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Circular Economy Adoption on Coffee Production: Case study of a Coffee Cooperatives Farmer in Indonesia

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Abstract. The coffee industry in Indonesia contributes 16.15% to the plantation sector's GDP. As coffee production increases, it leads to a rise in its waste, which can pollute the environment. Coffee waste could be processed into cosmetic ingredients, bioethanol, briquettes, cascara tea, fertilizer, and animal feed. This study aims to compare three scenarios of processing coffee husk waste into cascara tea, fertilizer, and animal feed based on economic and environmental perspectives. It evaluates the environmental and economic impacts of implementing a circular economy in the coffee and livestock industries using Life Cycle Assessment and Benefit and Cost Analysis. The use of Life Cycle Assessment to calculate environmental impacts, while Benefit and Cost Analysis aids in calculating economic impacts. The scenario of processing waste into fertilizer and animal feed was chosen because it has the best value using the Goal Programming method. This research provides insights into the application of circular economy to enhance the sustainability of coffee industry and other agriculture sectors in Indonesia.

1 Introduction

The coffee industry in Indonesia significantly contributes to employment, supporting almost two million farming families and an additional half a hundred thousand workers. As one of the leading commodities in the plantation sector, alongside palm oil and natural rubber, coffee accounts for about 16 % of the sector's Gross Domestic Product (GDP)[1].

In 2022/2023, Indonesia ranked third as the world's largest coffee producer, with production reaching 11.85 million bags. The data from the Central Bureau of Statistics (BPS), indicates that Indonesia's coffee production in 2022 was 794.8 thousand tons, an increase of 1.1% compared to the previous year [2].

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Several regions, including Jombang Regency in East Java, are actively developing coffee commodities. Jombang Regent's Decree Number 188.4.45/189/145.10.10/2010 designates locations and key commodities within the Metropolitan Area in Agricultural Development Area Unit I (SKPP I). The Roadmap for Strengthening Regional Innovation Systems (SIDa) 2016-2025, integrated into Jombang Regency Regulation Number 10 of 2014 concerning the Regional Medium-Term Development Plan (RPJMD) of Jombang Regency 2014-2018, also supports this initiative. One of its priorities is the development of horticulture and supporting sectors in the agropolitan area, including the development of the fertilizer industry and excelsa coffee processing [3].

Over the past five years, the highest coffee production in Jombang Regency occurred in 2017, with 770 tons. In 2018, coffee production decreased to 655 tons but increased again to 692 tons in 2019. The Wonosalam Coffee Association contributes to increase the income of the local community. The association also supports the development of the agricultural sector by involving various stakeholders in the coffee production chain, from farmers to coffee enthusiasts. However, the increase in coffee production has also raised the volume of coffee pulp w and liquid waste, which is considered to have a negatively impact to the environment [4]. Coffee pulp waste, which can account for 50-60% of the harvest, causes organic pollution that contaminates water and air.

In water, microbiological processes that require oxygen to decompose organic substances create anaerobic conditions and foul odors due to the high moisture content in coffee pulp, reaching 75-80% [5]. Waste from the coffee agro-industry has great potential to be turned into value-added products such as cascara tea, fertilizer, and animal feed [6], [7], [8]. To address these challenges, the circular economy offers an appealing approach in which all products and materials are designed to be reused, recycled, or repurposed [9], [10].

This research employs Life Cycle Assessment, Financial Feasibility Analysis, and Goal Programming methods to optimize waste management in the production process of the Wonosalam Coffee Association. This solution is expected to help the Wonosalam Coffee Association better manage production waste, improve resource use efficiency, and enhance overall productivity.

2 Literature Review

This section presents the literature review as the foundation for conducting this research.

2.1 Sustainability

Most of its definitions that have been circulating in recent years highlight the ecological perspective, which is the concept that human society and economy are closely linked to the natural environment. The models used to represent the concept of sustainability have evolved. From the 1980s to the early 21st century, the main model was the simple yet powerful tripartite Venn diagram, which illustrates the triple bottom line, as shown in Figure 1 [11].

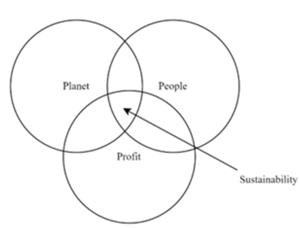

Fig. 1. Triple Bottom Line Concept

Several metrics can be used to measure the level of sustainability, including carbon footprint and energy consumption intensity

2.1.1 Carbon footprint

Carbon footprint can be used as a metric to assess or apply at various levels, ranging from individual activities, households, and companies, to entire countries [12].

Table 1. Greenhouse Gases (GHG) and Global Warming Potential

No	Greenhouse Gases (GHG)	Global Warming Potential	
		SAR[a]	AR5[b]
1	Carbon Dioxide (CO2)	1	1
2	Methane (CH4)	21	28
3	Nitrous Oxide (N2O)	310	265
4	Hydrofluorocarbons (HFCs)	140-11.700	138-12.400
5	Perfluorocarbons (PFCs)	7.000-9.200	7.910-11.100
6	Sulphur Hexafluoride (SF_6)	23.900	23.500

[a] Second Assessment Report
[b] Assessment Report 5

Based on Table 1, carbon dioxide (CO2) has a Global Warming Potential (GWP) of 1, and other greenhouse gases (GHGs) are measured about CO2. Several GHGs listed in Table 2.1 are converted into CO2-equivalents (CO2-e) by multiplying the mass of each gas by its global warming potential. For example, 1 kilogram of methane is equivalent to 25 kilograms of CO2-e based on the AR5 GWP.

2.1.2 Energy Consumption Intensity

Energy consumption intensity is a metric used to measure energy consumption in the context of specific organizational metrics. This measure provides an overview of how efficiently an organization uses energy concerning activity units, outputs, or other metrics [13]. SNI number 03-0196:2010 has classified the Energy Consumption Index (ECI) values for buildings with air conditioning (AC) systems (Table 2).

Table 2. Classification of ECI values for air-conditioned buildings according to SNI 03-0196:2010

Criteria	ECI (kWh/m^2/month)
Very Wasteful	23.75-37.5
Wasteful	19.2-23.75
Somewhat Wasteful	14.58-19.2
Quite Efficient	12.08-14.58
Efficient	7.93-12.08
Very Efficient	4.17-7.93

In the Regulation of the Minister of Energy and Mineral Resources (Permen ESDM) number 03 of 2012, there is also a classification regarding electricity energy usage in buildings equipped with air conditioning (AC) systems, as shown in Table 3.

Table 3. Classification of ECI values for buildings with AC

Criteria	ECI (kWh/m^2/month)
Very Efficient	IKE < 8.5
Efficient	8.5 < IKE < 14
Fairly Efficient	14 < IKE < 18.5
Inefficient	18.5 < IKE

2.2 Circular Economy

The circular economy is an economic concept aimed at maximizing resource utilization by ensuring that materials and products in the economic system remain in circulation or are reused for as long as possible. The goal is to create a sustainable environment, economic prosperity, and social equity for the benefit of current and future generations [14].

2.2.1 The Relationship between Low-Carbon Development and Circular Economy

Indonesia's future economic development emphasizes a low-carbon strategy aimed at balancing economic growth with reducing carbon emissions and strengthening climate resilience. This approach has been incorporated into the National Medium-Term Development Plan (RPJMN 2020–2024). The 6th National Priority focuses on low-carbon initiatives, including environmental conservation, disaster resilience, and climate change mitigation. Key sectors in this strategy include sustainable energy development, integrated waste management, green industrial practices, sustainable land restoration, and the inventory and rehabilitation of coastal and marine ecosystems [15].

2.2.2 The Relationship between Sustainable Development and Circular Economy

The existence of the circular economy can be considered a progressive step in the journey of Sustainable Development, as it aims to create an economic model that separates the use of resources from natural resources by reintegrating waste from consumption and production as new inputs in the production system. The concept of Sustainable Development originally emerged as a response to the need to carefully plan economic growth and consumption to minimize negative impacts on the environment [16].

2.3 Industrial Ecology

Industrial Ecology is an environmental management method in which industrial systems are considered as integral parts interconnected with their surrounding systems, rather than as separate entities [17].

Based on ecosystem classification, it is stated that in the natural balance, there are three types, they are as follows:
•Type I Ecology: Linear Flow of Materials
In industries with Type I ecology, the flow of materials and energy tends to be linear, where waste is generated and discarded from the system without significant recycling.
•Type II Ecology: Quasi-Cyclic Flow of Materials
Industries with Type II ecology have a material flow that nearly forms a cycle but still involves several trophic levels that generate waste that exits the system.
•Type III Ecology: Cyclic Flow of Materials

In industries with Type III ecology, there is a material flow that forms a complete cycle, where waste from one process can be reused by another process, creating a more sustainable system.

In the context of Industrial Ecology, there are principles derived from ecological principles with a focus on industry, including aspects of processes, goals, and impacts. In other words, an industry that is built and developed is considered to comply with the principles of Industrial Ecology if the industrial system incorporates the four main principles, namely industrial ecosystems, sustainability, efficiency, and environmental friendliness [18].

Practically, the relationship between Sustainable Development and Industrial Ecology can be understood through the illustration shown in Figure 2. Sustainable Development and Industrial Ecology relationship can be explained through the examination of economic, social, and ecological functions.

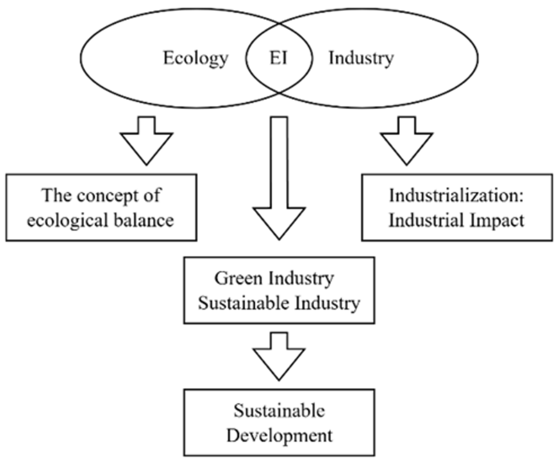

Fig 2. Sustainable Development and Industrial Ecology relation

2.4 Life Cycle Assessment

SNI ISO 14040:2016 and SNI ISO 14044:2017 have outlined the Life Cycle Assessment or LCA method that could be utilized to compile and evaluate inputs, outputs, and potential environmental impacts of a product system throughout its entire life cycle. LCA is the proper tool for evaluating and identifying the environmental impact aspects related to a product or service based on its life cycle [19]. The stages of LCA consist of several steps, as shown in Figure 3.

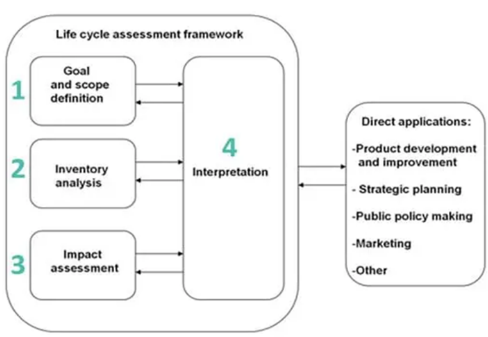

Fig. 3. Life Cycle Assessment (LCA) stages

2.5 Financial Feasibility Analysis

This is part of the economic feasibility analysis process that focuses in evaluating the financial aspects of a project, investment, or business activity. This analysis aims to assess whether the project has the potential to generate sufficient cash flow to recover the initial investment and provide the desired profit [20].

Net Present Value (NPV) is a way to assess investments by comparing the present value of net cash inflows with the present value of expenditures. In evaluating investments using NPV, data is needed about the initial costs, future net cash inflows, and the minimum expected rate of return [21]. The formula to calculate NPV is as follows:

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+R)^t} \tag{1}$$

Where,

R = discount rate used
C_t = cash flow at t period
n = the last period where cash flow is positive

The interpretation of the NPV value is as follows:

- NPV > 0 means the investment is feasible because it will be profitable.
- NPV < 0 means the investment is not feasible because it will be unprofitable.

Internal Rate of Return (IRR) is utilized to determine the profitability of an investment by finding the discount rate that makes the NPV equal to zero, IRR method is utilized [21]. The formula to calculate IRR is as follows:

$$IRR = i_1 + \frac{NPV_1}{(NPV_1 - NPV_2)}(i_2 - i_1) \tag{2}$$

Where,

i_1 = the discount rate that results in a positive NPV
i_2 = the discount rate that results in a negative NPV
NPV_1 = a positive NPV
NPV_2 = a negative NPV

The interpretation of the IRR value is as follows:

- IRR > MARR means the investment is feasible because it will be profitable
- IRR < MARR means the investment is unfeasible because it will not be profitable

Payback Period (PBP) calculates the time required to recover the initial investment from the cash inflows generated by an investment project within a specific period, Payback period is utilized [21]. The formula to calculate PBP is as follows:

$$PBP = \frac{investment}{net\ cashflow\ per\ period} \tag{3}$$

With the interpretation that if the payback period is shorter than the investment return target, the investment project is considered feasible. Conversely, if the payback period is longer than the investment return target, the investment project is considered not feasible.

Sensitivity Analysis is utilized to demonstrate how robust a decision will remain when faced with changes in factors or parameters that influence it. This analysis involves altering the value of a parameter at a specific point in time to assess its impact on an investment alternative [22].

2.6 Coffee Waste and Its Potential

As coffee production increases, coffee processing generates coffee husk waste that has a potential to cause environmental pollution. Therefore, innovations are needed to manage coffee husk waste so that it can be effectively utilized [23]. Furthermore, the value-added products present throughout the coffee life cycle and their potential benefits are shown in Table 4.

Table 4 . Value-Added Products in the Coffee Life Cycle

Coffee Leaf	Coffee Green	Coffee Flower	Spent Coffee Ground
• Caffeine • Mangiferin • Hydroxycinnamic acid esters • Essential oils	• Enzyme production • Bioethanol • Chlorogenic acid • Caffeic acid • Lactic acid • Beverages	• Biosugar • Melanoidin • N-pentadecane • 6,7-epoxygeraniol • 2,3-epoxygeraniol • Trigonelline	• Polyhydroxyalkanoates • Caffeic acid • Bio-oil • Ethyl tert-butyl ether • Biosorbents • Liquid polyols • Chlorogenic acid • Carotenoids • Iso-olefins • D-Mannose • Mannose-oligosaccharides • Biodiesel • Bioethanol

3 Methodology

This section presents the research methods used in this study as illustrated in Figures 4.

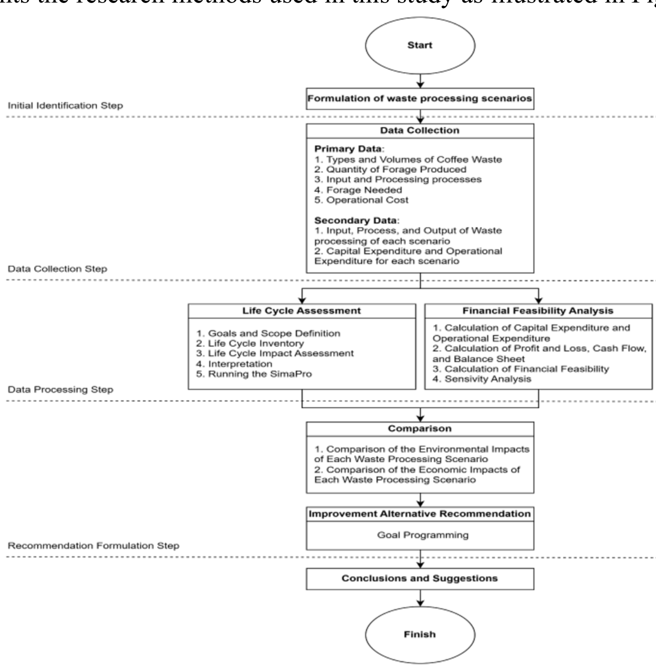

Fig. 4. Research Steps

3.1 Initial Identification

The initial identification is the first step conducted in this research, where potential scenarios for processing coffee pulp waste are identified, as shown in Table 5.

Table 5 . Value-Added Products in the Coffee Life Cycle

Scenario	Product	Feasibility in Association
1	Raw Materials for Cosmetic	
2	Cascara Tea	X
3	Bioetanol	
4	Briquettes	
5	Fertilizer	X
6	Animal Feed	X

3.2 Data Collection

In this step, data collection is carried out to serve as input for processing in the SimaPro software and data for financial feasibility analysis. The collected data consists of two types: primary data obtained from observations and interviews with the Wonosalam Coffee Association, and secondary data from credible external sources that are relevant.

3.3 Data Processing

In this step, the collected data is processed by utilising two analysis methods, they are:

- Life Cycle Assessment

SimaPro software is utilized during Life Cycle Assessment with the following stages Goal and Scope Definition, Life Cycle Inventory, Life Cycle Impact Assessment, Life Cycle Interpretation.

- Financial Feasibility Analysis

This analysis is includes several calculations, namely: (1) cash flow , (2) net present value (NPV),(3) internal rate of return (IRR), (4) payback period (PBP), and (5) sensitivity analysis..

3.4 Recommendation Formulation

In this step, in order to formulate recommendation, a comparison is made of the data processing results, specifically the economic and environmental impacts of waste processing, as well as selecting the best alternatives by utilizing Multi-Criteria Decision Making (MCDM) method and Goal Programming.

4 Discussion

This section presents descriptions of Coffee Cooperative's existing conditions, including its profile and production processes, then it is followed by environmental and economic impact analysis.

4.1 Wonosalam Coffee Association Profile

The Wonosalam Coffee Association was established in 2018. This organization consists of coffee farmers, coffee producers, and other coffee business players in Wonosalam. The Wonosalam Coffee Association is located Jombang, East Java, Indonesia. The purpose of establishing the Wonosalam Coffee Association is to strengthen, improve professionalism, and enhance the competitiveness of the coffee industry, to make a positive contribution to the local and national economy and improve the well-being of the community in general. The processes that occur at the Wonosalam Coffee Association are shown in Figure 5. It consists of four main stages: upstream, post-harvest, roastery, and downstream.

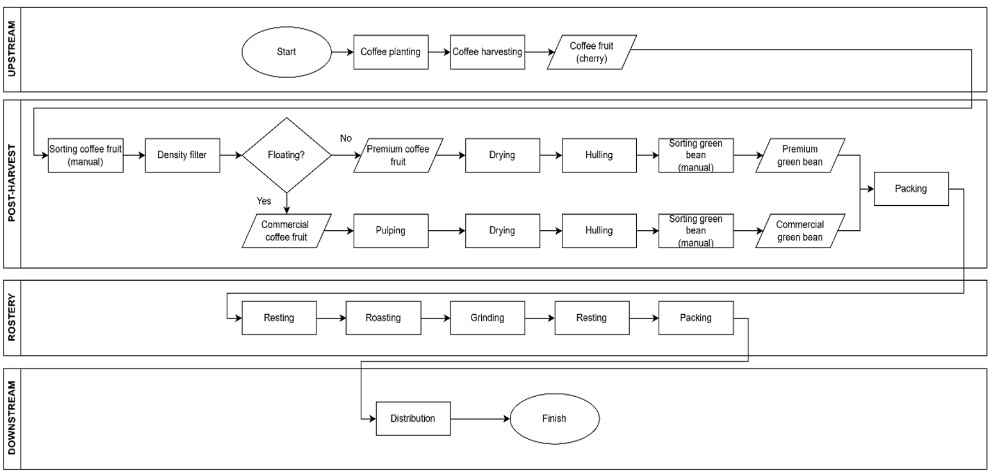

Fig. 5. Production Flow of Wonosalam Coffee Assocation

4.2 Environmental and Economic Impact Analysis of the Existing Condition

The objective of this LCA is to analyze the life cycle of the post-harvest process at the Wonosalam Coffee Association for the year 2023. The scope of the study is illustrated in Figure 6.

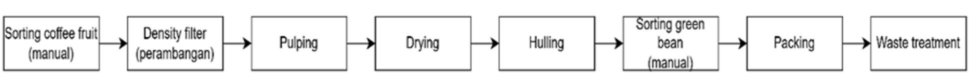

Fig. 6. Scope Definition in the Existing Condition

Based on the scheme, the calculations performed fall within a gate-to-gate scope. The functional unit in this study is as follows:

- Product Type: Green bean
- Varieties: Excelsa, Robusta, and Arabica
- Total Quantity: 20,000 kilograms

4.2.1 Environmental Impact Analysis

Based on the impact assessment results, the characterization outcomes can be seen in Figure 7.

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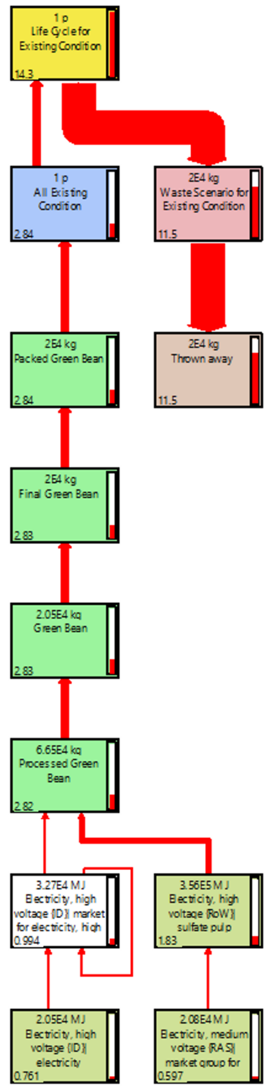

Fig. 1. Characterization of Existing Condition

According to Figure 7, the waste treatment process produces the highest environmental impact or hotspot. This is indicated by the thick red line in the waste treatment process.

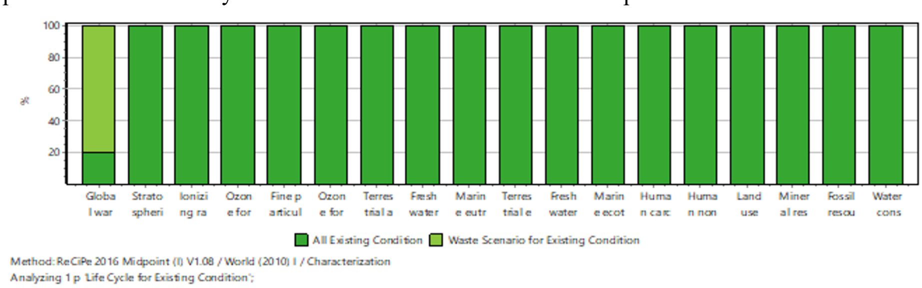

Fig. 8. Impact Assessment of the Existing Condition

Based on the impact assessment chart in Figure 8, it can be seen that the waste treatment process is not optimal and contributes 80% to the global warming impact generated from the entire process, amounting to 123,473.7 kg CO2 eq.

4.2.2 Economic Impact Analysis

Based on the financial feasibility calculations, the results are shown in Table 6.

Table 6. Financial Feasibility Analysis of the Wonosalam Coffee Association's Existing Condition

Analysis method	**Result**
NPV	207,849,732
IRR	21.24%
Payback Period	LESS THAN 3 YEARS
Conclusion	FEASIBLE

4.2.3 Sensitivity Analysis

The results of the sensitivity analysis for the inflation variable indicate that the business remains feasible, meaning the viability of the Wonosalam Coffee Association is not affected by the inflation rate. Furthermore, the sensitivity analysis for the credit interest rate variable shows that the WACC increased from 5.49% to 7.21% when the credit interest rate was at 8%. Meanwhile, when the credit interest rate was at 1.90%, the WACC decreased to 4.47%. However, the business remains feasible, as the viability of the Wonosalam Coffee Association is not affected by the credit interest rate. Additionally, the business feasibility analysis of the Wonosalam Coffee Association shows that by adjusting the WACC variable to 21.25%, it can be concluded that the maximum feasible WACC value is <21.24%.

4.3 Environmental and Economic Impact Analysis *of Waste Processing into Cascara Tea*

This section will present the environmental and economic impact analysis of the scenario for processing coffee husk waste into cascara tea.

4.3.1 Environmental Impact Analysis

Based on the impact assessment results, the characterization outcomes can be seen in Figure 9.

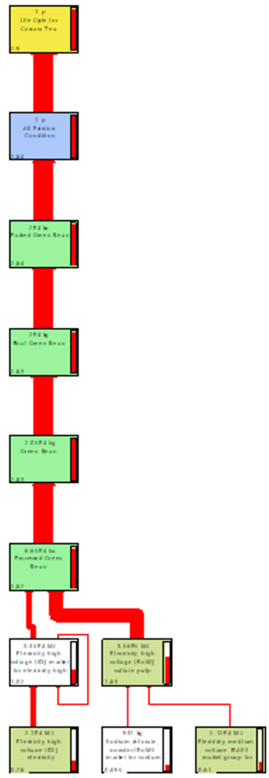

Fig. 9. Characterization of the Waste Processing Scenario into Cascara Tea

According to Figure 9, it can be seen that the production process generates the highest environmental impact or hotspot. This is indicated by the thick red line produced.

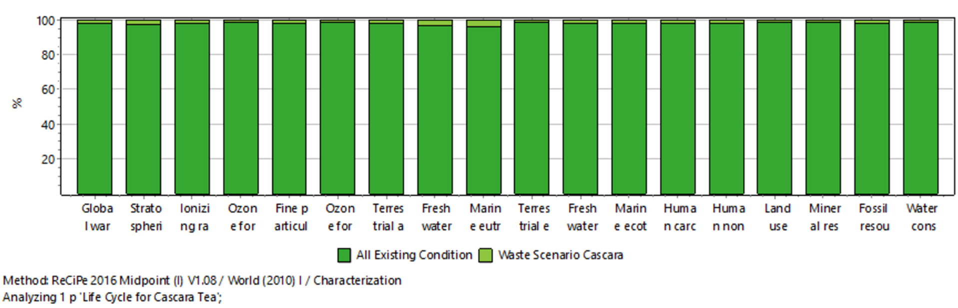

Fig. 10. Impact Assessment Chart for the Waste Processing Scenario into Cascara Tea

Based on the impact assessment chart in Figure 10, it is known that the waste processing only contributes 2% to the global warming impact generated from the overall process, amounting to 617.85799 kg CO2 eq.

4.3.2 Economic Impact Analysis

Based on the financial feasibility calculations, the results are shown in Table 7.

Table 7. Financial Feasibility Analysis for the Waste Processing Scenario into Cascara Tea

Analysis method	**Result**
NPV	268,949,015
IRR	28.58%
Payback Period	LESS THAN 3 YEARS
Conclusion	FEASIBLE

4.3.3 Sensitivity Analysis

The results of the sensitivity analysis on the inflation variable indicate that the business remains feasible, as the feasibility of the Asosiasi Kopi Wonosalam's operations is not affected by the inflation rate. Furthermore, the sensitivity analysis results on the credit interest rate variable show that the WACC, which was initially 5.49%, increases to 7.21% when the credit interest rate is at 8%. Meanwhile, when the credit interest rate is at 1.90%, the WACC value decreases to 4.47%. However, the business remains feasible, and the feasibility of Asosiasi Kopi Wonosalam's operations is not affected by changes in the credit interest rate. Additionally, a feasibility analysis was conducted by adjusting the WACC variable to 28.59%. It can be concluded that the maximum WACC value is <28.58%.

4.4 Environmental and Economic Impact Analysis *of Waste Processing into Fertilizer*

This section will present the environmental and economic impact analysis of the scenario for processing coffee husk waste into fertilizer.

4.4.1 Environmental Impact Analysis

Based on the impact assessment results, the characterization outcomes can be seen in Figure 11.

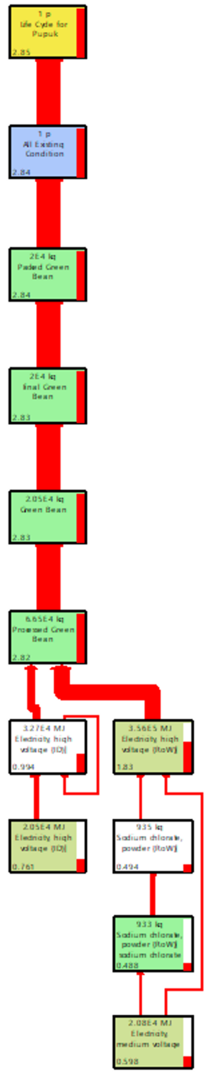

Fig. 11. Characterization of the Waste Processing Scenario into Fertilizer

According to Figure 11, it can be observed that the production process results in the highest environmental impact or hotspot. This is indicated by the thick red line produced.

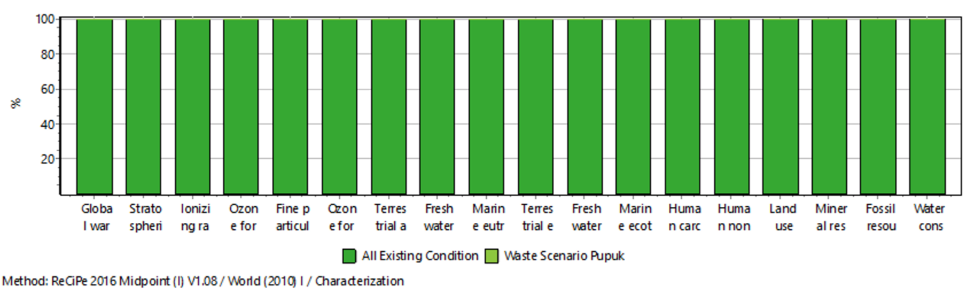

Fig. 12. Impact Assessment Chart for the Waste Processing Scenario into Fertilizer

Based on the impact assessment chart in Figure 12, it can be seen that the waste processing contributes only 0.3% to the global warming impact generated from the entire process, amounting to 91.635353 kg CO2 eq.

4.4.2 Economic Impact Analysis

Based on the financial feasibility calculations, the results are shown in Table 8.

Table 8. Financial Feasibility Analysis for the Waste Processing Scenario into Fertilizer

Analysis method	**Result**
NPV	329,960,608
IRR	26.86%
Payback Period	LESS THAN 3 YEARS
Conclusion	FEASIBLE

4.4.3 Sensitivity Analysis

The results of the sensitivity analysis on the inflation variable show that the business remains feasible, and the feasibility of the business at the Asosiasi Kopi Wonosalam is not influenced by the inflation rate. Furthermore, the results of the sensitivity analysis on the credit interest rate variable show that the WACC increases from 5.49% to 7.21% when the credit interest rate is at 8%. When the credit interest rate is at 1.90%, the WACC decreases to 4.47%. However, the business remains feasible, and the feasibility of the business at the Asosiasi Kopi Wonosalam is not influenced by the credit interest rate. Finally, the business feasibility analysis at the Asosiasi Kopi Wonosalam, with the WACC variable set to 26.87%, concludes that the maximum value of WACC is <26.86%.

4.5 Environmental and Economic Impact Analysis *of Waste Processing into Animal Feed*

This section will present the environmental and economic impact analysis of the scenario for processing coffee husk waste into animal feed.

4.5.1 Environmental Impact Analysis

Based on the impact assessment results, the characterization outcomes can be seen in Figure 13.

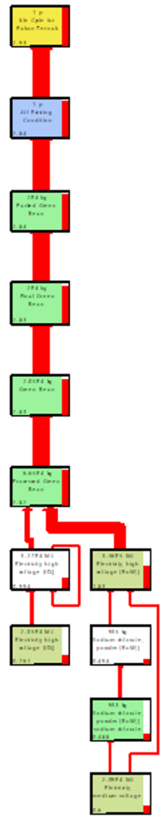

Fig. 13. Characterization of the Waste Processing Scenario into Animal Feed

According to Figure 13, it can be seen that the production process results in the highest environmental impact or hotspot. This is indicated by the thick red line produced.

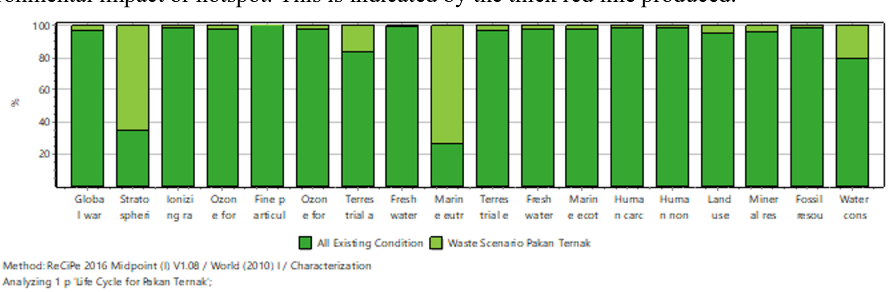

Fig. 14. Impact Assessment Chart for the Waste Processing Scenario into Animal Feed

Based on the impact assessment chart in Figure 14, it can be seen that the waste processing contributes only 0.3% to the global warming impact generated from the entire process, amounting to 91.635353 kg CO2 eq.

4.5.2 Economic Impact Analysis

Based on the financial feasibility calculations, the results are shown in Table 9.

Table 9. Financial Feasibility Analysis for the Waste Processing Scenario into Animal Feed

Analysis method	Result
NPV	269,472,178
IRR	22.52%
Payback Period	LESS THAN 3 YEARS
Conclusion	FEASIBLE

4.5.3 Sensitivity Analysis

The results of the sensitivity analysis for the inflation variable show that the business remains feasible, and the feasibility of the business at Asosiasi Kopi Wonosalam is not affected by the inflation rate. Furthermore, the sensitivity analysis results for the interest rate variable show that the WACC, which was previously 5.49%, increased to 7.21% when the interest rate was set at 8%. On the other hand, when the interest rate was set at 1.90%, the WACC decreased to 4.47%. However, the business remains feasible, and the feasibility of the business at Asosiasi Kopi Wonosalam is not affected by the interest rate. Subsequently, the feasibility analysis for Asosiasi Kopi Wonosalam with the WACC variable changed to 22.53% leads to the conclusion that the maximum value of WACC is <22.52%.

4.6 *Formulation of Recommendations*

In this section, the formulation of recommendations using the Goal Programming (GP) method will be presented to find the best waste processing combination that can be applied to the Asosiasi Kopi Wonosalam. A comparison of the results of economic and environmental impact calculations from the existing condition is added with each scenario, as shown in Table 10.

Table 10. Comparison of Environmental and Economic Impacts for Each Scenario

Scenario type	Carbon	NPV
Discarded	123473.7	0
Cascara Tea	617.85799	61099283
Fertilizer	91.635353	122110876
Animal Feed	1018.3816	61622446

Based on the existing comparison, a LINGO software run will be conducted as shown in Figure 15.

```
Lingo Model - Lingo1
MODEL:

! The goal is to minimize the value of D1min and D2plus;
MIN = D1min + D2plus;

! The constraint for the total amount;
X1 + 1.704 * X2 + 0.651 * X3 + 0.709 * X4 <= 92000;

! The constraint for NPV;
0 * X1 + 61099283 * X2 + 122110876 * X3 + 61622446 * X4 + D1minus - D1plus = 5250000000;

! The constraint for carbon emissions;
123473.7 * X1 + 617.85799 * X2 + 91.635353 * X3 + 1018.3816 * X4 + D2minus - D2plus = 1943.57;

END
```

Fig. 15. Input Model in LINGO Software

Based on the model run, the solution is obtained as shown in Figure 16.

Fig. 2. Output in the LINGO software

If all the coffee husk waste must be processed, the ratio of coffee husk waste processing into fertilizer to processing into animal feed is 27.9:1. Therefore, from the total waste produced, which is 92,000 kg, 88,816.61 kg of the coffee husk waste will be processed into fertilizer. Meanwhile, 3,123.39 kg of the coffee husk waste will be processed into animal feed.

5 Conclusion and Future Research

This section presents the conclusions from the research findings that address the objectives, provide recommendations for the company that is the subject of the study, and suggest directions for future research.

5.1 Conclusion

The Wonosalam Coffee Association identifies several potential ways to process coffee husk waste into value-added products, such as raw materials for cosmetics, cascara tea, bioethanol, briquettes, fertilizer, and animal feed. However, after selecting scenarios that consider various factors, including the capabilities of the management, available resources, accessible technology, and operational needs, the decision was made to focus on processing coffee husk waste into cascara tea, fertilizer, and animal feed. This selection is based on considerations of efficiency, resource availability, and the operational capacity of the Wonosalam Coffee Association.

This study finds that disposing of coffee husk waste without processing results in carbon emissions of 123,473.7 kg CO_2 eq and has an NPV of 0. This scenario shows a relatively high environmental impact because no processing is done, and it yields the lowest economic value due to the lack of waste treatment and added value. On the other hand, processing the waste into cascara tea produces carbon emissions of 617.86 kg CO_2 eq with an NPV of 61,099,283. Processing it into fertilizer results in carbon emissions of 91.64 kg CO_2 eq and an NPV of 122,110,876. Meanwhile, converting it into animal feed generates carbon emissions of 1,018.38 kg CO_2 eq and an NPV of 61,622,446.

Based on the comparison of environmental impact and economic benefits, the Wonosalam Coffee Association is advised to process 88,816.61 kg of coffee husk waste into fertilizer and 3,123.39 kg into animal feed. With this strategy, the association can achieve an optimal balance between reducing environmental impact and increasing economic gains from coffee husk waste processing.

5.2 Future Research

For further research, analysis of all waste generated in the production process of coffee production including social and cultural impacts of implementing the coffee husk waste processing strategy in the local community should be considered.

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