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Environmental Impact Analysis of Leather Production Using The Life Cycle Assessment and Analytical Network Process Methods

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A B S T R A C T

The leather industry is one of the fields that produces hazardous waste for the environment. One example is CV XYZ, a leather manufacturing company based in East Java, Indonesia. Liquid waste produced per production batch is over 4,000 liters and the electricity consumed is a maximum of 5,000 kWh per month. This study focuses on the environmental impacts in the leather production process of the CV XYZ using the Life Cycle Assessment (LCA) method. Additionally, the Analytical Network Process (ANP) method is used to select alternative improvements given that it minimizes environmental impact. The method of research used in this study is descriptive quantitative, and the source of primary data is interviews and questionnaires, while that of secondary data comprises a company report. The data were processed with SimaPro software and using the Eco Indicator 99 method. The results of the study suggest that the greatest impact on the environment is respiratory inorganic, with a value of 221.69 Pt, being caused by the process of chrome tanning due to the application of the process based on the use of chromium fuel, using a chrome raw material. As an alternative improvement to reduce chrome tanning waste content in chromium, the addition of coagulants CaO and FeCl3 is prioritized. To do so, this study underscores how handling the environmental impacts in the leather industry in a clean production way is to preserve human health and the ecosystem of the places around this industry while attempting to achieve this objective.

INTRODUCTION

It is a manufacturing sector with huge growth in the leather industry and medical equipment which take its place in the global economy (Wudu et al., 2024). The Indonesian leather manufacturing and associated products and footwear sector achieved gross domestic product growth from 28.6 trillion rupiahs in 2014 to 48.1 trillion rupiahs in 2022 (Putrawan et al., 2024). Economic growth is achieved through the leather tanning industry at both a local and global level, but this industry also has the potential to cause huge environmental and health hazards (Tasca & Puccini, 2019). The growth has also resulted in the generation of more waste as a result of leather production processes (Nazir et al., 2025). From the upstream (livestock farming, slaughtering, animal transportation), to the downstream (managing of tanning waste), there is a number of activities that will cause concern. (Marrucci et al., 2022). Water and chemical usage is the primary environmental issues in leather production (Puhazhselvan et al., 2017), and such materials are often overused to penetrate the leather (Ardolino et al., 2024). For instance, chromium as a hazardous element is used (Venkatesan et al., 2021), The tanning process also places surfactants, and organic solvents which will have a negative effect on the environment, contributing to environmental degradation (China et al., 2020; Wu et al., 2020). The discharge of untreated wastewater from tanning facilities causes severe environmental pollution near its surrounding areas (Nigam et al., 2023)

Carrier of one of the most ecologically aggressive and resource-guzzling industries (Syabani et al., 2019; Wrzesinka-Jedrusiak et al., 2023). About 0.25 mg of leather is produced from 1 mg of raw material, resulting in approximately 15–50 mg of wastewater and 400–700 kg of solid waste with associated water use of ~15,000 – 1,20,000 m³. Leather production also produces odors and greenhouse gas emissions (CO_2, H_2S, NH_3) as well as VOC including amines, hydrocarbons, and aldehydes (Chojnacka et al., 2021). Being a product with a complex production process, the leather industry tends to generate hazardous waste and greenhouse gas emissions that have a negative impact on the environment when not properly handled (Tiwari & Pal, 2022; Xu & Yang, 2022).

Tanneries generate varied amounts of solid waste depending on the type of process in the tannery and the final product tanned (Rimantho et al., 2024). One tonne of crude hides is estimated to produce between 339 and 459 kg of solid waste by trusted sources. This waste is of this waste, 25 percent contains chromium, and 75 percent is solid waste free of chromium or solids suspended in wastewater (Ahmed & Maraz, 2023).

These potentially harmful environmental impacts mean that the leather industry has enormous work to do in transitioning from dirty to cleaner production (Mengistu et al., 2024). Measures that can be taken include the use of water and chemicals in a way that minimizes the use of non-renewable resources, safe working conditions, and no release of harmful substances into the environment (Aquim et al., 2019). Nowadays, the leather industry should not omit its responsibility for business performance but the environment and pollution must be taken into account so as to support global sustainability in the future (Islam et al., 2024).

CV XYZ is a manufacturing company that uses sheep's and goats' hides in the capacity of finished sheet leather for the purpose of making bags, wallets, belts, etc. Maintaining both the amount and quality of the company products, as well as implementing more environmentally friendly production practices is a considerable challenge that the company is facing. Leather production for CV XYZ annually needs 96,000 pickle hides. About 1 million liters of water and 5,000 kWh of electricity per month is used for its machinery to produce while it also consumes the production process. Further, for the transportation of raw materials and the distribution of products, diesel-driven trucks are used by CV XYZ and thus it emanate air emissions. Research conducted by (Hoyo & Pinto, 2008) that 1 liter of diesel fuel equals 2.6 kg of CO_2. One greenhouse gas that causes global warming is CO_2, 13.6478% increase in CO_2 emissions from vehicles results in a 29.048% increase in global temperature (Donald et al., 2025). CV XYZ has yet to do a complete assessment of the waste and emissions it produces from its operations. If these issues are not mitigated with a careful evaluation of its leather production activities this could damage the local ecosystem as well as endanger the operational sustainability of the company in the future (Shi et al., 2024).

The solution to overcome all these challenges is to implement a Life Cycle Assessment (LCA). LCA is a technique used to assess the environmental effect of the product over the whole life cycle (Aziz et al., 2022; Fahlstedt et al., 2024). It assists in choosing eco-friendly production processes of the system and also helps identify critical from of the environmental system (Ramon et al., 2024). Additionally, the Analytical Network Process (ANP) method can be used to facilitate the decision process of chemical construction CV XYZ to transform its production processes into a more eco-friendly pattern (Keyvanfar et al., 2021).

Life Cycle Assessment (LCA) has already been the subject of extensive previous studies on evaluating environmental impacts in the leather industry (Abagnato et al., 2024; Brugnoli et al., 2025). Instead, however, this approach tends to focus on impact identification without providing strategic priorities for improvement. The ANP method facilitates more effective and realistic decision-making by considering both interdependencies within and between groups, as well as feedback among criteria (Santos & Fernandes, 2023; Topaloglu, 2024), However, it is rarely used in assessing the sustainability of leather production. The novelty of this study is the joint application of LCA and ANP methods in the environment assessment of leather products. This study seeks to fill this gap by combining LCA and ANP to quantify the environmental impacts while determining priorities to the potential for improvement from data such as that for the CV XYZ. One limitation of this research is that the environmental impacts of raw material delivery, leather processing, and product distribution processes are assessed. The process of any supplier or buyer is not inside the scope of this assessment; instead, it only looks at the business' operations. In addition, the vehicle emissions calculated are captured for truck emissions and are not global emissions.

Thus, this research aims to evaluate the environmental impacts generated by the operations of the leather manufacture of CV XYZ through Life Cycle Assessment (LCA) and superimpose Analytical Network Process (ANP) to determine strategic priorities in the field of sustainability improvements. This integration will allow the company to provide comprehensive data-driven recommendations.

MATERIALS AND METHODS

Location and Research Object

The research was conducted at CV XYZ, located in Sidoarjo, East Java, Indonesia. The research object is the finished leather sheets made from sheep and goat hides, which serve as the company's primary commodity. The study focuses on the supply chain areas, including raw material transportation, leather processing, and product distribution.

Data Collection Methods

The methodology is to collect secondary and primary data. Data were collected through interviews as well as observations of on-site activities and secondary data were gathered from the company's operational reports. Material input and product output data for each process is to be collected along with distances between the company and its suppliers and customers, and electricity consumption data for each machine, as well as diesel consumption for raw material transportation and product distribution for trucks.

The leather production process at CV XYZ involves three main stages: Figure 1 illustrates pre-production (raw material delivery), production (leather processing), and post-production (product distribution).

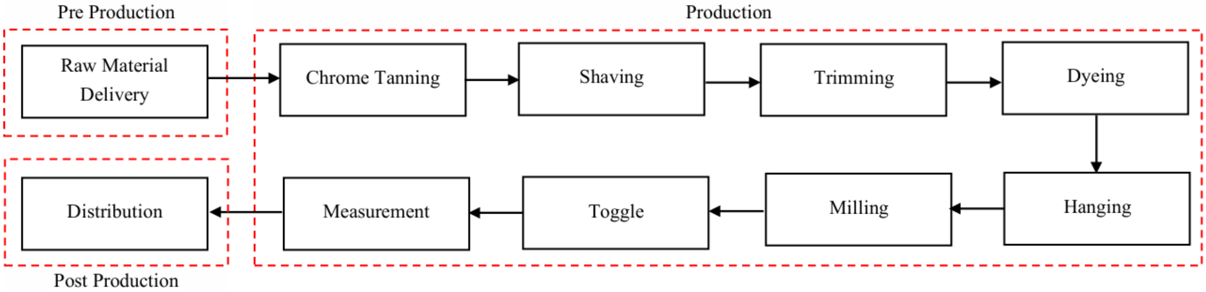

Figure 1. Leather Production Process

Data Analysis Method

The analysis was carried out using the Life Cycle Assessment (LCA) approach, which involved several stages: This involved setting the goal and scope, compiling a life cycle inventory, and performing an impact assessment with the Eco Indicator 99 framework in SimaPro software. The results were then interpreted to offer insights and provide conclusions about the overall environmental impact, along with suggesting potential improvements (Mohamed et al., 2024; Rosyidah et al., 2020).

The Analytical Network Process (ANP) was also applied to determine the priority ranking of different improvement options (Masudin et al., 2024). This involved constructing a network model, administering questionnaires, evaluating a series of pairwise comparison matrices, and computing the supermatrix to identify the most prioritized alternatives (Musyarofah et al., 2025). Super Decision software supports this ANP process. Based on the analysis results, recommendations are made to aid the sustainability of CV XYZ's supply chain.

RESULTS AND DISCUSSION

To value the environmental impact of leather production at CV XYZ, this study employs the Life Cycle Assessment (LCA) method. It covers a process for receiving raw materials; chrome tanning; shaving; trimming; dyeing; and distribution from the stage of goal and scope definition through life cycle inventory, impact assessment, and interpretation.ct distribution, following the stages of goal and scope definition, life cycle inventory, impact assessment, and interpretation.

Goal and Scope Definition

The primary goal of the Life Cycle Assessment (LCA) in this study is to identify and evaluate the environmental impacts of the leather production process at CV XYZ. The LCA results provide quantitative data that assist CV XYZ in formulating policies to minimize greenhouse gas emissions, optimize resource utilization, and promote the sustainability of the leather production supply chain. The company can ensure its operations align with global sustainability principles. The scope of the study covers a cradle-to-gate process, including raw material transportation, leather processing, and product distribution, excluding activities performed by suppliers and the end-use of products by consumers.

Life Cycle Inventory (LCI)

To conduct an LCI assessment, data must be inputted into the SimaPro software, including material and energy balances used in each process. These material and energy data represent the resources needed to produce 500 sheets of leather (one production batch). The LCI is prepared for each production station by calculating the amounts of input, output, and emissions generated.

In the raw material delivery process, the input data includes truck carrying capacity and diesel consumption. The transportation of raw materials (pickle leather) is carried out using a 16-ton capacity truck. The distance between the supplier and CV XYZ is 122.6 km. The diesel fuel consumption for the truck is assumed to involve the use of a truck with an optimal engine operating on the most efficient route. The diesel fuel requirement per kilometer is 0.2 liters. Each delivery transports 4,000 sheets of pickle leather, equivalent to 10 tons.

In the leather processing stages (chrome tanning, shaving, trimming, dyeing, hanging, milling, toggle, and measurement), the inputs required in SimaPro include data on the number of leather, water requirements, chemicals used, and electricity consumed by the machinery. The outputs required in SimaPro include the products generated from each process and emissions.

In the distribution process, the input data for SimaPro includes truck carrying capacity and diesel consumption. The distribution process uses a 5-ton box truck. The distance to the distribution destination is 277.8 km. The weight of the sheet leather transported per delivery is 1,750 kg, or equivalent to 1.75 tons. It is assumed that the truck used is an optimal engine truck traveling along the best route. The fuel consumption per kilometer is 0.14 liters. Overall, the LCI table for leather production is presented in Tables 1-10.

Table 1. LCI of Raw Material Delivery

Input			Output		
Materials	Quantity	Unit	Materials	Quantity	Unit
Carrying capacity of pickle leather	1,226	tkm	Carrying capacity of pickle leather	1,226	tkm
Diesel	49.04	Liter	Nitrogen oxide (NOx)	1.938	Kg
			Methane (CH_4)	0.012	Kg
			Non-Metal Volatile Organic Compound (NMVOC)	0.388	Kg
			Dinitrogen monoxide (N_2O)	0.008	Kg
			Carbon monoxide (CO)	1.735	Kg
			Carbon dioxide (CO_2)	143.438	Kg

This table presents the input and output data from the transportation process of pickle leather to CV XYZ using a 16-ton truck. The data includes diesel consumption and emissions such as NOx, CH_4, NMVOC, N_2O, CO, and CO_2. Vehicle emissions are calculated based on IPCC emission factors, assuming optimal engine performance and route efficiency.

Table 2. LCI of Chrome Tanning

Input			Output		
Materials	Quantity	Unit	Materials	Quantity	Unit
Pickle leather	500	Sheet	Wet blue leather	500	Sheet
Water	5,000	Liter	Chrome tanning wastewater	4,250	Liter
Sodium/Salt (NaCl)	8	Kg	BOD	1.564	Kg
Basic chromium sulfate ($Cr_2(SO_4)_3$)	90	Kg	Chromium	0.0521475	Kg
Syntetic oil	6.25	Kg	COD	0.021182	Kg
Magnesium oxide (MgO)	7.5	Kg	TSS	2.1335	Kg
Sodium bicarbonate ($NaHCO_3$)	10	Kg			
Anti-Fungus	1.25	Kg			
Electricity	50	kWh	Carbon dioxide (CO_2)	43.5	Kg

Table 2 presents the Life Cycle Inventory (LCI) for the chrome tanning process, where 500 sheets of pickle leather are processed into wet blue leather. This stage involves significant resource inputs, including 5,000 liters of water, 90 kg of basic chromium sulfate, and various chemicals such as sodium chloride, magnesium oxide, and anti-fungal agents. Electricity consumption during this stage is recorded at 50 kWh. The outputs consist of 4,250 liters of chrome tanning wastewater and emissions such as BOD, COD, TSS, chromium, and CO_2.

Table 3. LCI Shaving

Input			Output		
Materials	Quantity	Unit	Materials	Quantity	Unit
Wet blue leather	500	Sheet	Thinned wet blue leather	500	Sheet
Electricity	56	kWh	Carbon dioxide (CO_2)	48.72	Kg

Table 3 presents the shaving stage in the leather production process, where 500 sheets of wet blue leather are thinned to the desired thickness. This mechanical process consumes 56 kWh of electricity and produces 48.72 kg of CO_2 emissions. Although no materials are added, electricity use contributes to the environmental footprint, particularly through greenhouse gas emissions.

Table 4. LCI of Trimming

Input			Output		
Materials	Quantity	Unit	Materials	Quantity	Unit
Thinned wet blue leather	500	Sheet	Neat wet blue	500	Sheet
			Waste pieces of wet blue leather	50	Kg

Table 4 illustrates the trimming process, where the thinned wet blue leather is refined into neatly shaped sheets. The process generates 50 kg of waste pieces from 500 sheets of input material. This stage does not consume additional energy or chemicals but contributes to the total solid waste generated during production.

Table 5. LCI of Dyeing

Input			Output		
Materials	Quantity	Unit	Materials	Quantity	Unit
Neat wet blue	500	Sheet	Colored leather	500	Sheet
Water	2,500	Liter	Dyeing wastewater	1,750	Liter
Dyes	10	Kg			
Fixative agents	2.5	Kg			
Acetic acid	1.25	Kg			
Surfactants	0.75	Kg			
Retaining agents	2.5	Kg			
Fatliquors	7.5	Kg			
Electricity	30	kWh	Carbon dioxide (CO_2)	43.5	Kg

Table 5 describes the dyeing stage, where 500 sheets of neat wet blue leather are processed into colored leather. The process uses 2,500 liters of water and various chemicals including dyes, fixatives, acetic acid, surfactants, retaining agents, and fat liquors, along with 30 kWh of electricity. The outputs include 1,750 liters of dyeing wastewater and 43.5 kg of CO_2 emissions. This stage significantly contributes to water pollution and air emissions, especially due to chemical-intensive inputs such as fat liquors.

Table 6. LCI of Hanging

Input			Output		
Materials	Quantity	Unit	Materials	Quantity	Unit
Wet leather	500	Sheet	Dry leather	500	Sheet

Table 6 describes the hanging process that represents the initial drying stage in leather processing, where wet leather is air-dried to remove moisture content. According to the inventory data, 500 sheets of wet leather are used as input, resulting in 500 sheets of dry leather. This step is purely physical and does not require any energy input or produce any emissions, making it relatively environmentally benign compared to other stages.

Table 7. LCI of Milling

Input			Output		
Materials	Quantity	Unit	Materials	Quantity	Unit
Dry leather	500	Sheet	Softened leather	500	Sheet
Rubber ball	5	Kg			
Electricity	50	kWh	Carbon dioxide (CO_2)	43.5	Kg

Table 7 represents the Milling process, which is a mechanical operation aimed at softening dry leather to improve its flexibility and texture. The inputs for this stage include 500 sheets of dry leather, 5 kg of rubber balls, and 50 kWh of electricity. As a result, the process outputs 500 sheets of softened leather and generates 43.5 kg of carbon dioxide (CO_2) due to electricity usage. This stage is energy-intensive and contributes significantly to the overall environmental impact.

Table 8. LCI of Toggle

Input			*Output*		
Materials	Quantity	Unit	Materials	Quantity	Unit
Softened leather	500	Sheet	Loose leather	500	Sheet

Table 8 represents the Toggle process, where the softened leather is further processed into what is referred to as loose leather. The input consists of 500 sheets of softened leather, and the output is 500 sheets of loose leather. No additional materials, energy, or emissions are involved in this stage, indicating that it is a straightforward mechanical process with minimal environmental implications.

Table 9. LCI of Measurement

Input			Output		
Materials	Quantity	Unit	Materials	Quantity	Unit
Loose leather	500	Sheet	Measured leather	500	Sheet
Electricity	48	kWh	Carbon dioxide (CO_2)	41.76	Kg

Table 9 represents the Measurement process, which is the final stage in this sequence of operations. In this step, 500 sheets of loose leather are measured and prepared as finished material. The process consumes 48 kWh of electricity and results in 500 sheets of measured leather, while also producing 41.76 kg of CO_2 emissions. Despite its simple function, this stage still contributes to the carbon footprint due to its reliance on electricity.

Table 10. LCI of Distribution

Input			Output		
Materials	Quantity	Unit	Materials	Quantity	Unit
Carrying capacity of packed leather	486.15	tkm	Carrying capacity of packed leather	486.15	tkm
Diesel	77.784	Liter	Nitrogen oxide (NOx)	2.226	Kg
			Methane (CH_4)	0.019	Kg
			Non-Metal Volatile Organic Compound (NMVOC)	0.615	Kg
			Dinitrogen monoxide (N_2O)	0.612	Kg
			Carbon monoxide (CO)	2.751	Kg
			Carbon dioxide (CO_2)	227.51	Kg

Table 10 represents the Distribution process, where the transportation of packed leather is carried out over a total distance of 486.15 tonne-kilometers (tkm), using 77.784 liters of diesel fuel. While the same transport capacity is recorded as output, the process results in significant environmental emissions due to fuel combustion. These include 2.226 kg of nitrogen oxide (NOx), 0.019 kg of methane (CH_4), 0.615 kg of non-metal volatile organic compounds (NMVOC), 0.612 kg of nitrous oxide (N_2O), 2.751 kg of carbon monoxide (CO), and 227.51 kg of carbon dioxide (CO_2).

Life Cycle Impact Assessment (LCIA)

After processing the input and output of each Life Cycle Inventory process, the subsequent step involves the environmental impact evaluation of each process through Life Cycle Impact Assessment. In this stage, the calculation method used in SimaPro is Eco-Indicator 99 (E). Eco-Indicator 99 focuses on three main impact categories, which form the basis for evaluating environmental impacts: human health, resource depletion, and ecosystem quality. This comprehensive approach allows for a deeper understanding of the environmental effects associated with each stage of the lifecycle, ensuring a more sustainable and informed decision-making process.

Sankey Diagram

The Sankey diagram illustrates the movement of quantities (materials and energy) to identify the most impactful parts of the process. It helps to track the distribution and consumption of resources. The Sankey diagram is presented in Figure 2.

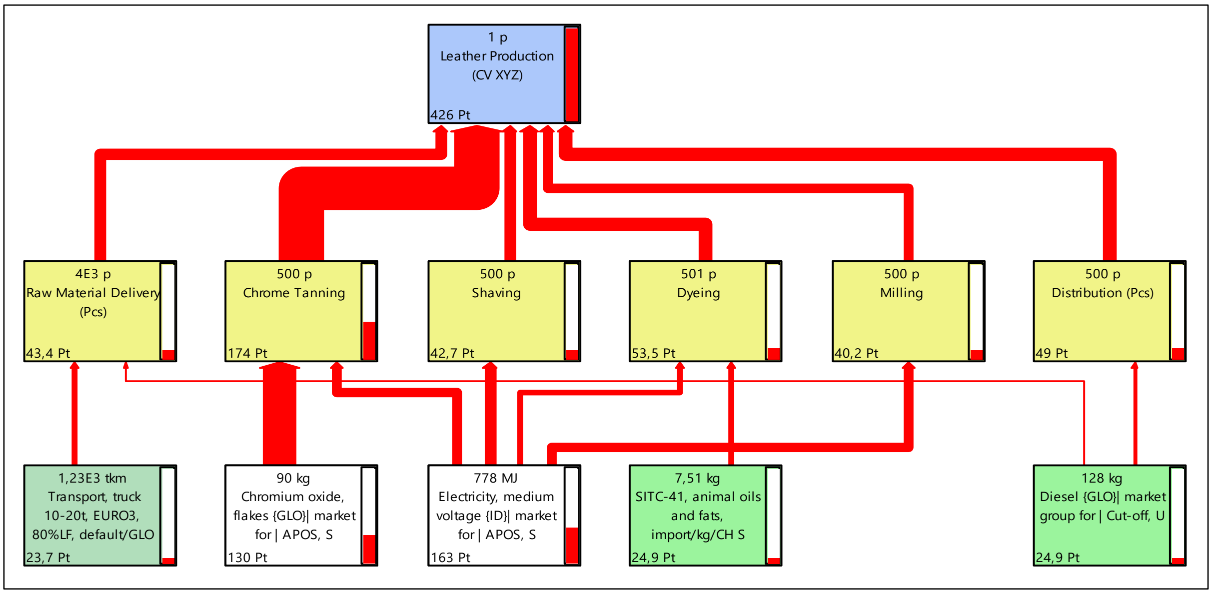

Figure 2. Sankey Diagram

Based on the Sankey diagram in Figure 2, the total environmental impact of leather production at CV XYZ is 426 Pt. The most impactful process is indicated by the thickest red arrow, which is chrome tanning with an impact of 174 Pt, attributed to the use of 90 kg of chromium material.

Characterization

Characterization is the stage where LCI results are directly compared across different categories. The aim is to provide values showing the overall impact of the process. The results of the characterization are presented in Figure 3.

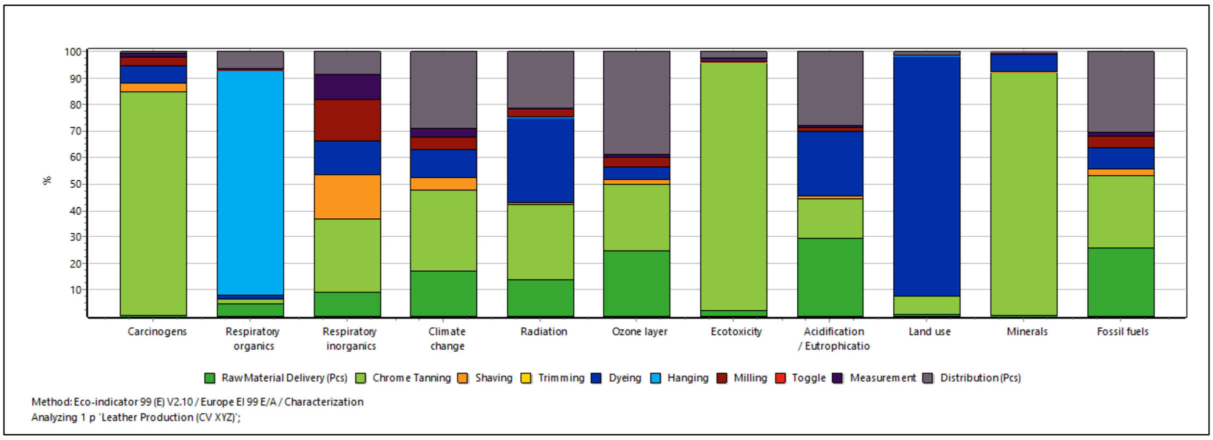

Figure 3. Characterization

The method used for evaluating environmental impact is Eco Indicator 99. Using this method, 11 categories are generated, including carcinogens, respiratory inorganics, respiratory organics, climate change, radiation, ozone layer, ecotoxicity, acidification, land use, minerals, and fossil fuels.

Normalization

Normalization is the stage where the overall impact assessed is compared and simplified based on a standardized measure. The objective of normalization is to provide a comparative value for each type of impact, facilitating easier interpretation. The normalization value for each impact category can be calculated by dividing the impact at the characterization stage by the normalization factor or reference value input into the SimaPro software, following the Eco-Indicator 99 (E) method. This step highlights the areas with the greatest contribution to environmental impacts and offers a deeper insight into the sustainability of each phase. Normalization assists in setting benchmarks for future improvements and sustainability goals. The normalization graph can be seen in Figure 4.

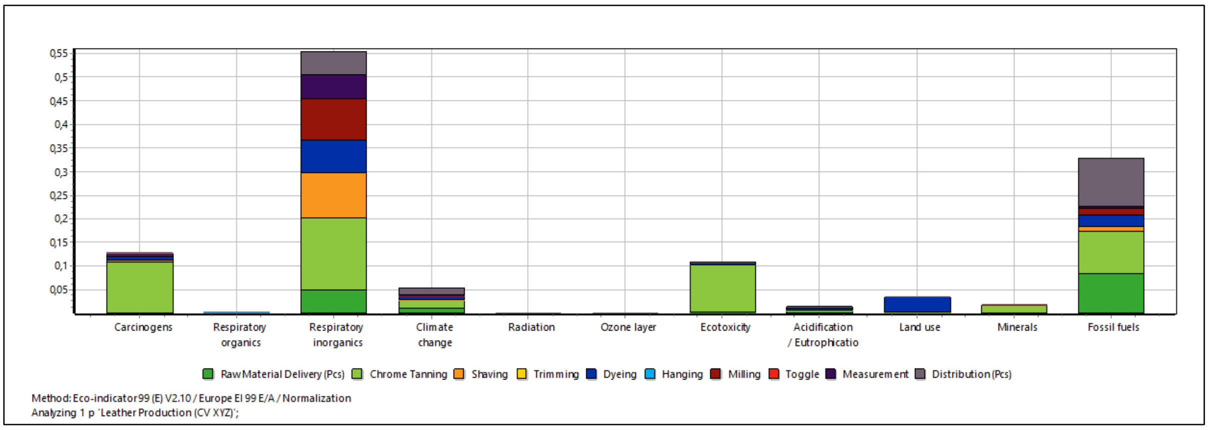

Figure 4. Normalization

Weighting

Weighting is the stage aimed at providing a relative unit value for impact categories, ensuring consistency in comparison across categories. In evaluating various environmental impacts, it is essential to make assessments relative, using a standardized unit, which in this case is Points (Pt). The weighting graph can be seen in Figure 5.

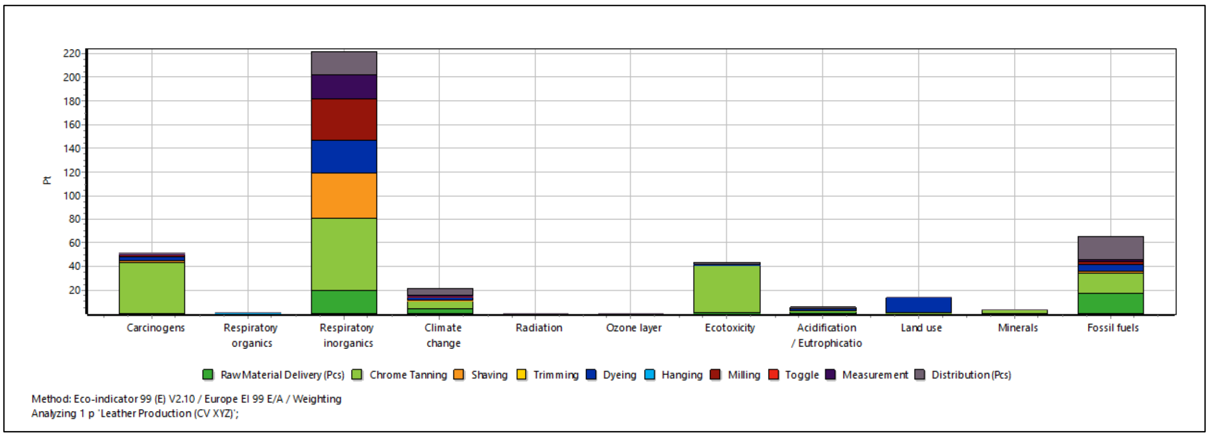

Figure 5. Weighting

The weighting graph above illustrates the contribution of various stages in leather production to the 11 impact categories, which include carcinogens, respiratory inorganics, respiratory organics, radiation, climate change, acidification, ozone layer, ecotoxicity, minerals, land use, and fossil fuels. This graph demonstrates environmental impacts in Points (Pt). It is evident that respiratory inorganics is the most dominant environmental impact. Respiratory inorganic refers to potential disturbances in human respiratory systems caused by exposure to inorganic pollutants in the air, such as chromium. Additionally, strong chemical odors from inorganic materials contribute to this impact. This impact arises from processes like raw material delivery, chrome tanning, shaving, dyeing, milling, measurement, and product distribution. The most significant contributor to respiratory inorganic impact is chrome tanning at 61.1 Pt, likely due to excess chromium usage during tanning. Dyeing contributes 28.2 Pt, attributed to the use of animal fatliquors. Furthermore, raw material delivery and product distribution generate air emissions from fuel consumption, while shaving, milling, and measurement processes also contribute due to high electricity usage and carbon dioxide emissions.

Single Score

In the single score stage, all impact categories are grouped based on damage categories. The Eco-Indicator 99 (E) method evaluates impact categories, which are grouped into three primary damage categories, including resource depletion, ecosystem quality, and human health. The single score graph can be seen in Figure 6.

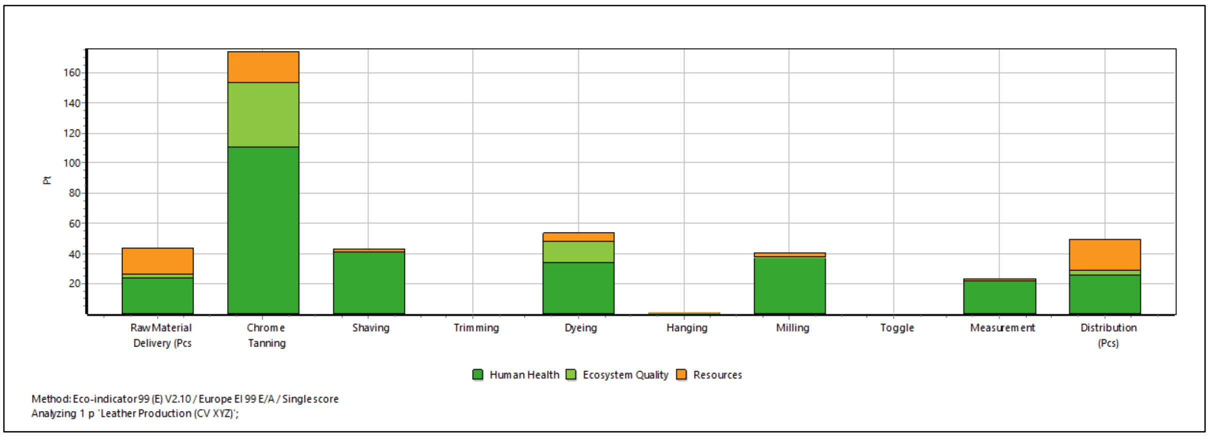

Figure 6. Single Score

The single score graph above explains the classification of impact categories into three damage categories including human health, ecosystem quality, and resource. From Figure 6, the most dominant process across human health, ecosystem quality, and resources is Chrome Tanning, with 111 Pt for human health, 42 Pt for ecosystem quality, and 21.1 Pt for resources. This indicates that chrome tanning has the greatest impact on human health, primarily due to the excessive use of chromium, which contributes significantly to the respiratory inorganic impact category.

Interpretation

Environmental impact assessment in this study adopts a cradle-to-gate approach, covering activities from raw material delivery, and leather processing (chrome tanning, shaving, trimming, dyeing, etc.), to product distribution. Using the Eco Indicator 99 (E) method, identified environmental impacts include respiratory organics/inorganics, carcinogens, radiation, climate change, ecotoxicity, and resource consumption, such as fossil fuels. The assessment is conducted through the stages of characterization, normalization, weighting, and single score to offer an in-depth understanding of the environmental impact per batch (500 sheets). The assessment reveals that the highest impact in leather production is respiratory inorganic, with two processes, chrome tanning, and dyeing, being the most influential and potentially modifiable to reduce environmental impacts.

Proposed Alternative Improvements

This proposed alternative improvement is the result of brainstorming sessions and prior research. The proposed alternatives to reduce the environmental impact of respiratory inorganic are as follows:

1. Addition of CaO and FeCl3 Coagulants

The solution employed a mixture of FeCl3 and CaO for effective chromium reductive and COD levels in chrome tanning wastewater. This indicates that chromium levels can be reduced up to 99.6% with just 3 grams of lime and 1 gram of ferric chloride (Esmaeli et al., 2014; Serrano et al., 2020)

2. Use of Vegetable Oil in the Dyeing Process

The plant-based oils used in this solution as an environmentally friendly alternative to animal-based oils in the dyeff section is castor oil, coconut oil or linseed oil, etc. Research conducted (Sivakumar et al., 2023). It shows that castor oil makes fatty emulsions whose mechanical properties to leather (tensile strength, tear resistance) are comparable to synthetic fats.

3. Vegetable Tanning

Instead, it uses natural materials such as from plants extract of tannins instead of synthetic chemicals like chromium. Research conducted by (Mustafa et al., 2024) demonstrates that water hyacinth produces strong, flexible, and environmentally friendly leather with a thermal shrinkage point of 83.31°C, tensile resistance of 286.33 kg/cm², and elongation of 63.33%.

Determining the Weight of Repair Alternatives with ANP Method

1. Determining Goals and Criteria

The determination of criteria is adjusted to the current conditions of the company. The purpose of using the ANP method is to identify improvement alternatives for reducing environmental impact in leather production. The criteria used are cost, technological reliability, human resource capability, and the ability to obtain raw materials.

2. Network Model

After defining the objectives, criteria, and alternatives, a network model is developed using Super Decisions 3.0 software to connect the elements within the clusters. The network model can be seen in Figure 7.

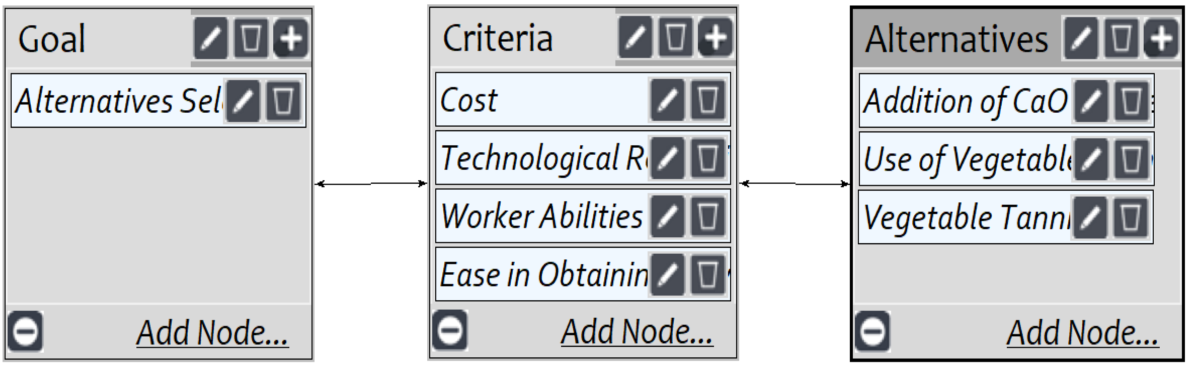

Figure 7. Model Jaringan

3. Survey Distribution

The creation of the questionnaire aims to provide values for the pairwise comparison matrix. In this researhc, the respondents providing the values from pairwise comparison in the questionnaire are Production Managers from CV XYZ. The questionnaire utilizes a scale derived from Saaty's 1 to 9 rating system. The results of the assessments are then entered into the Super Decisions 3.0 software to form the pairwise comparison matrix.

4. Pairwise Comparison Matrix

The matrix of pairwise comparison is used to determine the eigenvector value and assess the consistency ratio (CR), where the condition for a questionnaire evaluation is considered consistent if $CR \leq 0.1$. If $CR > 0.1$ the evaluation results are deemed inconsistent and need to be revised. CR is determined by dividing the consistency index (CI) by the random index (RI). CR values for each pairwise comparison matrix are presented in Table 11.

Table 11. CR Value Recapitulation

Pairwise Comparison	CR Value	Explanation
Alternative "Addition of CaO and $FeCl_3$ Coagulants" with Criteria Cluster	0.0980	Consistent
Alternative "Use of Vegetables Oil in the Dyeing Process" with Criteria Cluster	0.0655	Consistent
Alternative "Vegetable Tanning" with Criteria Cluster	0.0980	Consistent
Criteria "Cost" with Alternative Cluster	0.0479	Consistent
Criteria "Technological Reliability" with Alternative Cluster	0.0479	Consistent
Criteria "Worker Capability" with Alternative Cluster	0.0978	Consistent
Criteria "Ease in Obtaining Raw Materials" with Alternative Cluster	0.0978	Consistent

5. Creating Supermatrix

Once all pairwise comparison matrices are validated for consistency, the supermatrix results can be determined, including unweighted and weighted supermatrix, then the limit matrix. The unweighted supermatrix is created by incorporating all eigenvector values obtained from pairwise comparison matrices between elements, while the weighted supermatrix is derived from each block of priority vectors weighted based on matrices of pairwise comparisons between the clusters. The limit matrix contains the weighted supermatrix values multiplied by themselves until reaching the same value in each column. This limiting value is then used as the final result for ranking improvement alternatives.

6. Determining Priorities

The final step in processing with ANP is determining priorities. Priorities are obtained from the results of the limit supermatrix. Normalized by cluster is the weight derived from risk comparisons within each cluster. The normalization of weights across elements in each cluster ensures that these values are proportionally distributed within the cluster. The results of priority determination can be seen in Figure 8.

Icon	Name	Normalized by Cluster	Limiting
No Icon	Addition CaO and FeCl3 Coagulants	0.67790	0.169474
No Icon	Use of Vegetable Oil in Dyeing Process	0.10881	0.027202
No Icon	Vegetable Tanning	0.21330	0.053324
No Icon	Cost	0.07365	0.055241
No Icon	Technological Reliability	0.05984	0.044883
No Icon	Worker Abilities	0.14327	0.107450
No Icon	Ease in Obtaining Raw Materials	0.38990	0.292426
No Icon	Alternatives Selection to Improve The Environmenta~	0.33333	0.250000

Figure 8. Priorities Value

It is evident that the alternative addition of CaO and FeCl3 coagulants is the most prioritized improvement option, with the highest limiting value of 0.169474. The second-ranked alternative is vegetable tanning, with a limiting value of 0.053324, followed by the third-ranked alternative, the use of plant-based oils in the dyeing process, with a limiting value of 0.027202.

Conclusion

The environmental impact caused during the leather production process at CV XYZ through the Life Cycle Assessment method includes respiratory inorganic, fossil fuels, carcinogens, ecotoxicity, climate change, land use, acidification, minerals, respiratory organic, radiation, and ozone layer. Among these 11 impacts, the most significant is respiratory inorganic, amounting to 221.69 Pt. This impact is caused by hazardous chemicals such as chromium in the chrome tanning process and fatliquors in the dyeing process.

Alternative improvements to reduce the environmental impact of respiratory inorganic in leather production include the addition of CaO and $FeCl_3$ coagulants in the chrome tanning waste process, the use of vegetable oils in the dyeing process, and vegetable tanning. After weighting using the ANP method, the selected alternative prioritized for reducing environmental impact is the addition of CaO and $FeCl_3$ coagulants.

Future research could broaden the scope of LCA assessment by adopting approaches like cradle-to-grave or cradle-to-cradle. Additionally, methods for LCIA other than Eco Indicator 99 could be utilized, such as IMPACT+ or ReCiPe. Further studies could also be refined by incorporating a comparative LCA analysis before and after implementing improvement alternatives and increasing the number of respondents in the ANP weighting process..

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