IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Design & Nature and Ecodynamics
Vol. 19, No. 4, August, 2024, pp. 1371-1384
Journal homepage: http://iieta.org/journals/ijdne

Estimating the Management of Crystal Coconut Sugar Production with Life Cycle Cost Analysis and Eco-Efficiency Indicator

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https://doi.org/10.18280/ijdne.190430

Received: 18 January 2024
Revised: 15 April 2024
Accepted: 22 April 2024
Available online: 28 August 2024

Keywords:
crystal coconut sugar, eco-cost, Eco-Efficiency Index, energy sources, environmental impact, life cycle assessment, life cycle costing, net value, revenue

ABSTRACT

The conversion process of palm sap into crystal coconut sugar has increased the added value of the raw material in Banyumas Central Java. It is then important to analyze the economic sustainability of this agroindustry to ensure the future of this important industry due to abundant labor intake. The process uses technology in the form of the crystallization of coconut sugar from collected palm sap. The method used in analyzing crystal coconut sugar products is life cycle cost analysis and eco-efficiency indicators. Usually, life cycle assessment to analyze the environmental impact of the production process is also run alongside the life cycle costing. The life cycle cost (LCC) process which is part of life cycle assessment (LCA) consists of 4 stages, namely goal and scope, inventory, impact, and interpretation. In this study LCA analysis using gate-to-gate boundary and 50 kg crystal coconut sugar as the functional unit. Life cycle assessment results indicate that the environmental impact on human health is the highest impact with the normalization values for human health, ecosystems, and resources, respectively, are 0.222, 0.0165, and 0.00133. This is because the use of wood fuel has a greater influence and impact on society and the environment especially the smoke when compared to the use of fuel from electricity or gas. On the other side, LCC analysis showed the R/C calculation by dividing the Revenue value, which is USD 43,890 against the Total Cost of USD 40,301 with an R/C value of 1.0831 which is > 1 to indicate the affordability, meaning that efforts to manage coconut sugar provide significant results. However, the B/C (Benefit/Cost) value is 0.0831, and NPV is 0.0973 which indicates the benefit obtained is lower than the cost incurred, and the business isn't worth running. The resulting NPV is USD 2,239 and the BEP value is 3 years. The Eco-Efficiency Index (EEI) value is a division of the Eco-Efficiency Cost value by the Net Value, which is 0.0160 (EEI values between 0-1 sign affordable but not sustainable) that indicates unsustainable to be run in the future. The overall results showed that this industry is affordable but not sustainable. Based on LCA analysis, sustainability can be achieved with better fuel sources such as electricity or gas.

1. INTRODUCTION

Growth in the use of coconut as an industrial raw material is accelerated. These processed coconut products range from coconut meat, coconut oil, and coconut sap to coconut sugar and ant sugar. Information from the Logistics Agency in 2001 explains that national sugar consumption reached 3.3 million tons per year. Until November 2023, Indonesia still faces a deficit of 686,830 tons of sugar consumption or white crystal sugar. This is because domestic sugar consumption production is only around 2.42 million tons, while the demand reaches 3.11 million tons [1]. This achievement is not equal to the sugar production capacity of only about 1.6 million tons/year. Palm sugar can enter the market to fill the gap in sugar consumption. Coconut sugar is coconut sugar in powder form which can be made from palm sap, where a solution of palm sugar has been melted again by adding water at a certain concentration [2]. Apart from that, the meaning is that it is called ant sugar because its appearance resembles an ant's nest.

The weaknesses of coconut sugar products on the market include that they do not have a long shelf life (around three months), are not packaged properly, and are less practical in terms of presentation. The development of modern society requires the presentation of products that are practical, hygienic, and of high quality [3, 4]. Based on previous research, it is known that the volatile components of brown sugar are produced mainly through the Maillard reaction and caramelization. The addition of lime water during the clarification stage (increasing pH) and heating at high temperatures during the evaporation and concentration stages will accelerate the Maillard reaction and caramelization. Membrane filtration is a new filtration method that can remove impurities directly through the filtration process without adding lemon juice, retaining more nutrients without changing the pH, or increasing metal ions. Vacuum heating can reduce the evaporation temperature and concentration step, weaken the Maillard reaction and caramelization, and have a higher nutrient retention capacity than traditional brown sugar production [5].

Brown sugar and coconut sugar are products made from sugar cane by heating the sap until it reaches a certain viscosity and then shaping it into the desired shape. Meanwhile, ant sugar is a product diversification of brown sugar in the form of powder small crystals, or flour.

The way to make coconut sugar and brown sugar is the same, only the final step is different. In brown sugar processing, after the resin thickens/cooks, molding is done, while in coconut sugar processing, once the resin has cooled, it is crushed/pressed/removed to obtain fine particles [6].

In general, the quality of processed sugar at the level of farmers and domestic industries is still low because the processing process is not done properly, so the resulting product dissolves quickly because it still contains a high water content from 15 to 17% [7, 8].

The current state and existing problems of coconut sugar production establish the value of the research as the crystal coconut sugar production sector in this region is still considered tiny and traditional. Problems continue to arise in development initiatives. These issues include, among other things, a lack of tools and machines for processing crystal coconut sugar, packaging tools/materials, obtaining Ministry of Health permits, halal labels, and marketing difficulties [8]. Based on the challenges encountered, it is critical to utilize economic analysis research findings to identify limitations in the ant sugar business's viability.

Attempt to increase the selling value of soft jaggery by processing it into jaggery (ant sugar) [9], re-melting the molded sugar by adding water to the sugar solution, and then cooking it into granules (powder). To increase the crystallization ability up to a certain concentration, crystallization sugar can be added as the core of the crystallization process [10]. To accelerate crystal formation during processing and increase granulation capacity, granulated crystallized sugar should be added. When making granulated sugar, the cooking temperature ranges from 100℃ to 125℃ [11, 12].

Despite all of the above-mentioned obstacles, the process of converting the palm sap into crystal coconut sugar has increased the added value of the raw material. A study in Manyampa village in Bulukumba Regency [13] showed that the added value generated from one month of making coconut sugar in the village of Manyampa, Ujung Loe sub-district, was high, with an added value ratio of >50, with a percentage of 85%. Added value > 50% indicates a positive trend of the process to be applied.

Currently, many environmental impact assessment tools and indicators are being developed, including life cycle assessment (LCA). Life cycle analysis is a tool used to evaluate the environmental burden of a product, process, or activity over its life cycle. LCA includes four phases, which are goal and scope definition, inventory analysis, impact analysis, and interpretation [14]. The objective of this study is to perform LCA, analyze the energy requirement for 1 kg of coconut sugar product, and propose alternative improvements to reduce environmental impact and save energy.

Meanwhile, the scope of research is still limited to growing crops and transporting raw materials to the production process. Inventory analysis of the farming process, including manure and ash used for fertilization. Transportation inventory analysis includes gasoline and diesel. Analysis of coconut sugar product manufacturing inventory includes coconut sap, plastic manure, molded sugar, firewood, Liquefied Petroleum Gas (LPG), coconut oil, nuclear crystals, ash, resin, water, lime water, electricity, and dispersed sugar [13, 15]. The coconut sugar production process includes 2 types of processes: coconut sugar is directly produced by farmers, sent to collectors and further processed in factories, and coconut sugar is made from coir sugar collected by collectors. Local collection or Central Processing Unit (CPU) casting and further processing in factories.

The general process for producing coconut sugar, whether raw resin or molded sugar, includes heating and tempering, tempering and grinding, and sieving [16]. The factory's production process includes screening, drying, metal screening, and packaging. Waste from the coconut sugar production process at the factory is in the form of sugar scattered on the ground and plastic used as raw material for coconut sugar production. This spilled sugar is used by factory workers as drinking water for livestock so as not to cause emissions.

Hygiene issues will be addressed by providing advice and support to farmers on kitchen hygiene during production. It is hoped that this awareness will make farmers aware of maintaining cleanliness aspects in the production process. The solution of not branding coconut sugar products will be overcome by organizing seminars on product branding and packaging. Meanwhile, marketers who lack independence will overcome it by providing training and coaching at seminars on Internet marketing and web building in the product marketing process.

Based on the identification of problems faced by the partners, the problem was solved by proposing a business of producing coconut sugar and coconut sugar combined with health-promoting spices such as ginger, cinnamon, ginger and others. Compared to the parent product, printed brown sugar, financially, this type of coconut sugar brings very high profits. Profits can double or even more. Partners will also get an overview of coconut sugar packaging that is attracting consumer interest. The coconut sugar-making equipment uses more durable copper pans so they don't have to be replaced frequently. In addition, there is an 18-mesh stainless steel filter so the sugar output is more uniform.

The initial hypothesis in the research is that the efficiency of the use of fossil fuels in the process of making crystal coconut sugar causes energy costs and environmental impacts that occur around the coconut sugar management location. The state of the art is a strategy for managing crystal coconut sugar products and alternative uses of other energy fuels that are sustainable and environmentally friendly. There is also a knowledge gap that exists, namely the combination of the LCA method with eco-efficiency indicators as the final analysis in the conclusion [17-19]. The novelty in this research is the difference between the analysis carried out in previous research and economic calculation analysis, whereas in this research we use life cycle assessment analysis and eco-efficiency indicators as conclusions.

The purpose of this study is to determine how success can be determined by the presence of indicators of an activity, specifically the changes between before and after completion of the community service activity. Therefore, for scientific and technological activities directed towards the black sugar artisan community, this may serve a purpose, namely as an indicator of human resource capacity. The growing knowledge and understanding of coconut sugar artisans will bring huge market potential for coconut sugar and products derived from it, which could be a means to improve their well-being. Then another indicator is the method of processing coconut resin. This activity will change the coconut sugar production method from cast sugar to refined sugar, which is more expensive and has a longer shelf life [20].

Apart from that, there are additional spices that will provide added value to the product. In its manufacture, a machine will also be provided to stir the sap into sugar, which is more practical and hygienic. This activity can increase the income of coconut sugar craftsmen so that more craftsmen will get involved in the coconut sugar-making business.

2. METHODOLOGY

2.1 Site location and data collection

Primary data were obtained using in-depth interviews and Focus Group Discussion (FGD) while secondary data were obtained from the local stakeholders. Data was then run using the OpenLCA 2.0 software tool (the open-source software for sustainability assessment). After an interpretation of the results of the subsequent analysis, the next step is to use the Simapro 9.4.0.2 software. This methodology is standardized in two International Organization for Standardization (ISO) guidelines, namely, ISO 14040:2006 and ISO 14044:2006. Accordingly, the four stages of the LCA framework are captured in Figure 1 as follows: (i) define goals and scope, (ii) analyze Life Cycle Inventory (LCI), (iii) Life Cycle Impact Assessment (LCIA), and (iv) interpretation.

The method used is a combination of LCC and Eco-Efficiency Indicator methods for economic sustainability. LCC is a data processing process from the location of coconut sap products. The initial stages carried out in the LCA stage are goal and scope, inventory data, impact assessment, and interpretation. Specifically in LCA, a further strategy is LCC analysis to calculate and analyze in detail the cost of energy used. This energy is the use of fuel, water, and electricity. Then the results of the LCC process are combined with the eco-efficiency indicator method. Eco-efficiency indicator to analyze whether the management of crystal coconut sugar meets the requirements of being affordable and sustainable.

Crystal coconut sugar product management activities are carried out in Gandatapa village, Bancar Kembar sub-district in North Purwokerto sub-district, Banyumas Purwokerto-Indonesia. Implementation time is 19 -23 July 2023.

2.2 Goal and scope

LCA is a systematic tool for quantifying the environmental and human health burden of technology to achieve more environmentally compatible and sustainable products [21]. The objective of this study is to evaluate the total life cycle cost of dual-fuel engines compared to conventional engines. The economic benefits of using dual-fuel engines are demonstrated from a life cycle perspective [22]. In addition, the environmental benefits of using dual-fuel engines during operation are also considered. There are four cost components associated with the stages of an engine's life cycle: construction costs, operating costs, maintenance costs, and end-of-life value, as shown in Figure 2. In addition, external costs (i.e., carbon emission costs) are also considered during the operation phase [23].

Thus, the boundaries of the gate-to-gate system were established, focusing primarily on the life cycle stages between the raw material import process and the factory door. Emissions to air, water, and land from the process itself, as well as emissions from the extraction, production, and transportation of all materials and energy, are key considerations for setting out the limits of the system. A diagram of the system boundary is presented in Figure 2. For the system and cost model, it will include cost estimation models (analog, parametric, construction engineering, and accounting).

For the data collection process, public databases and indirectly derived data can also be obtained. Then for the final process, namely the deployment model and cost treatment. There is also an evaluation measurement, namely measures of economic evaluation.

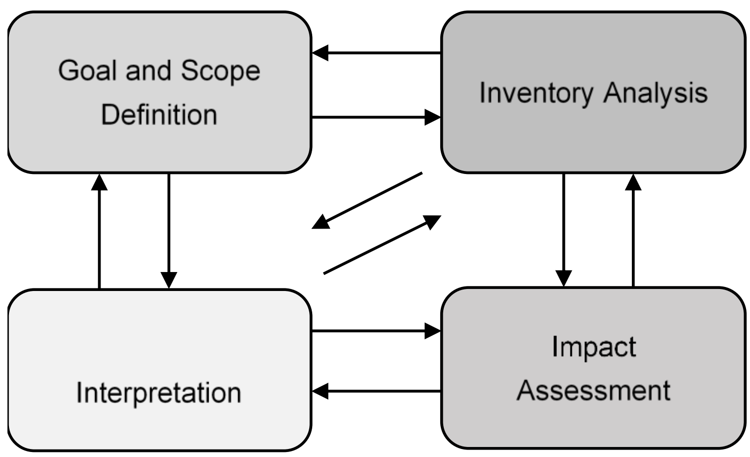

Figure 1. LCA framework [20]

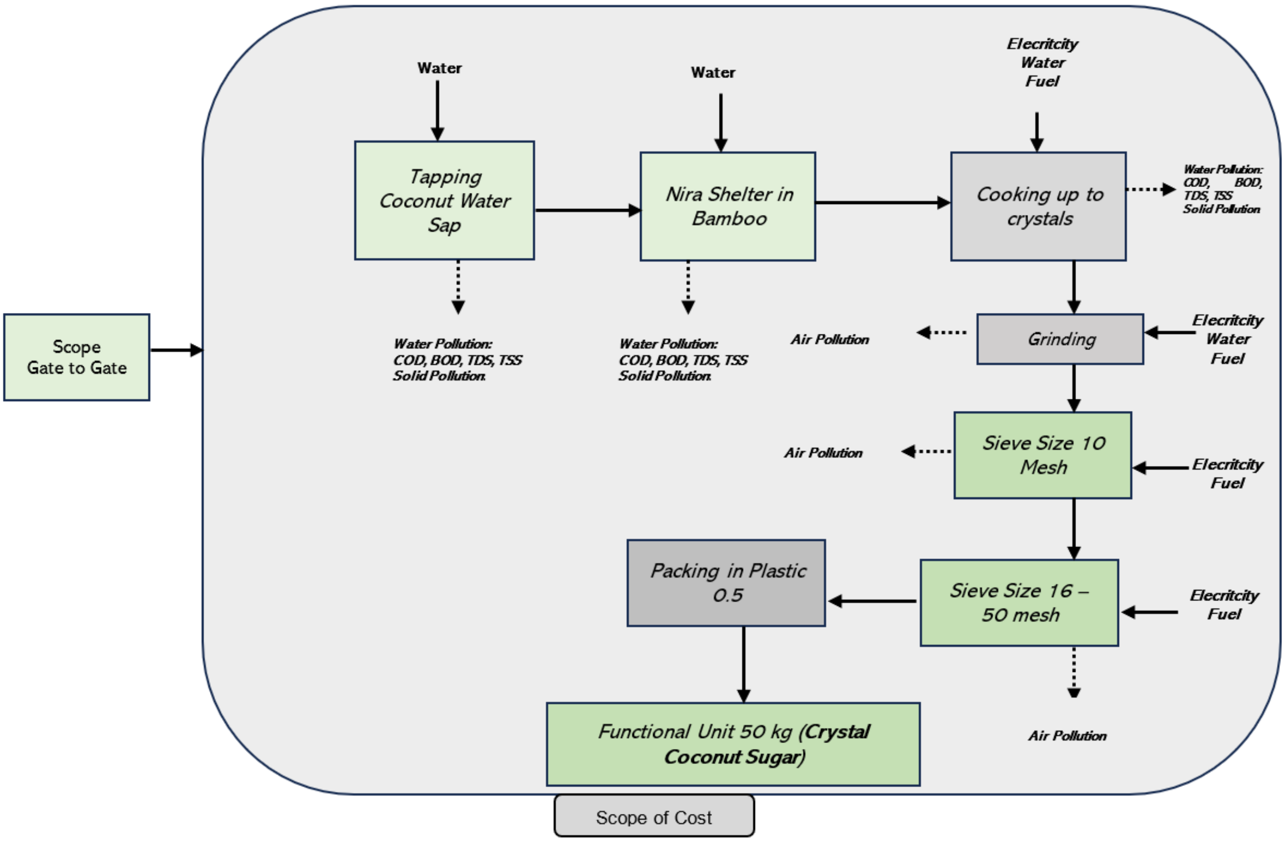

Figure 2. Boundary system of the LCA process unit

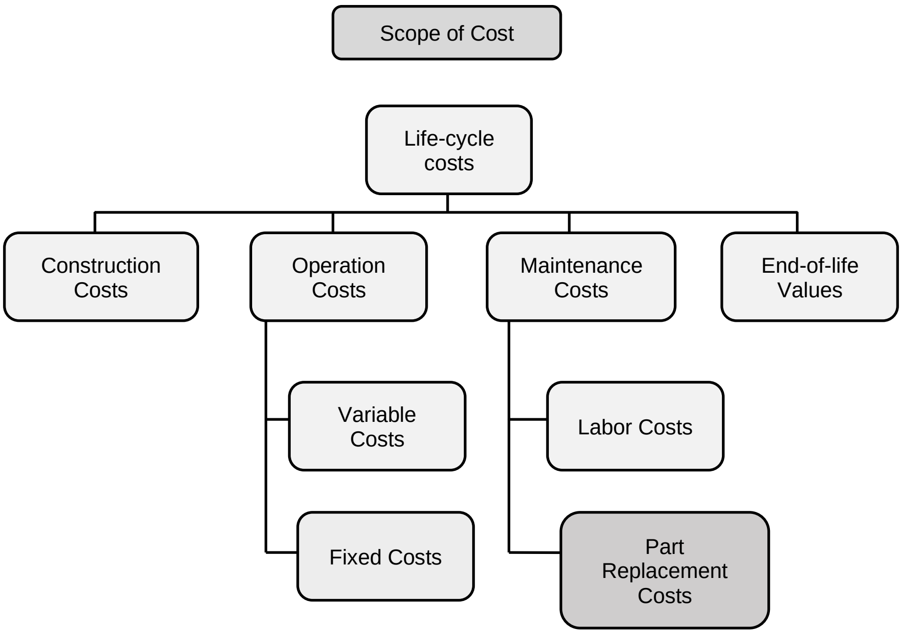

Figure 3. Scope of cost [21]

2.3 Boundary system

The limitation of the coconut sugar production process is presented in Figure 3, it starts with the use of coconut water (nira) and is then used as a downstream process [24]. The next step after extracting coconut sap is to collect the sap from bamboo. At this stage of coconut sap collection, costs are also essential, such as costs that need to be paid to farmers, transportation costs, and other energy costs [25]. The calculation of these costs will be the subject of life cycle costing at the end of this research analysis.

The next step after extracting coconut sap is the cooking process until crystallization. This cooking process also requires a lot of energy such as electrical energy, water energy, and transportation energy [26]. After this stage, farmers also really have to pay attention to the right cooking time to produce coconut sugar products that are expected [27].

Then the next process is sieving size 10 mesh and size 18-50 mesh. The size of the product that matches the desired size is then packed in plastic. After the sugar crystals are formed, they are sifted using an 18-mesh sieve so that the resulting sugar is homogeneous. If the water content is still quite high, especially if you use precast sugar to make coconut sugar, you must dry it in the oven until the water content is < 2%. The next process is the packaging stage. Coconut sugar is weighed into 20 grams and then primarily packaged. All 10 plastics were returned to secondary packaging [28, 29].

Primary packaging uses plastic, while secondary packaging uses paper, which is more environmentally friendly. Apart from single-use sizes, 0.5 kg and 1 kg sizes are also available. In the initial stage, it was planned to only use a crystal sugar mixing machine, but based on suggestions from entrepreneurs who were presented to motivate partners and open a marketing network, it was suggested that it would be better to use a frying pan, so the partners asked to be provided with a more durable brass pan for making the coconut sugar. The functional unit used is 50 kg of coconut sugar.

2.4 Inventory data

Data on the coconut sugar production process were collected from scientific literature data. Additionally, data on energy and raw material flows for coconut sugar processing were collected through a simulation process using OpenLca ecological invention database software.-The database provides initial data and performance of each process to simulate these processes, as presented in Table 1. The system constraints described above represent each process unit used in the production of coconut sugar. This study uses Midpoint Simapro 9.2 Recipe 2016 software to enter data directly from the location of coconut trees.

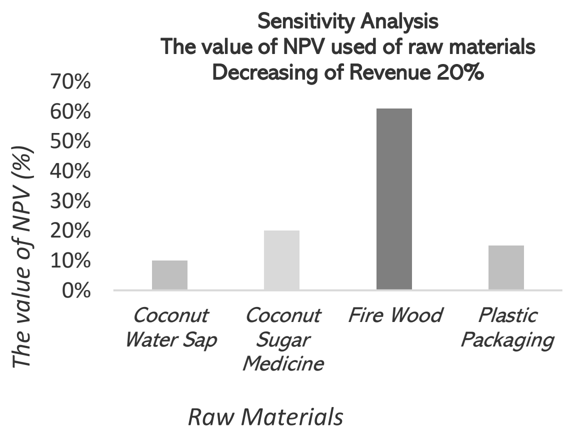

Figure 4. Sensitivity analysis – decreasing revenue 20%

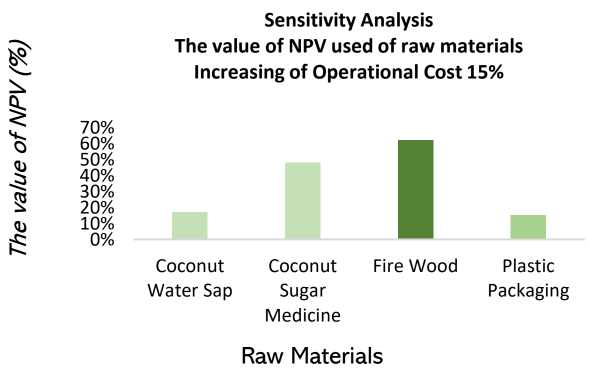

Figure 5. Increasing of operational cost 15%

According to Jasper et al. [30], which describes the use of processing software, the main source of raw material data is the Ecoinvent v3.9 database, which mainly includes European production averages and Global. Differences in database usage exist in this study because coconut sugar production and types of sugar vary from country to country. The processing unit will have inventory data which will then be analyzed using the LCA method. Each inventory data performed must provide a detailed explanation [31, 32]. Indeed, the data obtained must also have good validity. Good validity will be established from the calculation of the acceptable type of effect. For example, assume inventory data is appropriate and depicts coconut sugar production as shown in Figures 4, 5, and 6.

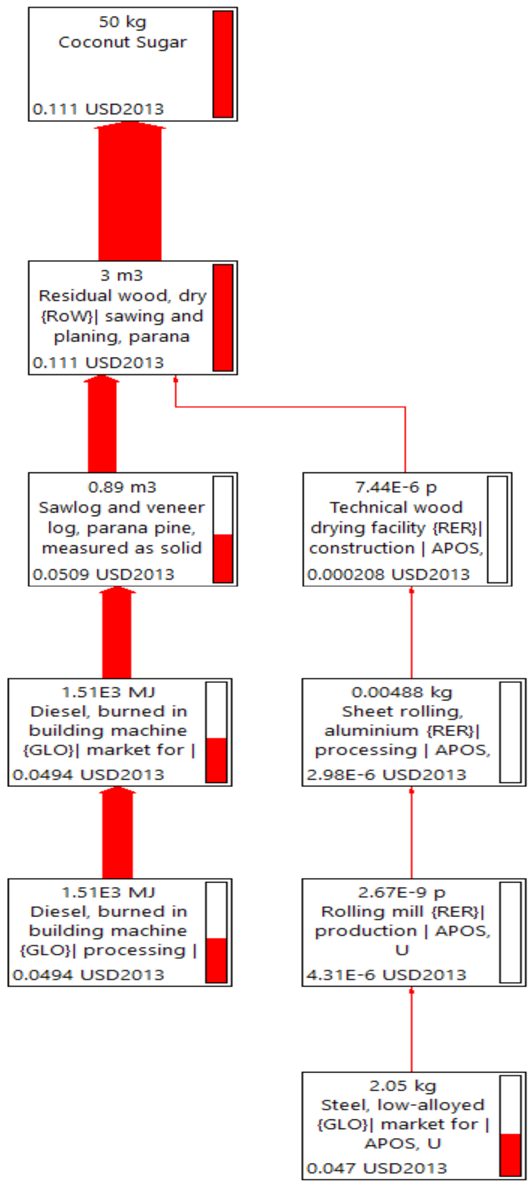

Figure 6. Characterization – mineral resource scarcity (USD 2013)

2.5 Construction cost

Construction costs include the cost of manufacturing the machine before its first use. In this case, the Engine Failure Structure (EBS) of a conventional diesel engine is provided to represent the costs of its major components and systems, as shown in Tables 2 and 3. EBS forms the basis of structural comparison between the use of a conventional appliance (cooking stirrer) and the use of a tubular oven. One of the structural differences between these tube furnaces is the fuel injection system because the dual-fuel engine is equipped with an electrical system [33, 34]. In addition, the installation of a Selective Catalytic Reduction (SCR) system does not apply to dual-fuel engines due to low emissions when operating in gas mode. EBS will also play an important role at a later stage when calculating engine component replacement costs.

Table 1. Variable costs for production facilities

No.	Type of Cost	Unit	Amount	Unit Price	Total Value (IDR)
	Raw Material		6	2000	12.000
1	Coconut Water Sap/ Nira	$dm^3 \times 10^{-3}$			
	Additional Ingredients	-			
2	Calcium Hidroxides	$kg \times 10^{-3}$	0.5	10	5
	Coconut Sugar Medicine	$kg \times 10^{-3}$			
	Fuel				
3	Wood	kg	1	1500	1500
	Husk	kg			
4	Plastic Packaging	m^2	1	40	40
	Harvest Cost	-			
5	Transportation	$m \times 10^3$	4	400.000	400.000
	Firewood	kg	1	1500	1500
	Total				**415.045**

Table 2. Variable costs for labor in the family

No.	Gender	∑ Person	∑ Day	∑ Hours/ Day	Cost/ Day	Total (IDR)
1	Male	1	6	8	75.000	450.000
2	Female	1	6	8	75.000	450.000
	Total					**900.000**

Table 3. Variable costs for outside family labor

No.	Gender	∑ Person	∑ Day	∑ Hours/ Day	Cost/ Day	Total (IDR)
1	Male	4	6	8	90.000	2.160.000
	Total					2.160.000

2.6 Operation cost

Data related to operation costs can be explained in Table 1. The data consists of variable costs, fixed costs, labor costs, and part replacement costs.

In addition to the internal costs incurred by the operation of the machine during its lifetime, the scope of this study is also expanded to include external costs (also called externalities) that are expected to be internalized shortly. This is the cost of carbon emissions that will be included in operating costs at a later stage when carbon pricing scenarios are taken into account. Carbon emission costs refer to the cost of Carbon dioxide (CO_2) equivalent emissions. This could be considered a carbon tax under the International Maritime Organization's (IMO), Market-Based Measured (MBM) or a carbon allowance under the European Union (EU) Emission Trading System (ETS) that can be received, purchased, or even traded [35, 36]. To determine these costs, the environmental impact of the engine needs to be calculated based on the estimated annual CO_2 emissions resulting from fuel combustion [37, 38].

Table 4. Fixed costs, R/C and B/C

Fixed Cost (IDR)	Variable Cost (IDR)	Total Cost (IDR)	Revenue (IDR)	R/C	B/C
317.846.775	319.218.254	637.065.029	690.000.000	1.0831	0.0831

Table 5. Criteria for eco-efficiency index

No.	Process	Status	
1	Eco-Efficiency > 1	Affordable	Sustainable
2	Eco-Efficiency = 0 - 1	Affordable	Not Sustainable
3	Eco-Efficiency < 0	Non - Affordable	Not Sustainable

Table 6. Unit conversion to currency value

No.	Unit	Conversion	The Value of the Currency
1	Species.yr	1.4	Euro
2	MJ Surplus	0.00411	Euro
3	DALYs	74000	Euro
4	1 Euro	16.386	Rupiah

The variable cost values, as presented in Table 1, Table 2, and Table 3, explain the cost values required to obtain raw materials such as coconut water sap, calcium hydroxide, wood, and plastic packaging. Then for the fixed cost values as presented in Table 4, explain that the R/C (Revenue/Cost) and B/C (Benefit/Cost) values are 1.0831 and 0.831, respectively. LCC can also determine the eco-cost value and then convert it to Indonesian rupiah (IDR), as depicted in Tables 5 and 6 [39-41].

2.7 Eco-Efficiency Index

The Eco-Efficiency Index (EEI) value can be obtained from calculations such as the equation below:

$$EEI = \approx \frac{Price - Cost}{Eco\ Cost}$$

The Eco-Efficiency Index (EEI) value can be obtained from calculations such as the equation above [42]. The EEI calculation can be done with a formula as shown in the equation. Data was obtained from both primary and secondary sources. Preliminary data were obtained with structured questionnaires and interview schedules from literate and illiterate farmers in the study area. Secondary data were obtained from annual reports of the state Agricultural Development Program, textbooks, journals, the internet, and previous studies of other resources.

2.8 Eco-Efficiency Ratio

The Eco-Efficiency Ratio (EER) rate value is part of the calculation to determine the eco-efficiency level, calculated by looking for the Eco Cost Value Rasio (EVR).

$$EVR = \frac{Eco\ Cost}{Net\ Value}$$

$$EER\ Rate = (1 - EVR) \times 100\%$$

The method used in the life cycle process uses an analytical approach to data processing. The data processing then uses the OpenLCA 2.0 software tool (the open-source software for sustainability assessment). After an interpretation of the results of the subsequent analysis, the next step is to use the Simapro 9.4.0.2 software.

The input data will be entered into the Simapro software and analyzed for an impact assessment value. Damage assessment obtained from data management, such as human health and resources. For inventory data from human health, it gives a value of 0.00232 DALY. Meanwhile, input in resources provides a value of 37.3 USD.

3 RESULTS AND DISCUSSION

3.1 Results

3.1.1 Net Present Value and Break-Even Point

The economic feasibility analyses used in this research are Net Present Value (NPV) and Break-Even Point (BEP) analyses. The NPV analysis obtained from the calculations is presented in Tables 7 and 8. The resulting NPV is IDR 35.201.489/USD 2,239, and the BEP value is 2.65 years or an estimate of ≈ 3 years. This means that the break-even point value will be obtained after receiving an approach assessment for 3 years.

NPV is an investment feasibility method that aligns future value to present value by discounting cash flows using a discount factor at a certain calculated level of capital costs. The value should be bigger than 1 or positive to be considered feasible as a business. On the other side, BEP (Break Event Point) is an investment analysis method to find out at what level of production the company can recoup the investment it has used. This analysis illustrates the time needed for a business is in a state of is in a state of not making a loss, but also not making a profit. The less time needed to achieve BEP indicates the more feasible the business.

Table 7. Net Present Value

Amount (IDR)	Yr	I (IDR)	Ct	r
48,2411,10.91	1	250.000.000	52.934.971	0.0973
43,963,465.7	2	250.000.000	52.934.971	0.0973
40,065,128.68	3	250.000.000	52.934.971	0.0973
36,512,465.76	4	250.000.000	52.934.971	0.0973
33,274,825.26	5	250.000.000	52.934.971	0.0973
30,324,273.45	6	250.000.000	52.934.971	0.0973
27,635,353.55	7	250.000.000	52.934.971	0.0973
25,184,866.08	8	250.000.000	52.934.971	0.0973
22,951,668.72	9	250.000.000	52.934.971	0.0973
20,916,493.86	10	250.000.000	52.934.971	0.0973
NPV		USD **2,239**		

Table 8. Break even point

Cost per kg	1.2 USD
Price per kg	1.53 USD
Total Fix Cost	20.217 USD
BEP	63,569 kg
Prod	24,000 kg/year
BEP	**2.65 ≈ 3 years**

Table 9 explains the amount of production produced at 50 metric tons. Then, with sales of IDR 24,000/kg or USD 1.53/kg, Total revenue also provides significant results, namely USD 43,890 a year, resulting in a net income of USD 3,589 a month.

Table 9. Production and revenue

No.	Description	Amount	Unit
1	Production	50	tonnes
2	Selling Price	1.53	USD/ kg
3	Total Sales	30	tonnes
4	Revenue	43,890	USD
5	Total Cost	**3,358**	USD monthly
6	Net Income	**3,589**	USD monthly

The results of data processing using OpenLCA 2.0 and an approach carried out using Simapro 9.4.0.2 are depicted in Figure 7. The results from Figure 6 explain that with a functional unit of 50 kg of coconut sugar, the total cost is equivalent to 37.3 USD. This calculation was obtained after inputting data, starting from the energy source used (electricity, water, gas cylinders, and the use of firewood to cook palm sap from coconut).

3.1.2 Sensitivity analysis NPV

Sensitivity analysis to analyze the NPV values obtained in this research. The first scenario is to analyze the NPV value if there is a 20% decrease in revenue. After carrying out a sensitivity analysis, it was found that the most sensitive NPV value was for the use of wood fuel, namely 61%, or IDR 909,396/USD 57.85, as presented in Table 10, Table 11, Figure 4, Figure 5, and Figure 6.

There are differences in the results of the costs required for processing coconut sugar, which is depicted in Figure 7, namely when using wood fuel as an energy source for the cooking process. This difference gives a different result of 27.55 USD. This value is obtained from the difference in the cost of energy used by residual wood, namely 35.2 USD, and the energy used when using electricity, which is 7.65 USD. This illustrates that more efficient energy values will be obtained by using electricity as an energy source rather than using energy fuel from residual wood.

Table 10. Net Present Value decreasing of revenue 20%

Raw Material	Before (IDR)	After Revenue Decreasing 20%	Percentage (%)
Coconut Water Sap	7.275.170	6.581.656	10
Coconut Sugar Medicine	547.249	438.994	20
Fire Wood	909.396	351.195	61
Plastic Packaging	7.755	6.585	15

Table 11. Net Present Value increasing of operational cost 15%

Raw Material	Before	After Increasing 15%	Percentage (%)
Coconut Water Sap	7.275.170	8.538.854	17
Coconut Sugar Medicine	547.249	808.166	48
Fire Wood	909.396	1.471.440	62
Plastic Packaging	7.755	8.919	15

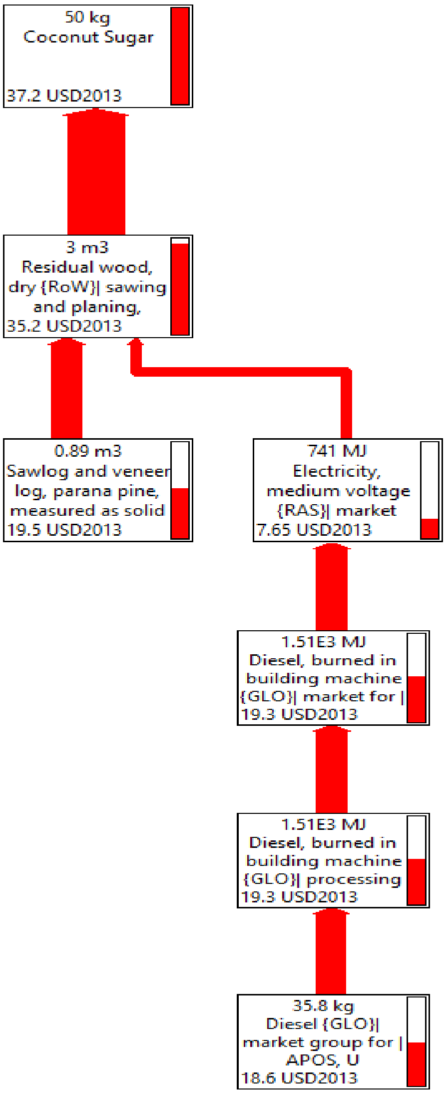

Figure 7. Characterization – fossil resource scarcity (USD 2013)

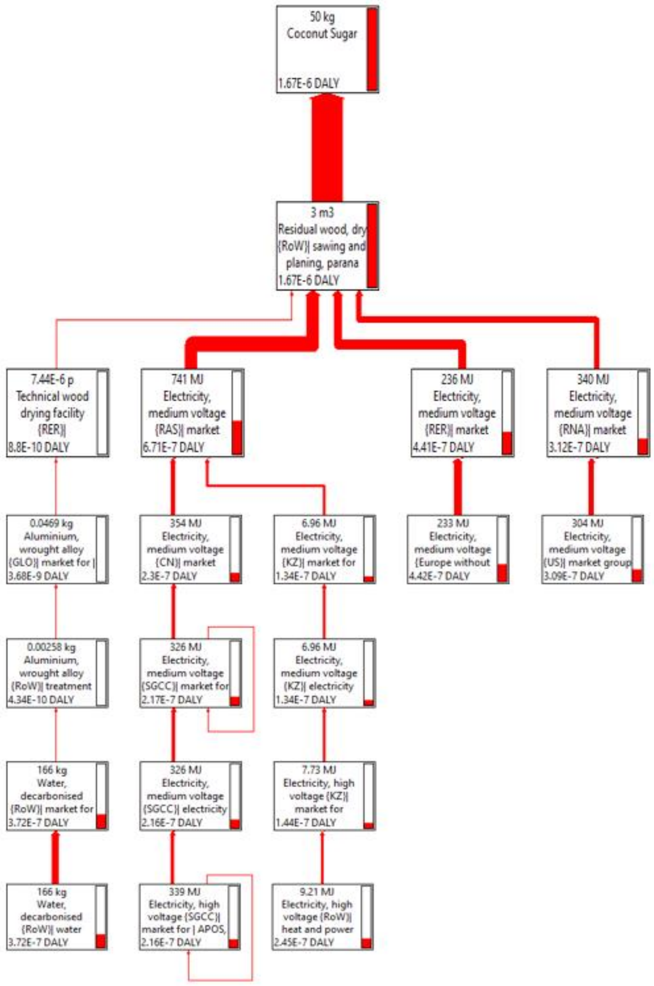

Figure 8. Characterization – water consumption, human health (DALY)

All results are based on the reference functional unit (FU) of 50 kg of crystal coconut sugar, as presented in Figure 8. Categories include acidification, eutrophication, ecotoxicity, global warming potential, and photochemical [43]. In addition, several types can be included as impact assessments, such as Global Warming Potential (GWP) and Ozone Depletion Potential (ODP) [44-46]. The LCIA phase has several steps: classification, characterization, normalization, grouping, weighting, and data quality analysis. The ISO 14042:2000 standard, type, and description are mandatory, while the other steps are optional [47].

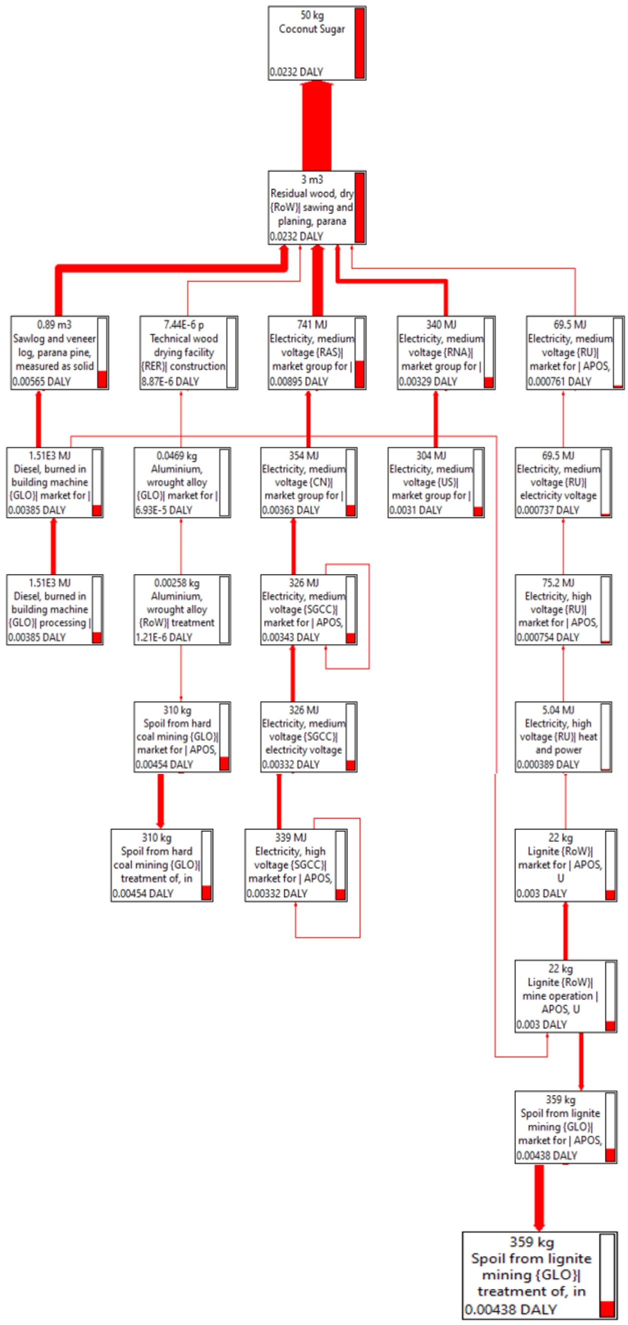

Figure 9. Damage assessment - human health (DALY)

Figures 9 and 10 illustrate the damage assessment value of the residual wood energy source to produce 50 kg of coconut sugar. So the difference in the value of the existing energy source and damage assessment can be seen from the direction of the arrow, which is larger when compared to the energy source that comes from electricity (medium voltage) [48, 49]. This is because the use of wood fuel has a greater influence and impact on society and the environment when compared to the use of fuel from electricity. LPG stoves had the lowest pollutant Emission Factor (EF), with mean PM2.5 and CO > 90% lower than biomass stoves [48, 49]. This explains that PM2.5 was greater in biomass kitchens than LPG kitchens (p = 0.02) [50]. The DALY value obtained can be converted to USD. The conversion value is life cycle cost, which is a quantitative method used and then assessed as presented in Figure 9.

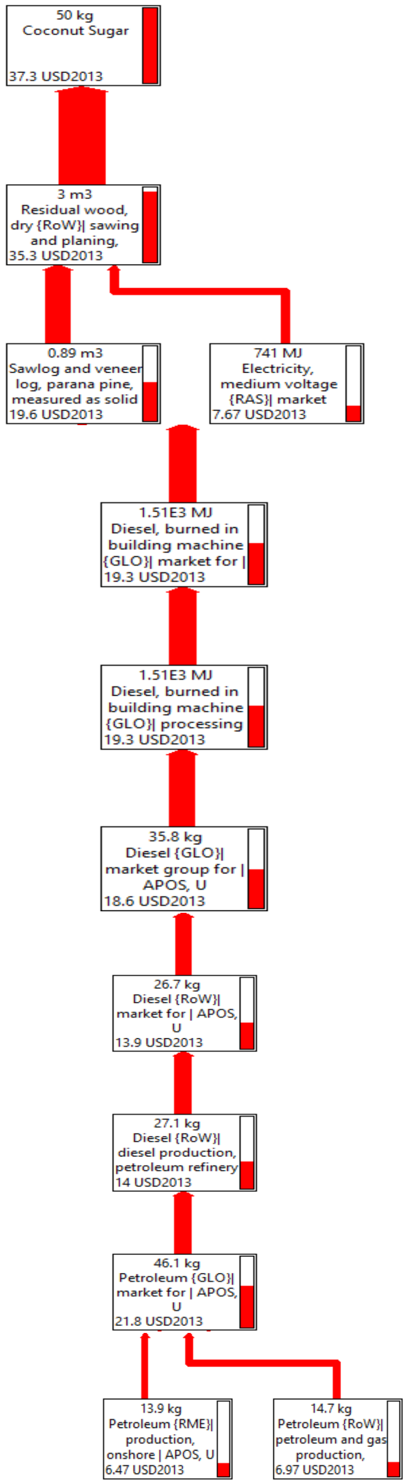

Figure 10. Damage assessment - resources (USD 2013)

The results of the R/C (revenue/cost) value from managing coconut sugar by farmers are obtained from the calculations in Table 6 above. The R/C calculation can be produced by dividing the revenue value, which is IDR 690,000,000, against the total cost of IDR 633,573,534 (IDR 52,797,794 × 12 months), with an R/C value of 1.8906. This R/C value gives a value > 1, meaning that efforts to manage coconut sugar provide significant results. Meanwhile, the B/C (benefit/cost) value is 0.0890. This value indicates that the benefit is not able to cover the cost incurred.

3.2 Discussion

Table 12 below illustrates the eco-cost values of the damage categories in human health, ecosystems, and resources. For human health, it gives a result of 0.0233 in DALY units, while for ecosystems, it gives a result of 3.17×10^{-5} in species/year units. Then, for the resources section, it gives a result of 37.3 in USD units (2013). The largest value converted to rupiah (IDR) is in the damage category of human health, namely 0.0233 ×74,000 × EUR 16,386; the result is IDR 28,252,741. Meanwhile, the Resources section gives results of 37.3 USD (2013) × IDR 12,189, and the result is IDR 454,650.

Then Table 13 below explains the determination of the net value and eco-cost values that have been obtained from previous calculations. The net value obtained is from processed coconut sugar carried out by farmers, with a value of IDR 454,650/ USD 37,30. Meanwhile, the eco-cost value obtained is IDR 28,252,741/USD 2,317. Therefore, the Eco-Efficiency Index (EEI) value is a division of the Eco-Cost value by the Net Value value, which is 0.0160 as presented in Table 14 below.

The value of 0.0160 describes the determination of whether coconut sugar management activities are affordable or sustainable. As described in the introductory section regarding determining the EEI value, it will illustrate whether a coconut sugar management business can be affordable or sustainable. If the EEI value is > 1, then coconut sugar management is affordable and sustainable. Meanwhile, if the EEI value is between 0 and 1, then managing coconut sugar is considered affordable but not sustainable. Then, finally, if the EEI value is <0, coconut sugar management is described as not affordable and not sustainable.

Table 15 below explains the normalization values for human health, ecosystems, and resources. The normalization values for human health, ecosystems, and resources, respectively, are 0.222, 0.0165, and 0.00133. The largest value for human health is 0.222. Then, for Table 16, explaining the weighting values of each human health, ecosystem, and resource, each value is 92.8, 6.89, and 0.279.

Table 12. Eco cost – damage category

Damage Category	Unit	Total	Coconut Sugar	Residual Wood, dry	Diesel, Burned in
Human Health	**DALY**	**0.0233**	3.43E-11	0.0232	2.43E-5
Ecosystem	Species.yr	3.175E-5	4.87E-12	3.17E-5	2.28E-8
Resources	**USD2013**	**37.3**	1.93	35.3	0.087

Table 13. Type of cost

Type of Cost/ Year	Amount
Net Value	*IDR 454,650/ *USD 37,30*
Eco Cost	*IDR 28,252,741/ *USD 2,317*

*1 USD = IDR 12.189 (year of 2013)

Table 14. Calculation of the value of the Eco-Efficiency Index and the eco-efficiency ratio

Value	Unit	Percentage
EEI	Index	0.0160
EVR	Index	62.14
EER Rate	%	-6114.2

Table 15. Normalization

Damage Category	Unit	Total	Coconut Sugar	Residual Wood, dry	Diesel, Burned in
Human Health	**DALY**	**0.222**	3.28E-10	0.222	0.000232
Ecosystem	Species.yr	0.0165	2.53E-9	0.0165	1.19E-5
Resources	**USD2013**	**0.00133**	6.89E-5	0.00126	2.88E-6

Table 16. Weighting

Damage Category	Unit	Total	Coconut Sugar	Residual Wood, dry	Diesel, Burned in
Total	%	100	100	100	100
Human Health	%	92.8	0.000953	**92.8**	**94.6**
Ecosystem	%	6.89	0.00736	6.9	4.84
Resources	%	0.279	100	0.264	0.588

Most global reports focus specifically on palm trees used to harvest sap (sugar syrup), grown in inland India, Philippines, Thailand, Myanmar, Sri Lanka, Indonesia, China, Vietnam, Cambodia, Bangladesh, Papua New Guinea and Australia, Central and South America, the Caribbean and Africa [51]. This is an agricultural industry that uses traditional processes and markets regulated by local customs in Indonesia.

Industrialization of rural areas plays an important role in creating new employment opportunities in rural areas of developing and underdeveloped countries in the geographical regions of South Asia and Africa. Palm sap processing can be one of the major opportunities for industrialization in rural areas. However, scientific and technical attention should be paid to extending the shelf life of palm juice using various processing techniques such as freezing, freeze drying, spray drying, low-temperature plasma, nanofiber membrane filtration, etc. They have their limitations. This results in reduced product acceptance or unavailability of commercial-scale equipment [52-54]. Overall, the crystal coconut sugar business in the producer countries faces similar problems such as lack of technology improvement, large investments in machinery, the cost and maintenance of advanced equipment are quite high and requires highly skilled personnel to undertake operational procedures and lack of awareness of the health benefits of the sap over artificial beverages is the most stupendous task to improve the industrialization, commercialization and consumption of palm sap.

4. CONCLUSION

The LCC results obtained provide the conclusion that managing coconut sugar requires quite a large amount of money. These costs are needed when using energy, which can be used for collecting palm sap from coconut trees to cooking lumps of coconut sugar up to a size of 16 mesh to 50 mesh.

Careful efforts are needed so that the energy used can be absorbed when the final product is obtained. The use of OpenLca and Simapro 9.4.0.2 software tools, then combined with variable cost, fixed cost, and revenue calculations, gives the result that total revenue also provides significant results, namely IDR 690,000,000 in a year, resulting in a net income of IDR 56,426,466 a month.

The R/C calculation can be produced by dividing the revenue value, which is IDR 690,000,000, against the total cost of IDR 633,573,534 (IDR 52,797,794 × 12 months), with an R/C value of 1.8906. This R/C value gives a value > 1, meaning that efforts to process coconut sugar provide significant results. On the other hand, the B/C (benefit/cost) value is 0.0890 which indicates the benefit obtained is less than the cost incurred.

However, there is something that needs to be noted regarding the EEI value obtained from the research, which is 0.0216. This value explains that the management of coconut sugar in this research is affordable but not sustainable.

Moreover, the specific practical significance of research for the coconut sugar industry and the potential impact on related policy-making is as follows:

1. Energy source

This can be influenced by the energy use included in the management process. A very influential use is when the use of fuel (residual wood) has an impact on the surrounding environment. This is different from using gas or electricity as fuel, which will have minimal negative results and impact on the surrounding environment. Therefore, the costs used can be used as an effort to improve ecosystem quality and human health. For other researchers who want to carry out further analysis, it can serve as a basis for better management.

2. Improvement of knowledge of farmers

Apart from that, it is also very necessary to involve the government and other stakeholders to provide space for farmers to improve more. Provision regarding improving work systems and product development and marketing strategies needs to be given to ant sugar processing entrepreneurs. The involvement of stakeholders will help coconut sugar products from farmers to compete not only domestically but also by exporting abroad.

3. Improvements to work systems

Improvements to the work system (work-station architecture, work method/work posture, and physical work environment) for crystal coconut sugar processing by ergonomic principles, which are effective, comfortable, safe, healthful, and efficient.

4. Technological enhancements

Improvement of crystal coconut sugar processing technology through the use of work aids, packaging machinery, and novel plastic package designs.

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NOMENCLATURE

B/C	Benefit/Cost
BEP	Break-Even Point
Bunch	One bond per bunch
CO	Carbon monoxide
CO_2	Carbon dioxide
CPU	Central Processing Unit
DALY's Tonnes	Particulates or atmospheric particulate matter with a diameter of 2.5 µm or less
EBS	Engine Failure Structure
EEI	Eco-Efficiency Index
EER	Eco-Efficiency Ratio
EF	Emission Factor
EVR	Eco Cost Value Rasio
ETS	Emission Trading System
EU	European Union
FGD	Focus Group Discussion
FU	Functional Unit
IDR	Indonesian rupiah
IMO	International Maritime Organization's
ISO	International Organization for Standardization

kg	Kilogram
km	Kilometre
LCA	Life Cyle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCC	Life Cycle Cost
Litre	A metric unit of volume
LPG	Liquefied Petroleum Gas
MBM	Market-Based Measured
MJ	Micro Joule
NPV	Net Present Value
ODP	Ozone Depletion Potential
pH	Acidity or basicity denotes "the potential of hydrogen"
PM2.5	Particulate Matter 2.5
R/C	Revenue/Cost
Sack	One sack of husk
SCR	Selective Catalytic Reduction
USD	United States Dollar