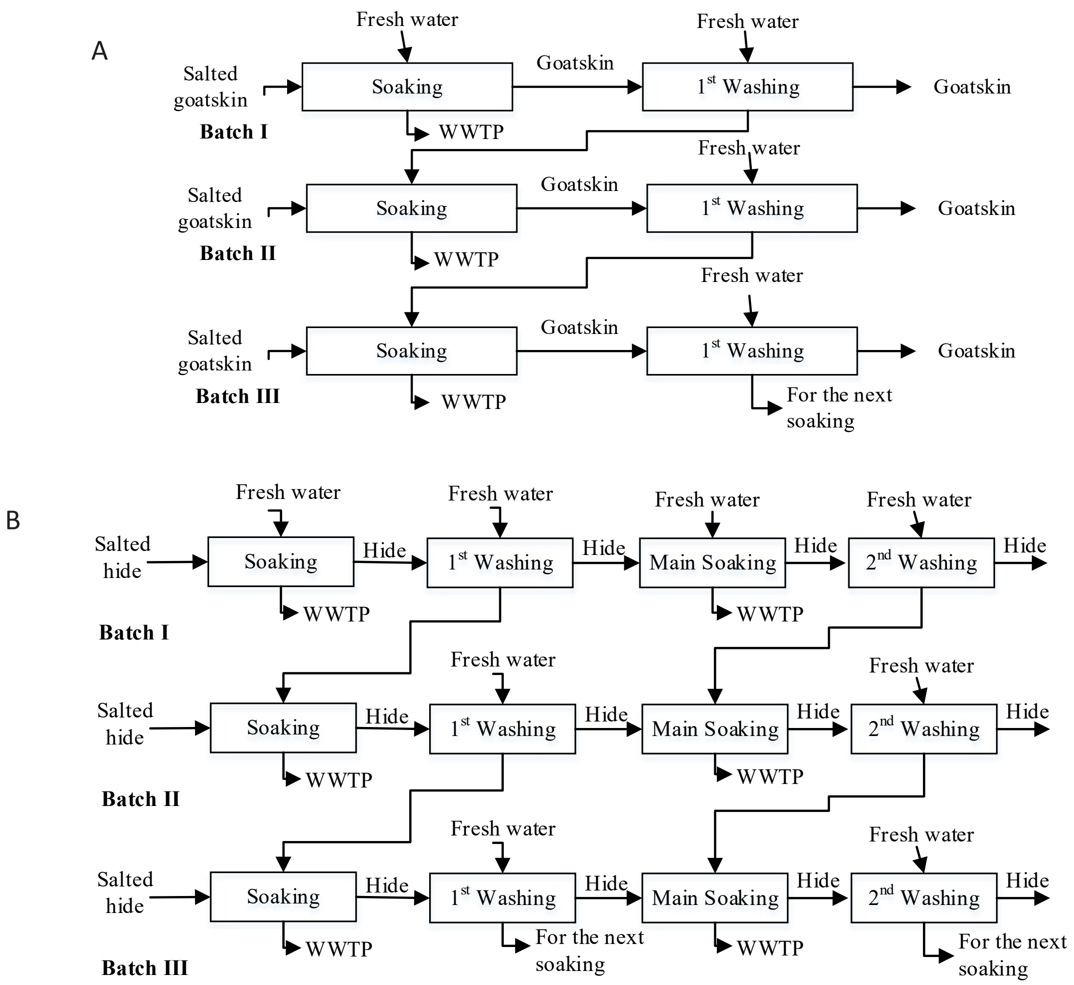

Figure 5. Countercurrent soaking scheme at Tannery A and Tannery B

According to IUE (2008) [32], this technique can save ≤40% of sodium sulfide and ≤50% lime while reducing COD by 30–40% and the nitrogen in liquid waste by 30%; however, the application is labor intensive because it requires a high level of control. In addition, this technique requires filtrating suspended materials, adjusting the temperature, and adding lime, sulfite, and water. The quality of the resulting leather could be negatively affected if there is any lack of control during this procedure because the suspended melanin and insoluble pieces of cuticle from the soluble part of the hair would be pushed into the grain by the equipment, resulting in a dirty product [32,33].

According to Rao *et al.* (2003) [31], countercurrent techniques can be applied to the liming process. In this technique, the water to be reused comes from washing the previous batch, while the used water from the liming process is directly discharged to WWTP. This technique is convenient because the washing process is done only by adding water; therefore, the water is easier to use in the liming process. By applying this technique, water consumption would be reduced by 50%. The schemes for implementing countercurrent water recycling during liming at Tanneries A and B is are shown in Figure 6. By applying this alternative at Tannery A, it is predicted that the value of environmental indicators would be reduced to 8.126. This reduction would be the result of reduced water consumption and a decrease in the total value of COD in the effluent, both of which have significant effects on decreasing environmental impacts. The GPI calculation for this alternative at Tannery A is 0.178. At Tannery B, this alternative is predicted to reduce the value of the environmental impact to 8.087 and increase the GPI value to 0.197.

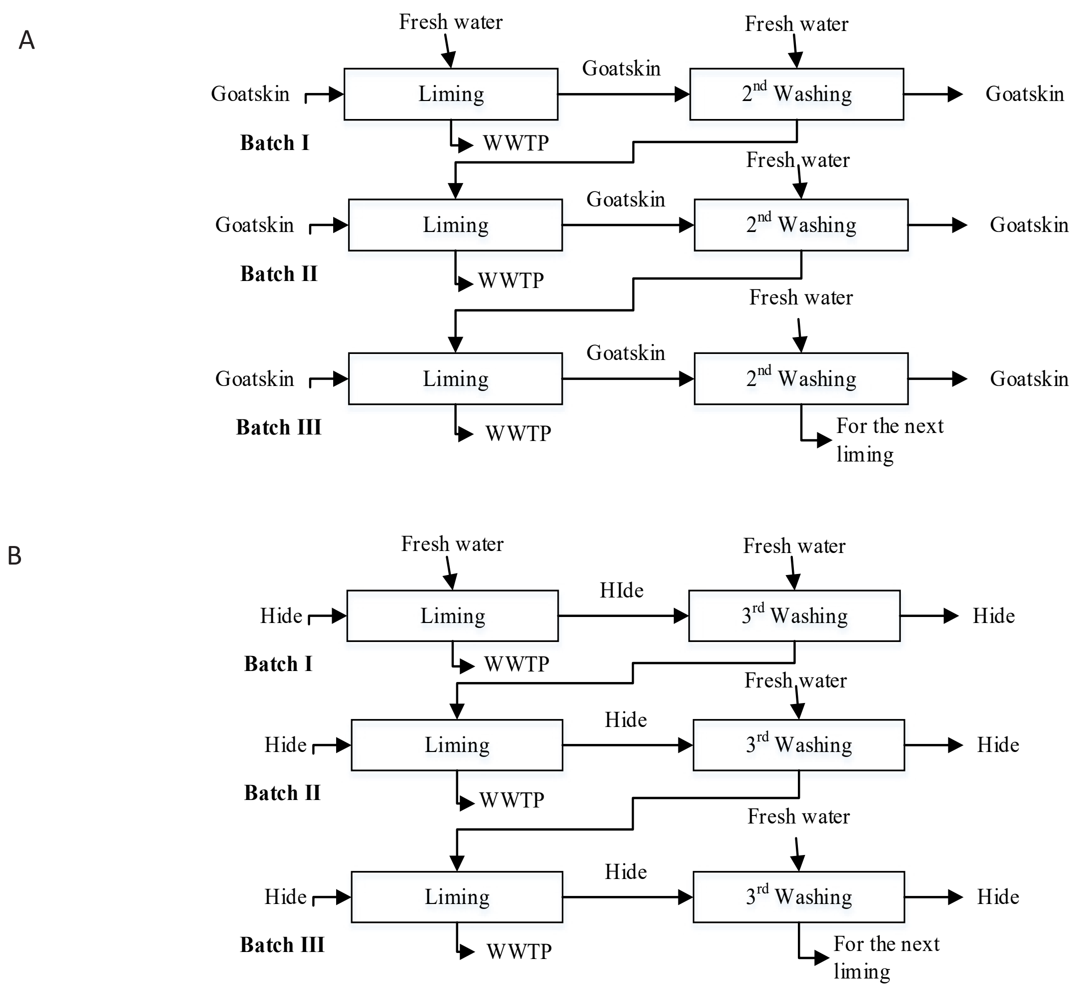

Figure 6. Countercurrent liming at Tannery A and Tannery B

Alternative 2: Using the Shaving Scraps

Scraps from shaving contribute 47% to total emissions at Tannery A, which is a result of these wastes not being fully utilized and being openly burned. According to Mardliyan (2014) [35], shaving scraps can be sold to a leather board manufacturer for Rp1500/kg. If this alternative is adopted at Tannery A, there would be a reduction in the environmental impact indicator to 10.341 and a slight improvement in the economic indicator to 1.449; however, the overall improvement in the future GPI value that would be very small compared with that of only 0.140 under initial conditions. This option is not necessary at Tannery B because the shaving scraps are used as filler in manufacturing footwear.

Another possible solution is to incorporate the shaving scraps into other products to add value and realize a more significant economic improvement. Leather scraps are composed of collagen, which can be extracted into collagen hydrolysate. Collagen hydrolysate has high economic potential and can be used in various products [36, 8], such as polycondensate adhesive substitute [37], biodegradable film [38], microencapsulated polymers [39], and superabsorbent hydrogels [40-42]; however, there is no company that performs hydrolysis; therefore, collagen hydrolysate cannot yet be efficiently extracted from the scraps for using in making these various products.

Alternative 3: Chrome Recovery

Tanneries A and B use chromium tannin as the main tanning chemical. For a one-time production process with a capacity of 1500 kg salted hides, Tannery A consumes ~65 kg chromium while Tannery B consumes ~47 kg. The results of research by Wiegant *et al*. (1999) [43] showed that only ~70% of the chromium can bind to the hide's collagen, leaving ~30% that is dissolved and discharged with liquid waste. The chromium(III) oxide (Cr_2O_3) contained in the wastewater is not toxic; however, if not immediately treated, it can oxidize into chromium(IV) dioxide (CrO_2), which is carcinogenic under acidic conditions, when exposed to heat and sunlight [44], and when reacting with oxidizing agents, such as MnO_2 [45] and chlorine, to then contaminate the groundwater [46]. From one production batch, 19.7 kg chromium waste is produced at Tannery A and 14.2 kg at Tannery B. With the chrome tanning price of ~Rp20,000/kg, it is worth Rp394,000 at Tannery A and Rp284,000 at Tannery B.

Cr_2O_3 in liquid tanning waste can be recovered for the next tanning process using a fairly simple treatment. Using this approach, Wiegant *et al*. (1999) [43] recovered and reused chromium in the tanneries in the Kanpur region of India. First, the liquid waste from the tanning process is filtered to separate the impurities. Organic materials contained in tanning wastes (fats, syntans, and high-fixation auxiliaries) can sometimes cause problems, such as grayish shades and color inconsistency, in high-quality leather production; therefore, the production staff must ensure that the fat content is within the maximum range of 45 mg/L. The dissolved chromium in the liquid waste is precipitated by adding magnesium powder or slurry at pH 8–9 and stirring for ~3 h, after which the sludge formed is separated from the liquid. The sludge is then dissolved in sulfuric acid concentrate and reused in the next tanning process [47]. This technique has also been tested by [47] and [48] using wet blue leather that has the same quality as the normal process, with 70% chrome recovery and 30% fresh chrome. A simple flow chart of this process is shown in Figure 7. The total number of chromates that could be recovered from this technique is ~23.3% of total chromium consumption [47].

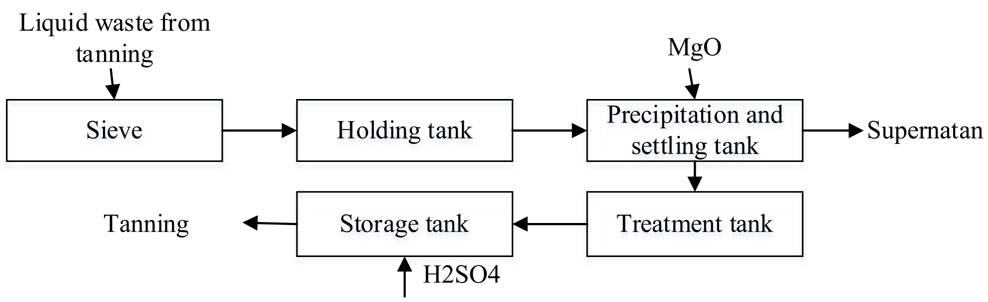

Figure 7. Flow diagram of chrome recovery

Applying this alternative is estimated to save ~Rp301,415/batch at Tannery A and ~Rp225,012/batch at Tannery B. In addition, there would be a slight increase in economic indicators to 1.451 at Tannery A and 1.492 at Tannery B. There would also be a slight decrease in environmental indicators to 10.403 at Tannery A and 9.983 at Tannery B. The environmental indicator value would not be significantly different from that under initial conditions so that an increase in GPI value would be nearly negligible or remain at 0.139 at Tannery A and 0.161 at Tannery B.

Alternative 4: Salt Recovery

Salting is the most widely used technique throughout the world to preserve hide and skin. Salt is generally inexpensive, widely available, and has good dehydration properties. Salt dispersed onto the surface of the skin/hide is expelled during soaking and discharged along with the liquid waste, which contributes to an increase in total dissolved solids (TDS). An alternative is to thresh the hide before soaking to remove some of the salt. The salt remaining after threshing the salted hide before soaking can be reused in the pickling process. This will beneficially reduce the amount of TDS in the liquid waste.

Salt was recovered from salted hide by tanneries in India during 1997–1998 under the United Nations Industrial Development Organization (UNIDO) program. Finished leather from the utilization of residual salt in the pickling process was of the same quality as that made from fresh salt. There are two ways that salt can be threshed form the skin—by using the conventional method and by using a DODECA table designed by UNIDO. Manual threshing involves holding the side of the hide and hitting it two or three times on the surface of a table. According to the workers, this technique is uncomfortable and exhausting [49]. Threshing using a DODECA table is done in a similar way; however, the DODECA surface is designed in such a way that makes it easier to remove the salts, resulting in an increase in salt release from 5% to 8%.

The salt recovery for the pickling process can reducing the consumption of fresh salt by ≤50%. The residual salt obtained from this process is first purified by preparing a 12% solution and then filtered to separate hair, tissue, sand, and other insoluble materials. The filtrate is then mixed with 300 mg/L polyaluminum chloride and 2 mg/L polyelectrolytes and allowed to stand for 4–6 h. This solution can be used in the pickling process up to 50%. The process must be controlled to ensure that the salt concentration is at 80° Bé. The recovery of residual salt is highly feasible and the process has been done at tanneries in India. If this alternative is implemented, it is estimated to save Rp117,250/batch at Tannery A and Rp194,050/batch at Tannery B. There would be a slight increase in economic indicators to 1.446 at Tannery A and 1.603 at Tannery B and a decrease in the environment indicator to 10.399 at Tannery A and 9.979 at Tannery B; however, GPI value would remain the same as that under current conditions.

Alternative 5: Constructed Wetlands for Wastewater Treatment

Treating wastewater using a constructed wetland (CW) system is a technique that can potentially be applied at Tannery A, which is without WWTP, because it is efficient, inexpensive, and powerful [50]. CW have been widely used to treat various forms of liquid waste, such as industrial, rural household, urban household, and nonpoint-source pollutants [51-53]. Tannery A is classified as an SME; therefore, a simple and inexpensive treatment for liquid waste is needed. A CW system connected to a plant is an important element that plays a role in processing liquid waste. Together with animals and microorganisms that live in the water and filler, CW has a unique flora and fauna environments. When liquid waste flows into a CW system, it is purified through filtration, adsorption, sedimentation, ion exchange, plant absorption, and microbial decomposition [50].

The wastewater from a tannery is usually turbid and malodorous because it generally contains meat and blood remnants, lime slurry, fluff, dissolved protein, salt residue, acids, residual paints, and Cr_3O_2. Cr_3O_2 can be oxidized to CrO_2, which has a toxicity rate 10–100 times that of Cr_3O_2 [54]. USEPA has classified CrO_2 as one of 17 chemicals toxic to humans, and it is considered to be one of 20 contaminants that must be addressed before being discharged into the environment.

CW plants play an important role in processing wastewater. Various plant species are known to have the ability to absorb and accumulate various types of toxic metals, phenolic compounds, azo dyes, and various other organic and inorganic contaminants. Among the CW plants, *Typha domingensis* and *Borassus aethiopium* have the highest chromium removal efficiency of 99%, *Phragmites australis* has the highest ammonium removal efficiency of 82.5% [55], and *Phragmites* (reeds) species have the highest COD removal efficiency 85% [56]. Research by Calheiros *et al*. (2007) [57] has shown that *T. latifolia* and *P. australis* propagation is highly adaptable in liquid waste from a tannery. The horizontal subsurface flow type of CW systems is recommended for use with tanneries because it is able to tolerate input fluctuations, including excess input. This characteristic is very important because, in general, the production capacity of SME tanneries in Indonesia fluctuates throughout the year. If this option is implemented and COD is reduced by 70%, the environmental indicator would increase to 8.902, but GPI would remain the same as that under current conditions.

Selection of GP Improvement Strategy Using the GP Ratio

The GP ratio is an instrument that could be useful in the process of decision making to improve GP by helping to determine whether one alternative is superior to current conditions and other alternatives. GPI and GPI ratio calculations for each alternative at Tanneries A and B are presented in Table 5.

Table 5: Comparison of the alternatives by green productivity index value

Alternatives	Tannery A				Tannery B			
	EI	Env. Indicator	GPI	GP_{ratio}	EI	Env. Indicator	GPI	GP_{ratio}
Current condition	1,44	10,41	0,14	-	1,60	9,99	0,16	-
Alternative 1	1,44	8,13	0,18	1,28	1,60	8,09	0,20	1,23
Alternative 2	1,45	10,34	0,14	1,01	-	-	-	-
Alternative 3	1,45	10,40	0,14	1,00	1,61	9,98	0,16	1,01
Alternative 4	1,45	10,40	0,14	1,00	1,60	9,98	0,16	1,01
Alternative 5	1,44	10,36	0,14	1,00	-	-	-	-
Combination	1,46	8,03	0,18	1,31	1,61	8,08	0,20	1,24

Based on the calculations, the GP ratio for all alternatives except alternative 4 is >1 at Tannery A. It expected that applying these alternatives would improve green productivity at both tanneries. The same method is applied in the calculation of the economic indicator ratio (EI ratio) and the environmental indicator ratio (Env. I ratio), as presented in Table 6.

Table 6: Comparison of alternatives by green productivity (GP) ratios

Alternatives	Tannery A			Tannery B		
	EI *ratio*	Env. I *ratio*	GP *ratio*	EI *ratio*	Env. I *ratio*	GP *ratio*
Alternative 1	1,000	0,781	1,281	1,000	0,810	1,231
Alternative 2	1,004	0,994	1,007	-	-	-
Alternative 3	1,006	1,000	1,000	1,005	0,999	1,006
Alternative 4	1,002	0,999	1,000	1,004	0,999	1,006
Alternative 5	1,000	0,995	1,000	-	-	-
Combination	1,011	0,772	1,309	1,009	0,809	1,244

Recycling the water (alternative 1) at both tanneries improves the environmental performance but not the economic performance because the EI ratio is 1. On the other hand, using shaving scraps more efficiently (alternative 2) at Tannery A improves both the economic and environmental performance, although still lower than that of alternative 1. Applying a combination of all alternatives at both tanneries results in the highest GP ratio with a higher increase in economic and environmental performance.

The GP portfolio or GP ratio is illustrated by plotting the EI and Env ratios. The GP portfolio is helpful for identifying the strengths and weaknesses of the existing alternatives [58]. Figure 8 and Figure 9 show the GP portfolio for Tanneries A and B, respectively, where the reciprocal ratio of environmental performance between the alternative and the current process is plotted against the ratio of economic performance between the alternative and the current process. If an alternative solution lies above the dotted curve, it is considered to be better than the current practice. An alternative that is located in quadrant 1 is considered to be favorably profitable from an economic and environmental perspective. The most favorable alternative is located in the upper right quadrant and the most unfavorable is located in the lower left quadrant of the portfolio [20].

In the GP portfolios for both tanneries, all alternatives are located in quadrant 1, which means that these are positive alternatives to current operations from an economic and environmental perspective. The most advantageous alternative is located at the top of the right quadrant and the least advantageous in the bottom left quadrant. These alternatives are more favorable from an environmental perspective than an economic perspective because they lie above the diagonal line in quadrant 1. Alternatives 1 and 5 at Tannery A and alternative 1 at Tannery B predict an improvement in environmental impacts but no improvement in economic impact, which means that they would increase environmental performance but not economic performance. On the other hand, alternatives 2, 3, and 4 at Tannery A and alternatives 3 and 4 at Tannery B would result in improvements of both environmental and economic performance, but it is still lower than alternative 1 at both tanneries. From both portfolios, we can conclude that alternative C, which is a combination of all alternatives, at both Tanneries A and B is the best solution because it improves both environmental and economic performance.

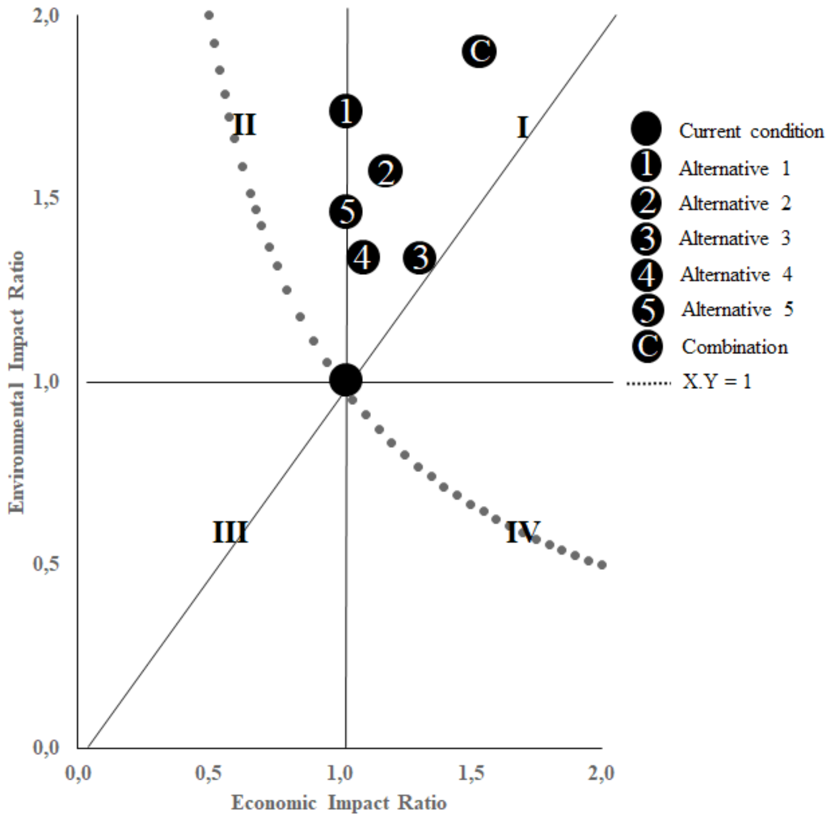

Figure 8. Green productivity portfolio of alternatives at Tannery A

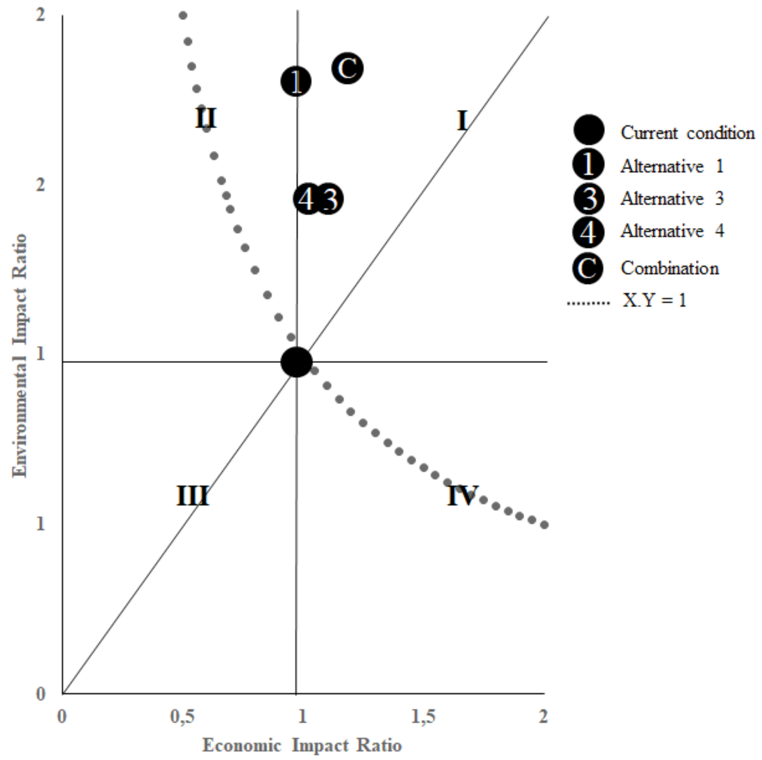

Figure 9. Green productivity portfolio of alternatives at Tannery B

Green Productivity Improvement Strategy for Small to Medium Tannery

AHP was used to determine the most applicable alternative for the SME tanneries. The AHP model can be used to calculate the weights of each quantitative and qualitative criterion [59]. Its development comprised four levels—goals, objectives, criteria, and alternatives. The most applicable alternative based on expert opinion is water recycling. Water recycling contributes more to increasing GP at the tanneries than any other alternative. Nevertheless, the other alternatives, even though they have a lower weight, might also increase GP; however, the impact would be lower compared to those from the selected alternatives.

The results of the AHP method and the GP portfolio for selected alternatives are not the same. In the opinion of experts, alternative C has the lowest weight and would require a high investment and high maintenance costs. This alternative would be too difficult for SMEs to implement. The GPI and GP ratio measurements show that water recycling provides the second highest improvement after alternative C. When independently compared to each alternative, water recycling has the highest impact on reducing environmental impacts; therefore, it is the best alternative for improving GP at both tanneries.

CONCLUSIONS

The leather-tanning processes at Tannery A result in 535.81 KWh energy consumed, 19,965.57 L water consumed, 430.54 kg material used, 1,584.21 kg garbage produced, 0 km transportation, and 416.82 kg emissions. The GPI calculation at Tannery A was 0.14. The leather-tanning processes at Tannery B result in 355.48 KWh energy consumed, 19,765 L water consumed, 291.76 kg material; 575.63 kg garbage produced, 0 km transportation, and 24.25 kg emissions. GPI at Tannery B was 0.16. The GP levels at both tanneries were insufficient because many resources, especially water, were not being optimally utilized. Using large quantities of water has an impact on the amount of liquid waste that is generated.

To increase the GPI value at both tanneries, six alternatives were developed for Tannery A and four for Tannery B as follows: water recycling in soaking and liming, using shaving scraps, recovering chromium, recovering salt, constructing CW for liquid waste treatment, and a combination of all of these strategies. Based on the highest GPI ratio, alternative C was chosen for Tanneries A and B. By applying this selected alternative, the GPI value at Tannery A would increase to 0.18 and to 0.20 at Tannery B. In the future, studies are needed on the implementation of the selected GP improvement strategies in the leather industry.

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