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Improving the sustainability index through life cycle assessment: A case study in a bag manufacturing company

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ABSTRACT
The bag manufacturing industry is one of the most resource-intensive and environmentally impactful sectors, producing significant waste and emissions during manufacturing. This study focuses on the Audero Bag, a product of the Less Catino brand, which contributes the most to production waste among all models. This research applies the Life Cycle Assessment (LCA) method following ISO 14040:2006 to evaluate the environmental impact of each production stage, from material cutting to finished goods, within a gate-to-gate system boundary using SimaPro software. The results show that the Cutting Division contributes the highest environmental impact (88.4%) due to substantial material waste and energy consumption. The most dominant impact categories identified are terrestrial ecotoxicity (6.27E-03), marine aquatic ecotoxicity (4.90E-03), and freshwater aquatic ecotoxicity (1.72E-03) caused by fabric material usage. The sustainability assessment based on economic, environmental, and social indicators yields an overall Sustainability Index (SI) of 80.68%, indicating a relatively good level of performance. After the implementation of proposed 6R improvement strategies (Reduce, Reuse, Recycle, Repair, Remanufacture, and Recover) the index improved to 66.51%, reflecting the need for a more balanced integration of efficiency and environmental management. Strengthening waste treatment systems and optimizing material recovery are recommended to enhance long-term sustainability performance in the bag production process.

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1. INTRODUCTION

The bag Industry is involved in manufacturing a wide range of bags, catering to both women's and men's styles. Bags are an essential item for humans; besides functioning as a storage tool, bags also have an essential role in the fashion world. In addition, bags are a top-rated product nationally and internationally, with a vast target market. In 2020, bags were the 7th most popular product, with 54 million purchases.

Waste is a global problem in human life that affects several factors, such as health, ecosystem sustainability, and other aspects [1]. The fashion and apparel industry is one of the major contributors to global environmental degradation due to high material consumption, waste generation, and emissions during production [2]. In addition, some sectors produce a lot of waste. Waste generated by sectors can be seen in Figure 1.

Figure 1. Waste generated by sectors

Given the dangers of exhaust emissions, especially carbon monoxide, which can kill people who breathe it in, efforts are needed to control and reduce air pollution to reduce its negative impact on humans [3]. Consumers who choose fashion products for style and trends may overlook the environmental impacts of producing and disposing of these fashion products. Choosing more sustainable products, on the other hand, means considering the environmental impact of materials and production processes, and supporting greener practices.

The bag manufacturing company produces various Less Catino brand bags, namely (Audero, Devica, Keyna, and others), resulting in waste such as fabric and leather scraps, thread, and chemical byproducts. Leather and dye waste is likely to have the biggest environmental impact. More research is required to pinpoint specific effects and create suitable waste management solutions. From monthly observations, the production of various bag models generates residual waste from the production process, which has the potential to cause environmental pollution in the company. Based on monthly production data and waste estimates, as shown in Table 1, Audero, Keyna, and Devica bags demonstrate significant production volume and contribution to total waste generation compared to other bag models. This makes them the primary focus of this research.

Table 1. Bag production quantity

Bag Model	Amount of Production (unit)	Percentage (%)	Waste Estimation per Unit (kg)	Total Waste Estimate (kg)
Audero	30.000	65%	10	300.000
Keyna	7.500	15%	5	37.500
Devica	5.000	10%	8	40.000
Total	42.500	90%		377.500

Audero bags need extra care to guarantee the efficacy and efficiency of its production process because it manufactures a lot of bags. Maintaining product quality and satisfying consumer demand depend heavily on the production process. The Less Catino brand's Audero Bags product line is the focus of this last project's investigation.

Companies must prioritize consumer needs and embrace sustainability principles to generate positive environmental and social impacts. However, to effectively implement Life Cycle Management, which is an integrated concept for overseeing the full life cycle of a product to encourage sustainable production and consumption, a method is needed that evaluates the environmental impacts of all inputs and outputs at each stage of the production process. One analytical approach commonly used for this purpose is Life Cycle Analysis (LCA). Previously, LCA calculations have been carried out in a previous study at the bag company on different bag products during the COVID-19 period [4]. The results showed that some workstations, especially in the painting division, contributed significantly to the environmental impact of the bag production process. Water filtration has been attempted to reduce this impact, but has yet to be successfully implemented. Therefore, the LCA assessment was carried out again to evaluate the current level of environmental impacts. Based on ISO 14040:2006, LCA is defined as a method for examining the environmental effects of a product across its entire life cycle, starting from the extraction of raw materials and ending with its final disposal. Research on the leather product industry has shown that applying LCA can identify production stages with the highest environmental impact, allowing for process optimization to reduce emissions and waste. These findings are relevant to the bag manufacturing industry, which extensively uses leather or synthetic materials, where LCA can help enhance production sustainability [5].

The boundaries in LCA are divided into four types: Cradle to Grave, Cradle to Gate, Gate to Gate, and Cradle to Cradle [6]. Cradle-to-grave starts from raw materials to product operation, Cradle-to-gate starts from raw materials to reach a certain point in the process, gate-to-gate reviews nearby activities such as the production process, and cradle-to-cradle takes into account raw materials to material recycling. Furthermore, in the LCA stage, there are four phases: Goals and Scope Definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and Interpretation [7]. By knowing the amount of environmental impact generated from the LCA calculation using SimaPro, improvement efforts can be made by identifying the process stages most significant to environmental impacts, which 6R (Reduce, Reuse, Recycle, Repair, Remanufacturing, Recovering) on the waste produced can do. As research by Shaumaesi et al. [8] states that the integration of 6R principles in the manufacturing process can increase resource efficiency and reduce ecological impacts if combined with life cycle-based analysis, such as LCA.

The growing awareness of environmental degradation makes implementing sustainability-oriented strategies essential for the manufacturing industry. The integration of *Green Supply Chain Management* (GSCM) helps Small and Medium Enterprises (SMEs) in Indonesia improve their environmental and economic performance by optimizing resources and reducing waste. Therefore, the implementation of sustainable practices throughout the production process is sought to support competitiveness and long-term sustainability [9]. To refine this research, a sustainability index calculation was conducted using weight values obtained from experts in assessing the level of sustainability pillars and formulating sustainability indicators. This index calculation is crucial in determining the overall sustainability index value within the sustainability pillar, as previously applied in studies discussing the use of Life Cycle Assessment (LCA) in the textile industry and bag production [10]. The following is a depiction of the research scope in Figure 2.

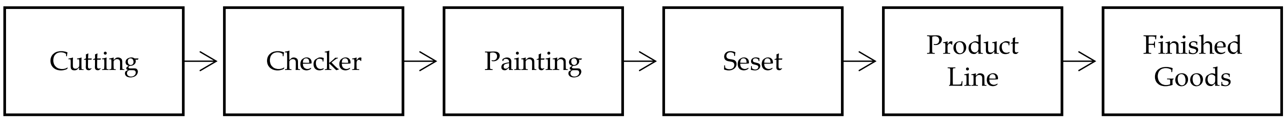

Figure 2. Research scope at the bag manufacturing company

This figure illustrates that the research system's boundaries focus on the "Gate to Gate" stage, assessing the environmental impact during the production process in the factory, from cutting materials to producing finished goods. Cutting is the production process in which the main raw material (such as synthetic leather or fabric) is cut according to the bag design pattern. Checking is the process of checking the cut results to ensure the size and shape meet standards before proceeding to the next stage. Painting is the coloring or coating of materials to achieve the appearance and color characteristics according to the product design. Seset is the joining or smoothing of parts of the colored material, usually involving edge joining or additional layers. The product line is the assembly stage where all components are assembled into a complete product, while finished goods represent the final stage before packaging and distribution. Based on this scope, the objective of this research is to identify and quantify the environmental impacts generated at each stage of the bag production process using the LCA method and to determine the production stages that contribute the most significant impacts. Furthermore, this study aims to evaluate the company's sustainability performance by integrating LCA results into a Sustainability Index (SI) assessment. The contribution of this research lies in providing a combined LCA–SI analytical framework specifically tailored for the bag manufacturing company, enabling companies to pinpoint critical improvement areas, optimize resource usage, and support the development of more sustainable production strategies.

2. MATERIALS AND METHODS

This study employs an approach to assess the environmental impacts associated with the bag manufacturing process at Audero Bags. The LCA method is used to examine every stage of the production chain and identify which processes have the greatest influence on environmental impact. The LCA framework includes four key phases: establishing the goal and scope, compiling the LCI, carrying out the LCIA, and interpreting the findings to offer recommendations for enhancing sustainability [11]. The overall research flow and methodological steps used in this study are illustrated in Figure 3.

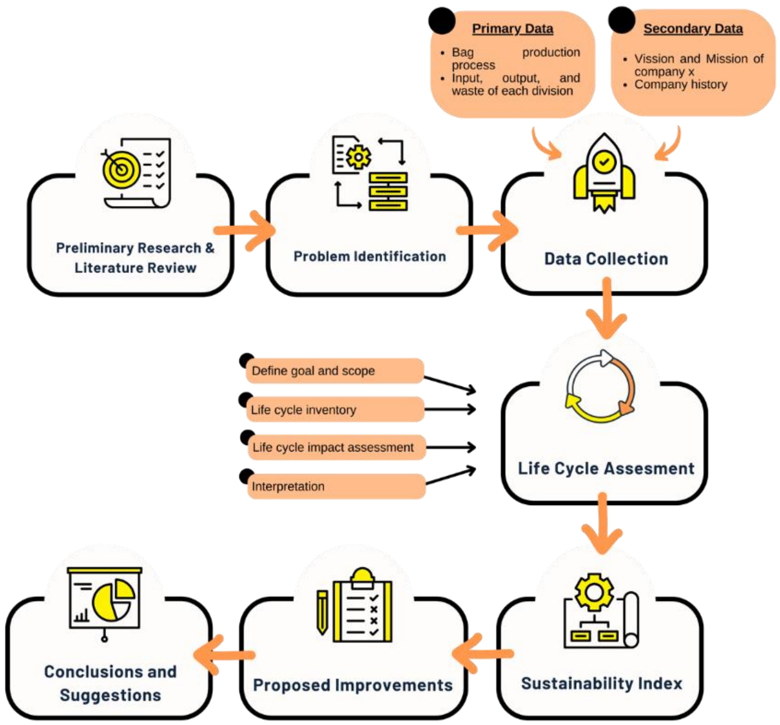

Figure 3. Flowchart of research methodology

The first step (define goal and scope) in conducting an LCA is to determine the purpose and scope of the study. The purpose and scope must be clearly defined to ensure the details of the study [12]. After the objectives are determined, the scope of the LCA is determined. The first thing to determine the scope is the system's function, functional unit, and reference flow (ISO, 2006b) [13]. The functional unit used in this study is 30000 pcs bags. The second thing done in making the scope is determining the system boundaries. The scope is to focus on the impact of energy use, and the boundaries of this study are to conduct LCA during bag production, which consists of the cutting, checker, painting, seset, production line, and finished goods divisions. The system restrictions in this study use gate-to-gate restrictions from the cutting division to the finished goods division because, this boundary is appropriate. After all, the core manufacturing processes, involving substantial electricity consumption, raw material transformation, and chemical applications, take place within these divisions. Limiting the scope to these stages allows for a focused analysis of the most impactful processes.

The LCI stage is the second phase of LCA and is the most crucial phase for its success. At this stage, detailed data on input, output, and waste are collected at each production station as key indicators in the LCI stage, with a particular focus on waste, using methods that include direct observation, interviews with production staff, and analysis of historical company records, where the data collection duration is adjusted to the production cycle to ensure comprehensive coverage of operational variations. A good inventory will produce good LCA results [13].

The LCIA stage analyzes the potential environmental effects associated with the resources identified in the LCI phase. This evaluation covers impacts on ecosystems, human health, and the use of natural resources. The LCI aims to connect specific products or processes with their possible environmental consequences. During impact assessment, inventory data is translated into potential impacts using defined categories, indicators, and characterization models. In this study, environmental impacts are examined using the CML IA Baseline method, which includes categories such as Abiotic Depletion, Abiotic Depletion (fossil fuels), Acidification, Eutrophication, Global Warming, Ozone Layer Depletion, Human Toxicity, Marine Aquatic Ecotoxicity, Freshwater Aquatic Ecotoxicity, Terrestrial Ecotoxicity, and Photochemical Oxidation [14]. These methods are classified into baseline and non-baseline types, with the baseline categories being the ones most widely used in LCA. According to Introduction to LCA with SimaPro (2016), the CML-IA method incorporates midpoint categories, which represent direct environmental impact categories and align with the key impact areas highlighted in the Minister of Environment and Forestry Regulation No. 1 of 2021 on the Corporate Performance Rating and Environmental Management Assessment Program. These include global warming potential, ozone depletion potential, acidification potential, and eutrophication potential. Data generated during the LCI stage is entered into the SimaPro version 9.0 software to produce the corresponding environmental impact categories [12].

Interpretation of results is the final step in LCA. In interpreting critical environmental issues, the analysis method that can be used is the contribution analysis approach. This method aims to identify data that significantly contributes to the environment [15]. At this stage, it will be determined which part of the process needs or can be done to reduce emissions.

3. RESULTS AND DISCUSSION

3.1. Goal and Scope Determination

The LCA research aims to identify and evaluate the potential environmental impacts generated throughout the bag production process. This study seeks to determine which stages in the production chain contribute the most to resource consumption, waste generation, and environmental emissions by applying the LCA approach. The scope of this research is defined as gate-to-gate, that the analysis focuses solely on the internal production activities within the factory, starting from the cutting process up to the finished goods stage. External processes such as raw material extraction, product distribution, and post-consumer disposal are excluded from the analysis. The functional unit used in this study represents the production of 30,000 bags within one month, manufactured through a single production line, which serves as the reference basis for quantifying environmental inputs and outputs during the assessment.

3.2. Inventory Analysis

The LCI stage involved collecting data to feed into the SimaPro software to produce an output showing the environmental impact of the bag production process. This data is obtained from the company, and presents the LCI data for each stage of the Bag Company production process. The table categorizes the data into six key divisions Cutting, Checker, Painting, Seset, Production Line, and Finished Goods which together represent the gate-to-gate boundaries of the production system analyzed in this study can be seen in Table 2. Each division includes information on three essential components: Input, Output, and Waste, illustrating the material and energy flow within the production process.

Table 2. LCI research at the bag manufacturing company

Cutting Division								
Input			Output			Waste		
Material	Unit	Quantity	Material	Unit	Quantity	Material	Unit	Quantity
Fabric	470	kg	Cut Result	94	Kg	Fabric	200	kg
Material						PVC		
Stuffing						Cardboard	1	kg
Electricity	195,3	kWh						
Checker Division								
Input			Output			Waste		
Material	Unit	Quantity	Material	Unit	Quantity	Material	Unit	Quantity
Cutting Results	94	kg	Check Result	91	kg	Fabric	3	kg
Electricity	49,32	kWh						
Painting Division								
Input			Output			Waste		
Material	Unit	Quantity	Material	Unit	Quantity	Material	Unit	Quantity
Hasil Pengecekan Bahan	91	kg	Painting Result	91	kg	Water	10	kg
Cat	300	kg				Scrap Paint	1	kg
						Paint Cans	2	kg
Electricity	2138,4	kWh				Plastic Drigen	4	kg
Seset Division								
Input			Output			Waste		
Material	Unit	Quantity	Material	Unit	Quantity	Material	Unit	Quantity
Painting Result	91	kg	Thinned Materials	91	kg	Pondcloth	5	kg
Electricity	1053,6	kWh				Fabric	10	kg
Production Line Division								
Input			Output			Waste		
Material	Unit	Quantity	Material	Unit	Quantity	Material	Unit	Quantity
Material Check Result	91	kg	Semi Finished Goods	30000	pcs	Oil	17	kg
						Thinner		kg
						Gasoline		kg
						Fabric	3	kg
						Plastic	1	kg
Electricity	3265,4	kWh				Metal	1	kg
Finished Goods Division								
Input			Output			Waste		
Material	Unit	Quantity	Material	Unit	Quantity	Material	Unit	Quantity
Semi-finished Goods	30000	Pcs	Finished Goods	30000	pcs	Metal	2	kg
Accessories	120	kg						
Electricity	30,9	kWh						

The cutting division processes raw materials like synthetic leather or fabric into specific patterns using cutting machines powered by electricity and labor. The output is precisely cut components, while the main waste is leftover fabric scraps. The checker division handles quality control, using electricity and manpower to ensure that components meet specifications, with defective pieces classified as waste. The painting division uses paint, solvents, and electrical energy to produce colored components, generating waste such as excess paint, solvent residues, and VOC emissions. The seset division smooths and bonds material edges to improve bag appearance and durability, using adhesives, finishing chemicals, and energy, while producing glue residues and small offcuts as waste. The production line assembles bags using threads, zippers, linings, and electricity, with waste from thread trimmings and assembly scraps. The finished goods division handles inspection, packaging, and labeling using packaging materials and energy, producing market-ready bags with minor plastic and packaging waste.

3.3. Life Cycle Impact Assessment (LCIA)

At the LCIA stage, the environmental impacts arising from the bag production process were classified and assessed based on data from the LCI. These impacts were analyzed using the CML IA Baseline method, which included 11 impacts [16]. The data processing results carried out using the CML-IA Baseline method in Simapro resulted in three assessments: network, characterization, and normalization [17]. The analysis was conducted to determine the most significant impact of the 11 impacts. The LCIA also displays a network result that illustrates the relationship between processes that impact the environment, with red upward arrows indicating the impact on the environment, lines indicating the relationship between materials and processes, and green lines indicating processed emissions with no impact on the environment. The network diagram showing environmental contribution flows is presented in Figure 4. The detailed network relationship between processes contributing to environmental impacts can be seen in Figure 5.

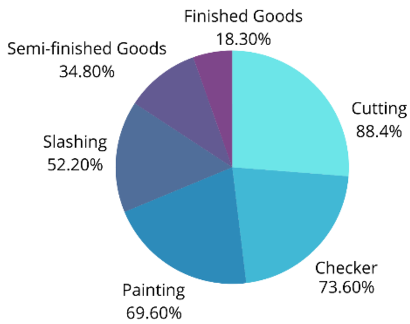

Figure 4. Network diagram result of the bag production process

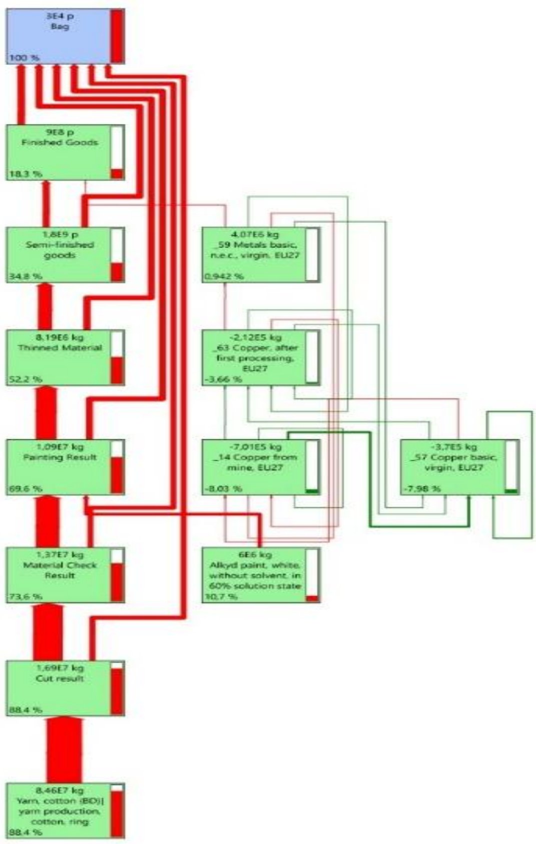

Figure 5. Network result of the bag production process

Based on the network analysis results, the production stage that contributes the most significant impact is the Cutting Division, with 88.4%, followed by the Checker Division (73.6%), Painting Division (69.6%), Seset Division (52.2%), Semi-finished Goods Division (34.8%), and Finished Goods Division (18.3%). These percentages are derived from the environmental impact characterization results shown in Table 2, calculated using the CML-IA Baseline method. The calculation involves adding the contribution of each process to the relevant environmental impact categories, such as Global Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Potential (EP), and then comparing these values to the total impact produced by the overall production process through normalization.

Furthermore, Figure 5 shows that the Cutting Division has the highest impact, as indicated by the larger arrowscompared to other divisions. This signifies that the Cutting Division has the most significant influence in the production network, mainly due to its high energy consumption and the substantial material waste generated from wood cutting. Additionally, the Checker and Painting Divisions also have relatively high contributions, possibly due to the use of additional materials such as adhesives and paints containing potentially harmful chemical compounds. The size of the arrows in Figure 5 represents the degree of influence between divisions in the production network, where larger arrows indicate a greater contribution of impact from one division to another. The Cutting Division has the largest arrow, demonstrating that this process is the primary factor in the overall environmental impact contribution.

Table 3 presents the characterization of the bag production process based on various environmental impact categories. The table shows that the abiotic depletion category records the highest value among all categories, indicating that the use of raw materials in production plays a major role in depleting natural resources. Moreover, the human toxicity and freshwater aquatic ecotoxicity categories suggest that the production activities may pose risks to human health and affect freshwater ecosystems. Characterization involves assessing the amount of material contributing to the impact category based on the data in the impact contribution table [14].

After characterization, normalization is performed to equalize the units of each impact. This process involves comparing the characterized results with reference data based on regional or global impact contributions. The impact categories analyzed in the normalization process are consistent with those in Table 3. The results of this normalization process are summarized in Table 4, while Figure 6 visualizes the distribution of characterization results across all impact categories, highlighting that the painting stage contributes significantly to several environmental burdens. Furthermore, Figure 7 presents only the three impact categories with the highest normalized values: terrestrial ecotoxicity, marine aquatic ecotoxicity, and freshwater aquatic ecotoxicity, as these represent the most dominant environmental impacts, whereas other categories show lower levels and are therefore less influential in the final normalization results. The following is an explanation of the three impacts with the most significant value generated:

1. Terrestrial ecotoxicity

   Based on Figure 7, it can be seen that *Terrestrial ecotoxicity* is the first highest impact resulting from the bag production process with a value of 6.27E-03. The impact value of *Terrestrial ecotoxicity* can be seen in Table 4.
2. *Marine aquatic ecotoxicity*

   Based on Figure 7, it can be seen that *Marine aquatic ecotoxicity* is the second highest impact resulting from the bag production process with a value of 4.90E-03. The impact value of *Marine Aqutaic Ecotoxity* can be seen in Table 4.
3. *Fresh water aquatic ecotox*

   Based on Figure 7, it can be seen that Freshwater aquatic ecotox has the third highest impact resulting from the bag production process with a value of 1.72.E-03. The impact value of Freshwater aquatic ecotox can be seen in Table 4.

3.4. Interpretation

After calculating the impact for each process, the source of the impact that contributes most to the impact category in the product system under study is obtained so that improvement recommendations can be made to reduce environmental impacts. The highest normalization stage value is Terrestrial ecotoxicity's environmental impact. The impact has a total value of 6.27E-03 and is the first highest impact value among other impacts. The second highest impact value is Marine aquatic ecotoxicity, which has a total impact value of 4.90E-03. Freshwater aquatic ecotox has the third highest impact value; the impact value is 1.72E-03. The leading cause of the three impacts is fabric, the most significant contributing component.

3.5. Sustainable Indicator Mapping

After the LCA calculation using SimaPro Software, it will proceed to Indicator Mapping. Sustainable indicators used in this study were previously formulated from several journals and related sources to produce several related indicators that can be used in calculations, as seen in Table 5. Of the 13 indicators that have been defined, the selection of eight indicators is based on their relevance to the production processes and resources of the company, covering aspects of efficiency, quality, and safety. More details on the indicators that have been previously met can be seen in Table 5.

The economic pillar includes indicators of production time (C1), inventory management (C2), defective products (C3), and equipment effectiveness or Overall Equipment Effectiveness (C4) which refers to efficiency and productivity. The environmental pillar includes indicators of raw material consumption (E1), electricity consumption (E2), waste generation (E3), water use (E4), and the results of environmental impact calculations through Life Cycle Assessment (E5), which assesses production activities in affecting the environment. The social pillar consists of indicators of employee satisfaction levels (S1), noise levels (S2), occupational safety (S3), and employee training (S4), which emphasize aspects of worker welfare and safety. Of the total of 13 indicators reviewed from various literature sources, this study selected 8 indicators that were most relevant to the conditions and production resources of the Bag Industry. The results of this mapping became the basis for determining parameters for calculating the sustainability index, so that the indicators used in the study were comprehensive and also in accordance with the characteristics of the bag industry being studied.

3.5.1. Calculation of the current sustainability index before the proposal is made

The sustainability index (SI) is calculated by considering 8 key indicators across the three main pillars: economic, environmental, and social. These indicators are: C1 (Time), C2 (Inventory), C3 (Defects), E2 (Electricity Consumption), E4 (Water Consumption), E5 (LCA - Ecotoxicity), S2 (Noise Level), and S3 (Safety Level). Details of the sustainability index calculation before the proposal is carried out can be seen in Table 6.

For the economic pillar, the SI was recorded at 63.19%, which is interpreted as moderate performance. For the environmental pillar, the sustainability index was recorded at 113.74%, indicating that the company's environmental management is relatively strong compared to the other two pillars. Electricity (E2) and water (E4) consumption showed values close to the target, indicating efficient resource use. However, the LCA results for the ecotoxicity category (E5) showed a small negative change of -0.0004. Although small, this still highlights the potential environmental risks resulting from chemical waste emissions in the production process. For the social pillar, the sustainability index reached 91.02%, indicating strong performance in terms of working conditions. Noise levels (S2) slightly exceeded the target, indicating that working conditions were within acceptable standards, but some production areas required improved noise control or worker protection. The safety level (S3) decreased by 10% from the target. These indices are then used to determine the Overall Sustainability Index (SI) using the formula:

$$Overall\ SI = (W_{Ec} \times SI_{Ec}) + (W_{Sc} \times SI_{Sc}) + (W_{En} \times SI_{En}) \quad (1)$$

Combining the three pillars using a sustainability weighting formula yielded an overall sustainability index score of 80.68%. This score indicates that the company's sustainability performance is already at a fairly good level, approaching the established standard. Improved economic efficiency (particularly in time management, inventory control, and reducing product defects) and enhanced occupational safety can further strengthen sustainability.

The overall sustainability score of 80.68% demonstrates a strong baseline, particularly within the environmental and social pillars. However, variation among individual indicators reveals that certain areas require further improvement to achieve balanced sustainability performance. The moderate score in the economic pillar indicates persistent inefficiencies in time, inventory, and defect management. Additionally, the slight negative trend in the ecotoxicity indicator highlights the need for improved waste management to mitigate potential long-term environmental risks.

Table 3. Characterization of bag production process

Impact category	Unit	Total	Cut Result	Material Check Result	Painting Result	Thinned ingredients	Semi-finished Goods	Finished Goods
Abiotic depletion	kg Sb eq	3.26.E+03	4.81.E+02	4.81.E+02	5.68.E+02	5.68.E+02	5.68.E+02	5.99.E+02
Abiotic depletion (fossil fuels)	MJ	7.32.E+09	1.16.E+09	1.16.E+09	1.25.E+09	1.25.E+09	1.25.E+09	1.24.E+09
Global warming (GWP100a)	kg CO2 eq	8.15.E+08	1.27.E+08	1.27.E+08	1.37.E+08	1.39.E+08	1.39.E+08	1.46.E+08
Ozone layer depletion (ODP)	kg CFC-11 eq	1.02.E+01	1.53.E+00	1.53.E+00	1.78.E+00	1.78.E+00	1.78.E+00	1.78.E+00
Human toxicity	kg 1,4-DB eq	5.12.E+08	7.93.E+07	7.93.E+07	8.84.E+07	8.84.E+07	8.84.E+07	8.84.E+07
Fresh water aquatic ecotox.	kg 1,4-DB eq	8.93.E+08	1.44.E+08	1.44.E+08	1.51.E+08	1.51.E+08	1.51.E+08	1.51.E+08
Marine aquatic ecotoxicity	kg 1,4-DB eq	5.72.E+11	8.74.E+10	8.74.E+10	9.93.E+10	9.93.E+10	9.93.E+10	9.93.E+10
Terrestrial ecotoxicity	kg 1,4-DB eq	3.04.E+08	5.04.E+07	5.04.E+07	5.08.E+07	5.08.E+07	5.08.E+07	5.08.E+07
Photochemical oxidation	kg C2H4 eq	1.37.E+05	1.85.E+04	1.85.E+04	2.39.E+04	2.42.E+04	2.42.E+04	2.82.E+04
Acidification	kg SO2 eq	6.34.E+06	1.01.E+06	1.01.E+06	1.06.E+06	1.06.E+06	1.06.E+06	1.15.E+06
Eutrophication	kg PO4--- eq	9.37.E+06	1.54.E+06	1.54.E+06	1.56.E+06	1.57.E+06	1.57.E+06	1.58.E+06

Table 4. Impact values of terrestrial ecotoxicity, marine aquatic ecotoxicity, and fresh water aquatic ecotox values

Process	Value Terrestrial ecotoxicity	Value Marine aquatic ecotoxicity	Fresh water aquatic ecotox values
Cutting	1.04.E-03	7.49.E-04	2.78.E-04
Checker	1.04.E-03	7.49.E-04	2.78.E-04
Painting	1.05.E-03	8.51.E-04	2.92.E-04
Seset	1.05.E-03	8.51.E-04	2.92.E-04
Production Line	1.05.E-03	8.51.E-04	2.92.E-04
Finished Goods	1.05.E-03	8.51.E-04	2.92.E-04
Total	6.27.E-03	4.90.E-03	1.72.E-03

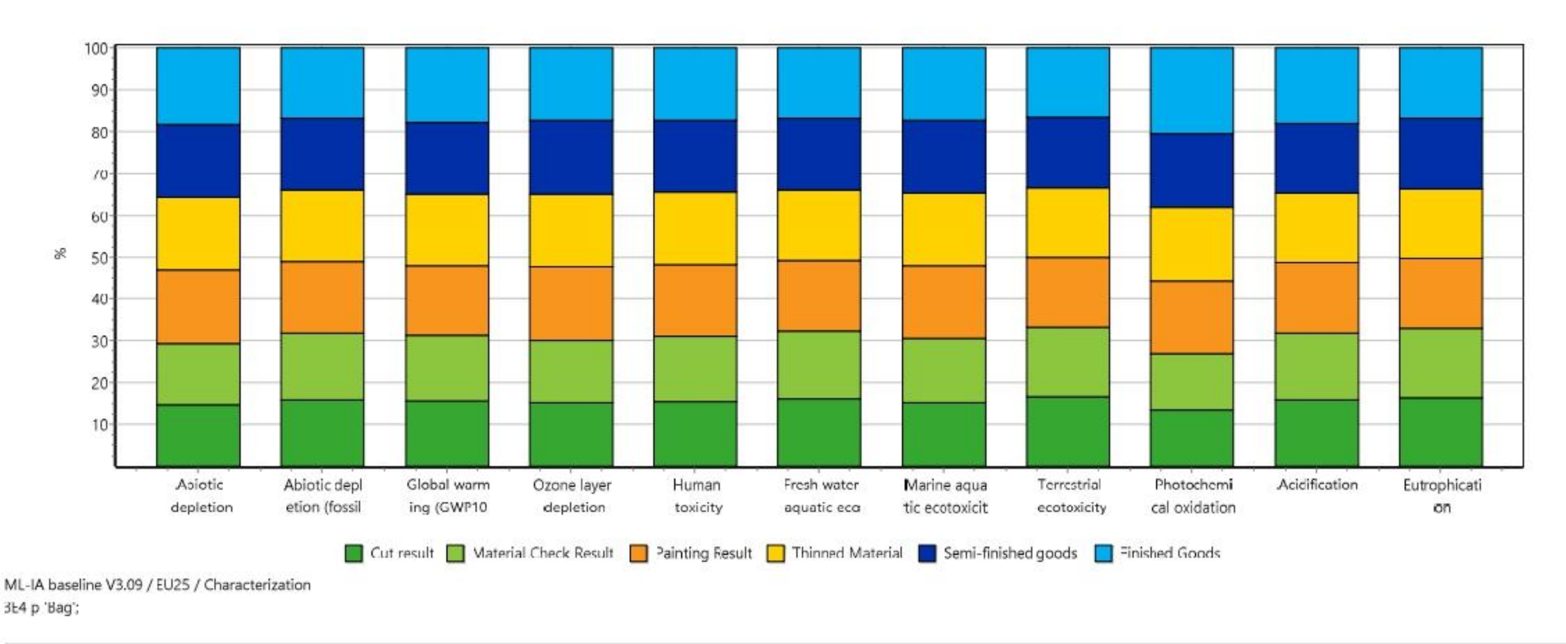

Figure 6. Characterization chart of bag production process

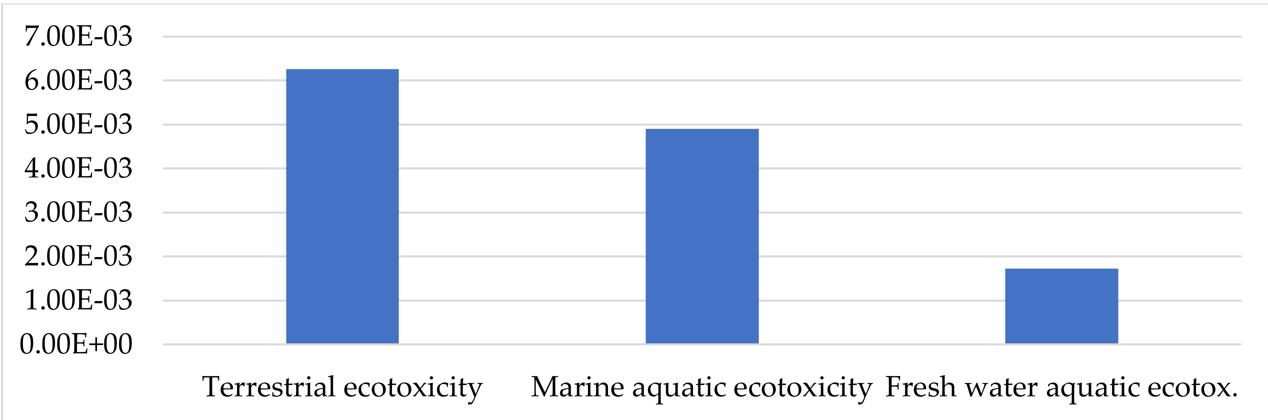

Figure 7. Normalization

Table 5. Mapping of sustainability indicators

Authors	Economy				Environment					Social			
	C1	C2	C3	C4	E1	E2	E3	E4	E5	S1	S2	S3	S4
Saraswati et al. [18]	✓	✓	·	·	·	✓	✓	✓	·	·	·	·	·
Feng et al. [19]	·	·	·	·	·	✓	·	✓	✓	·	·	·	·
Marie et al. [20]	✓	✓	✓		✓	✓	✓	✓	·	✓	✓	✓	✓
Rathi et al. [21]	·	·	·		✓	✓	·	✓	✓	·	·	·	·
Hartini et al. [22]	✓	✓	·	·	·	·	✓	✓	·	✓	·	✓	✓
Sari et al. [23]	✓	✓	·		✓	✓	·	✓	·	·	✓	✓	✓
Wen et al. [24]	·	·	·	·	✓	✓	·	✓	·	·	·	✓	·
Kaswan et al. [25]	·	✓	·	·	·	·	✓	·	·	·	·	✓	·
Marie et al. [26]	·	✓	·	·	·	✓	·	·	·	·	✓	·	✓
Tiwari et al. [27]	✓	·	·	·	·	·	·	·	✓	·	·	✓	·
Gholami et al. [28]	·	·	·	·	·	·	·	·	·	·	✓	·	·
Goyal et al. [29]	·	·	✓	·	·	·	·	·	·	·	·	·	·
Zarte et al. [30]	·	·	·	·	✓	✓	✓	✓	·	✓	✓	✓	·
Hartini et al. [31]	✓	✓	✓	·	✓	✓	·	·	·	✓	·	✓	✓
Domingo et al. [32]	·	·	·	✓	·	·	·	·	·	·	·	·	·
Sari et al. [33]	·	·	·	·	·	·	·	·	·	✓	·	✓	✓
Selected Indicators	✓	✓	✓			✓	✓	✓	✓	·	✓	✓	·

Note:
Economic Pillars: C1: Time, C2: Inventory, C3: Defects, C4: OEE
Environmental Pillar: E1: Raw Material Consumption, E2: Electrical Energy Consumption, E3: Waste, E4: Water Consumption, E5: LCA
Social Pillar: S1: Satisfaction Level, S2: Noise Level, S3: Safety Level, S4: Employee Training

Table 6. Calculation of the sustainability index based on current conditions

Pillar	Code	Description	Unit	Existing	Target	Value Of Change	Log	SI
Economy	C1	Time	Minutes	28	26	-2	0.30	63.19
	C2	Inventory	Unit	4000	3500	-500	2.70	
	C3	Defect	%	9	7	-2	0.30	
Environment	E2	Electricity Energy Consumption	Kwh	6732.92	6700	-32.92	1.52	113.74
	E4	Water consumption	Kg	10	8	-2	0.30	
	E5	LCA (*Terrestrial ecotoxicity ,Marine aquatic ecotoxicity, Fresh water aquatic ecotox*)		0.0069	0.0065	-0.0004	-3.40	
Social	S2	Noise Level	DB	82	85	3	0.48	91.02
	S3	Safety Level	%	95	85	-10	1.00	
		Sustainable Index Overall						80.68%

3.5.2. 6R strategy and proposal

Based on the results of interviews with the company, currently the company has only implemented three things: Reduce, Reuse, and Repair the company still needs to implement the 6Rs fully. The following 6R strategy can be seen in Table 7.

Table 7. Company's 6R strategy

No.	Work Station	Input	Output		6R						6R Strategy
			Products	***Waste***	***Reduce***	***Reuse***	***Recycle***	***Repair***	***Remanufacturing***	***Recovering***	
1	Cutting	Fabric Material Stuffing	Fabric that has been cut	Fabric PVC Cardboard		√					Reprocessed into small wallets
3	Checker	Fabric that has been cut	Materials that have been checked	Fabric	√						Sold to collectors
4	Painting	Materials that have been checked Cat	Painted materials	Water Scrap Cat Paint Cans Plastic Drigen			√				Used paint cans are reused for paint containers
5	Seset	Painted materials	Thinned ingredients	Pondcloth Fabric							-
6	Production Line	Preset materials	Semi-finished goods	Oil Tiner Gasoline Fabric Plastic Metal							-
7	Finished Goods	Semi-finished Goods Accessories	Finished Goods	Metal							-

Based on Table 7, the company's current 6R strategy focuses on reusing leftover materials and reducing waste across several divisions, including the Cutting, Checking, and Painting divisions. In the Cutting division, scraps of fabric are reused to make small products like wallets, supporting the principle of reuse. In the Painting division, used paint cans are reused as paint containers, also reflecting the practice of reuse. Since only three of the 6R strategies have been realized in the Bag Industry, it is necessary to immediately improve the sustainability strategy through the more complete implementation of the 6R principles by implementing all six principles. The company can develop a recycling system for plastic and fabric waste, as well as implement a recovery program such as utilizing energy from production waste. Furthermore, a remanufacturing approach can also be applied to extend the product life cycle by repairing or modifying defective items for resale. Comprehensive implementation of the 6Rs will reduce environmental impact, increase production cost efficiency, and strengthen the company's image as an entity committed to sustainable production practices. The proposed 6R improvements that can be applied to the production process can be seen in Table 8.

Table 8. Proposed 6R's

No.	Work Station	Proposed 6Rs
1	Cutting	Recycle (Reprocessing waste fabric into new fibers)
2	Checker	Remenufacturing (Converting unsuitable fabric patterns into new fabric patterns for other products)
3	Painting	Recovery (Conducting liquid waste treatment before being released by the company using the WWTP system)
4	Seset	Recycle (Reprocessing waste fabric into new fibers)
5	Production Line	Repair (Repairing bag bodies to prevent waste that could harm the company)
6	Finished Goods	Repair (Fix accessories to make them usable again)

Research conducted by Purwani et al. [34] on MSMEs found that many only apply a few of the 6R principles, such as reduce, reuse, and recycle—while remanufacturing and recovery are rarely implemented due to limited human resources and infrastructure. The study explains that when companies do not implement remanufacturing and recovery, several consequences arise: low resource efficiency (because new raw materials are continuously used without any attempt to reuse them), increased waste volume (because residual production materials and final products are not returned to the production chain), increased emissions and hazardous waste accumulation, and suboptimal circular economy value (because there is no further recycling process that can generate new added value from waste). It can be emphasized that the lack of remanufacturing and recovery implementation causes the environment to continue to bear the burden of waste, while companies lose the potential for long-term economic efficiency. Although this research was conducted on a large-scale industry (Less Catino (Audero Bags)) with different resources, a theoretical parallel can still be drawn, namely that even with more complete facilities, the effects of partial implementation of 6R can hinder efforts to reduce environmental impact and production efficiency in the bag manufacturing sector.

3.5.3. Calculation of the future sustainability index

It is essential to calculate the sustainability index value again after applying the proposed improvements to determine changes in the index. Details of the calculation of the sustainability index after the proposal is made can be seen in Table 9.

Table 9. Calculation of the Sustainability Index After Improvement

Pillar	Code	Description	Unit	Existing	Target	Value Of Change	Log	SI
Economy	C1	Time	Minutes	28	26	-2	0.30	63.19
	C2	Inventory	Unit	4000	3500	-500	2.70	
	C3	Defect	%	9	7	-2	0.30	
Environment	E2	Electricity Energy Consumption	Kwh	6732.92	6700	-32.92	1.52	53.20

Pillar	Code	Description	Unit	Existing	Target	Value Of Change	Log	SI
	E4	Water consumption	Kg	10	8	-2	0.30	
	E5	LCA (*Terrestrial ecotoxicity ,Marine aquatic ecotoxicity, Fresh water aquatic ecotox*)		0.005382	0.0065	0.001118	-2.95	
Social	S2	Noise Level	DB	82	85	3	0.48	91.02
	S3	Safety Level	%	95	85	-10	1.00	
Sustainable Index Overall								66.51%

Table 9 shows changes in the index values for each pillar, resulting in a Sustainability Index value of 66.51%. This value represents a decrease compared to the pre-improvement condition (80.68%). Therefore, although improvements have occurred in some operational aspects, other factors need to be evaluated to ensure the implemented strategy has a positive overall impact. In the economic pillar, indicators for production time (C1), inventory quantity (C2), and product defect rate (C3) show improvements, such as a decrease in production time from 28 minutes to 26 minutes and a decrease in the defect rate from 9% to 7%. These changes reflect efficiencies in the production process and improved quality control. However, it should be emphasized that the increase in efficiency is not fully reflected in the overall increase in the sustainability index value, as other factors, such as inventory management, still need to be optimized to align with long-term sustainability targets.

In the environmental pillar, electricity (E2) and water (E4) consumption were successfully reduced to near the target, indicating an increase in resource efficiency. However, the LCA (Life Cycle Assessment) results showed an increase in the potential for ecotoxicity impacts (E5) of 0.001118, which means there was a slight decrease in environmental quality due to possible emissions or chemical waste from the production process. This is an important concern for the company to strengthen its waste management system, especially in the post-production stage, to avoid future ecological risks. Meanwhile, in the social pillar, the noise value (S2) increased from 82 dB to 85 dB, indicating the potential for disruption to work comfort due to more intensive production activities. The occupational safety level (S3) decreased from 95% to 85%.

3.5.4. Comparison of Sustainable Index Value

Based on the calculation results, a comparison of the Sustainable Index Value before and after the proposal is made can be seen in Table 10.

Table 10. Comparison of Sustainable Index Values

Pillar	Before	After
Economic	63.19%	63.19%
Environment	113.74%	53.20%
Social	91.02%	91.02%
Overall Sustainable Index	80.68%	66.51%

The sustainability index value experienced changes in each pillar, especially the environment. The economic pillar index value remained at 63.19%, meaning production time efficiency, inventory management, and product defect control remained at the same level as before the improvements were made. The social pillar also showed no change with a value of 91.02%, meaning that work safety and comfort conditions remained stable. The most prominent change was seen in the environmental pillar, with the index value dropping from 113.74% to 53.20%. The decrease was caused by adjustments to the LCA (Life Cycle Assessment) indicator as a product's environmental impact on ecotoxicity. In other words, products produced after improvements have a smaller environmental footprint in terms of waste emissions and potential pollution. It can be concluded that although the environmental index value decreased numerically, this is actually a positive indication because it shows an improvement in the environmental sustainability aspect.

4. CONCLUSION

This study aims to evaluate the environmental impact and sustainability performance of the bag production process at Audero Bags by integrating the Life Cycle Assessment (LCA) and Sustainability Index (SI) approaches. The analysis shows that the Cutting Division contributes the best environmental impact (88.4%) due to high energy use and material waste with Terrestrial Ecotoxicity identified as the dominant impact category. The integration of LCA and SI provides an extensive understanding of the company's sustainability performance, as illustrated by the overall Sustainability Index before improvement is 80.68%, hence moderate sustainability performance with strength in environmental management but still needs to be improved in economic efficiency and occupational safety.

The novelty of this study lies in the combination of LCA-based impact quantification with sustainability index mapping to identify improvement points for the Bag Industry, a practice rarely implemented in this industry. This research provides practical, actionable recommendations through the 6R strategy (Reduce, Reuse, Recycle, Repair, Remanufacturing, and Recover) to improve sustainable practices across all stages of production in an industry. Future studies are encouraged to expand the analysis to include end-to-end LCA, incorporate carbon footprint assessment, and explore digital monitoring systems to support ongoing sustainability improvements in the manufacturing process.

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