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LIFE CYCLE ASSESSMENT OF GRANULATED COCONUT SUGAR PRODUCTION FARMERS LEVEL IN PURWOREJO

ANALISIS PENILAIAN DAUR HIDUP PRODUKSI GULA SEMUT TINGKAT PETANI DI PURWOREJO

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ABSTRAK

Gula semut merupakan gula kelapa berbentuk bubuk yang diproduksi dari nira kelapa oleh petani Purworejo. Penggunaan teknologi sederhana oleh petani menjadi masalah utama terbentuknya dampak lingkungan karena tingkat efisiensi yang rendah dan pelepasan emisi yang tidak terkontrol. Tujuan dari penelitian ini adalah untuk mengidentifikasi tahapan proses produksi gula semut petani dari nira kelapa menjadi gula semut petani, kemudian menganalisis total dampak lingkungan yang dihasilkan dari produksi gula semut petani menggunakan pendekatan Life Cycle Assessment (LCA) menggunakan metode perhitungan CML-IA Baseline. Lingkup kajian yaitu inventarisasi input dan output yang bersifat "gate-to-gate", perhitungan setiap tahapan proses dari proses pemanasan nira hingga menjadi gula semut, dan intepretasi hasil perhitungan. Unit fungsi yang digunakan dalam analisis dampak lingkungan yang dihasilkan yaitu jumlah dampak yang terbentuk per 1 kg gula semut petani yang diproduksi. Analisis dampak lingkungan menggunakan software SimaPro 9.4.0.2 sebagai alat bantu perhitungan. Hasil analisis dampak untuk memproduksi 1 kg gula semut petani yaitu sebesar 4,762E0-2 kg CO_2 eq untuk dampak GWP, 9,45E-04 kg SO_2 eq untuk dampak AP, dan 2,77E-04 kg PO_4 eq untuk dampak EP. Indikator kontribusi penghasil dampak terbesar GWP terletak pada penggunaan LPG yaitu 2,89E-02 kg CO_2 eq, kontribusi dampak terbesar AP dan EP terletak pada penggunaan kayu bakar yaitu sebesar 8,16E-04 kg SO_2 eq dan 2,12E-04 kg PO_4 eq. Skenario perbaikan dari proses produksi gula semut petani yaitu dengan substitusi penggunaan kayu bakar dengan sekam padi, menurunkan dampak 86% total dampak AP dan menurunkan 93% total dampak EP.

Kata kunci: dampak lingkungan, gula semut, LCA, SimaPro

ABSTRACT

Granulated coconut sugar is a powdered coconut sugar manufactured by Purworejo farmers from the sap of the coconut. Farmers' usage of simple technologies is the primary cause of environmental problems due to poor efficiency levels and uncontrolled emission emissions. The objectives of this research were to identify the stages of the granulated coconut sugar production farmer level process, from coconut sap to farmers' granulated coconut sugar, and then analyze the total environmental impact of granulated coconut sugar production farmer level process using the Life Cycle Assessment (LCA) approach and the CML-IA Baseline calculation method. The study's scope included an inventory of "gate-to-gate" inputs and outputs, computation of each stage of the process from sap heating to granulated coconut sugar, and interpretation of the calculation results. The amount of impact created per 1 kg of farmer-produced coconut sugar was employed as the unit of function in the analysis of the consequent environmental impact. SimaPro 9.4.0.2 software was used to calculate environmental impact analysis. The GWP impact of manufacturing 1 kilogram of farmer granulated coconut sugar was 4.76E-02 kg CO_2 eq, the AP impact was 9.45E-04 kg SO_2 eq, and the EP impact was 2.77E-04 kg PO_4 eq. The biggest GWP effect contribution indicator was the use of LPG, which was 2.89E-02 kg CO_2 eq, while the largest AP and EP impact contribution indicator was the use of firewood, which was 8.16E-04 kg SO_2 eq and 2.12E-04 kg PO_4 eq. The improvement scenario of the granulated coconut sugar production farmer level process, namely substituting the use of firewood with rice husks, reduces 85% of the total AP impact and reduces 93% of the total EP impact.

Keywords: environmental impact, granulated coconut sugar, life cycle assessment, SimaPro

INTRODUCTION

Coconut sugar is powdered sugar made from coconut sap or molded sugar. Coconut sap is a sweet liquid derived from coconut flower buds which is usually used as a raw material for making coconut sugar (Trinidad *et al.*, 2015). According to Chinnamma *et al.* (2019) The glycemic index of coconut-based sugar is lower than other sugar sources. The development of coconut sap utilization has led to an increase in the number of coconut sugar farmers in the Purworejo area, which has led to

**Coressponding Author*

uncontrolled environmental impacts due to the absence of a comprehensive measurement of emissions resulting from coconut sugar production.

Most coconut sugar farmers in Purworejo use simple technology to produce coconut sugar. According to Mela and Ahsan (2019) The use of simple technology is considered very outdated because it has a low level of efficiency, a lot of waste is formed, and the release of uncontrolled emissions, so it is necessary to analyze the environmental impact formed in the production of farmer coconut sugar.

This emission analysis includes material analysis which is used to quantify input-output materials and examine the flux path of each material flow in the entire production system. (Islam and Huda, 2019). The identification of coconut sugar farmer scale production system is carried out to know the stages of the process from sap to coconut sugar, the inputs and outputs that play the most role in producing environmental impacts such as Global Warming Potential (GWP), Acidification (AP), and Eutrophication (EP). The impacts resulting from the production of farmer coconut sugar can contribute to climate change which results in the retreat of glaciers and the increase in sea water volume (Shahzad, 2015), increased NOx, NH3, and SO2 content in the soil which causes a decrease in base saturation resulting in soil acidification. (Hauschild dan Huijbregts, 2015) and increase anthropogenic inputs of nitrogen and phosphorus to terrestrial and aquatic ecosystems thereby reducing biodiversity and decreasing oxygen content in water (Hauschild dan Huijbregts, 2015).

Measurement of the environmental impact resulting from the production of farmer coconut sugar is carried out using the Life Cycle Assessment (LCA) approach which consists of four stages, namely determining the purpose and scope, inventory analysis, impact calculation, and interpretation of results. According to SNI ISO 14040: 2016 LCA is a comprehensive method for analyzing the environmental impact of a product or service, determining whether a production process is efficient in terms of energy use in the production system. Efficiency optimization can result in significant energy and cost savings while minimizing CO_2 emissions. (Astuti *et al.*, 2018). The LCA approach can make it easier to design a product, select suppliers, develop process stages, improve environmental management systems, choose strategies to make decisions easier because it has an actual database and facts.

Several studies on the GWP impact of the sugar industry such as those conducted by Astuti *et al*. (2018) where energy plays a major role in generating emissions. Most of it is generated from the use of fuel oil (BBM), the use of coal, and some comes from burning bagasse. Research conducted by Wedharingtyas dan Ushada (2017) on the GWP impact of the coconut sugar industry resulted in an impact of 10.193 kg CO_2 eq/kg coconut sugar, there was also studies conducted by Suckling *et al*. (2023) on the GWP impact of stevia sugar resulted in an impact of 20.25 kg CO_2 eq/ kg sugar.

There is a significant difference in impact between the two studies, so it can be concluded that the stages of the process, the amount of energy used, are generally different in each industry. This requires conducting a different analysis in each related industry, so the purpose of this study is to identify the stages of the production process of farmer coconut sugar from coconut sap to farmer coconut sugar, then analyze the total environmental impact resulting from the production of farmer coconut sugar.

RESEARCH AND METHODS

Determination of the objectives and scope must be based on literature studies, interviews, observations in related industries, then conduct an analysis using the LCA framework presented in Figure 1 where there are stages of goal and scope, inventory analysis, impact assessment, and interpretation. The main considerations are the product system diagram, system boundaries and the specified unit of function. LCA of coconut sugar production farmer level aims to determine the amount of environmental impact that can be measured quantitatively. Calculation of impacts allows knowing the impact with numerical units and the total impact that contributes most to the production process. The impact categories to be observed are GWP, Acidification (AP), Eutrophication (EP) with the unit of function determined as the impact per kilogram of farmer's coconut sugar produced.

Inventory analysis consists of identifying inputs and outputs based on predetermined system boundaries and data collection referring to SNI 14044: 2017. Data collection is by field observation, conducting interviews with farmers or coconut sugar activists, to literature studies by collecting journals and books that discuss the coconut sugar production farmer level process, and the resulting emissions. Field observations were conducted to observe direct conditions and identify the stages of production flow. Interviews were conducted to determine the number of inputs and outputs from the coconut sugar production farmer level process.

Impact assessment is carried out to evaluate the amounts of emissions that will result from a production process. The inventory results were calculated using SimaPro 9.4.0.2 software with a calculation method using the CML-IA Baseline which will result in impact characterization and normalization of the impact of coconut sugar production farmer level.

The interpretation stage contains the evaluation and report of the results of the impact assessment that has been carried out. Based on SNI 14044:2017, the life cycle interpretation stage of the LCA study consists of several elements, namely:

identification of important issues based on the results at the inventory analysis and environmental impact analysis stages; evaluation that considers completeness, sensitivity, and consistency checks; conclusions, and limitation.

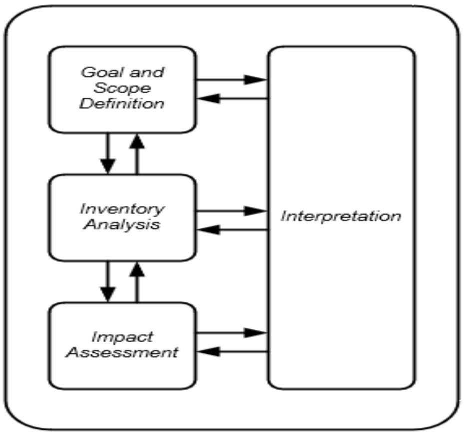

Figure 1. Life Cycle Assesment Framework (ISO 14040:2016)

RESULT AND DISCUSSION

Objective and Scope

The scope of this study is "gate-to-gate" where coconut sap will go through process stages such as heating, heating and mixing, mixing, grinding and sieving, so that the finished product is obtained in the form of coconut sugar. The determination of the unit of function is based on the impact generated per 1 kg of coconut sugar produced by farmers.

The system boundary in Figure 2 has background data covering the secondary scope with data obtained from literature studies, while foreground data is determined after observing farmers in Purworejo by harmonizing each stage of the production process carried out by farmers. The determination of the function unit in the calculation of emissions is very necessary because it facilitates measurement in the product system with impact analysis carried out on the impact categories contained in the LCA study method, namely GWP, AP, and EP. The selection of impact categories is based on the statement of Agathe *et al.* (2014) where the three impacts are the most relevant impacts on food and agricultural products.

Inventory Analysis

Inventory analysis of coconut sugar production farmer level is designed based on the maximum daily production capacity of farmers. Inventory analysis relates data to the unit process by representing the output of the unit process and requires collecting all inputs and outputs as needed per unit process. The final step of the inventory analysis is data aggregation where all unit process data in the product system is combined into a system life cycle model.

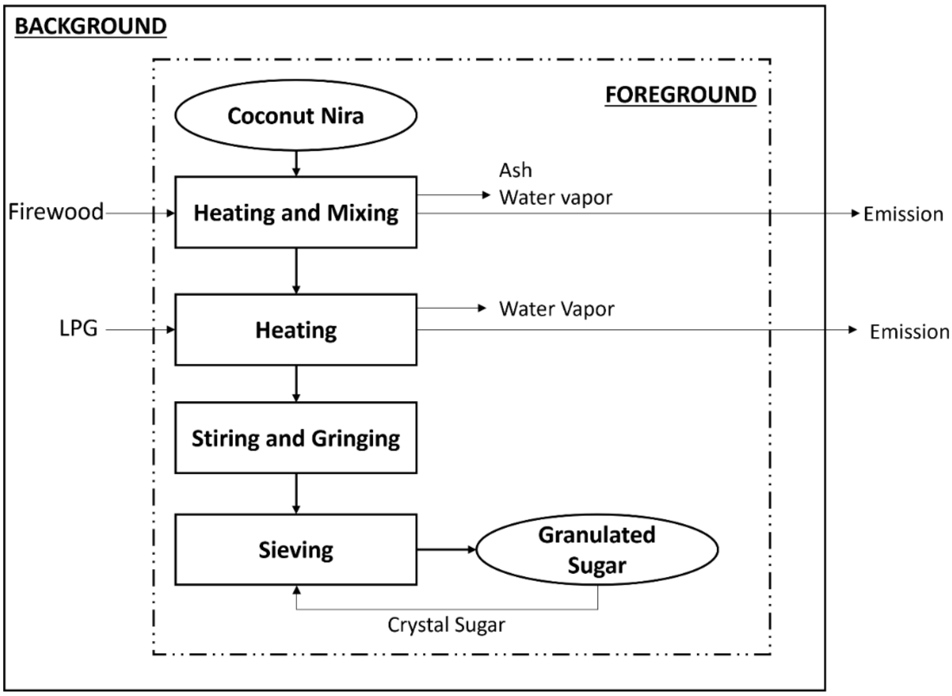

Figure 2. System boundary of coconut sugar farmer

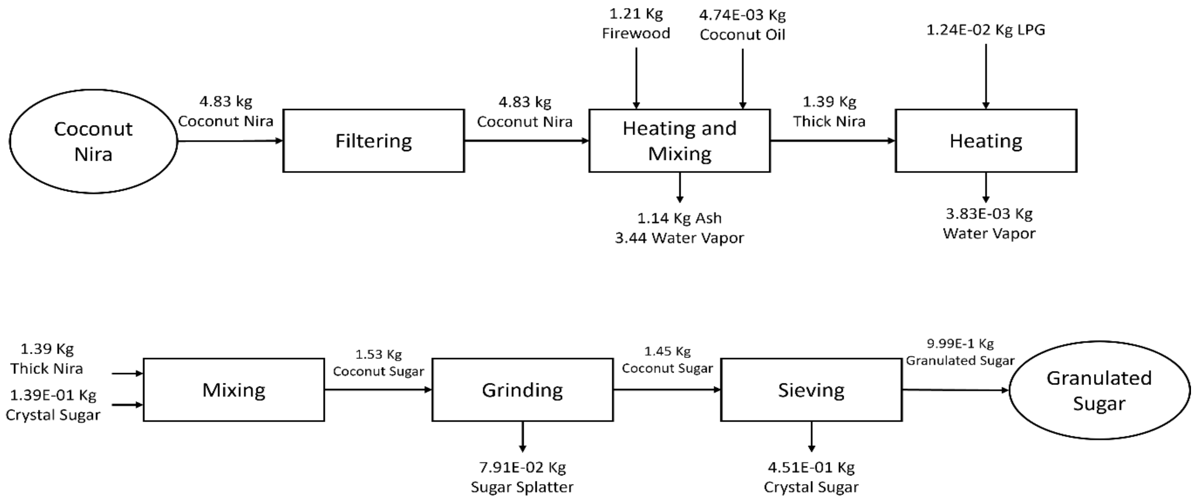

Figure 3. Mass balance granulated coconut sugar production farmer level process

The coconut sugar production farmer level process in Figure 3 starts with heating coconut sap using firewood for 60 to 90 minutes until the sap becomes thick and brownish. To produce 1 kg of coconut sugar requires about 2.5 kg of firewood (Budiarto *et al.,* 2020). Coconut oil is added during the heating and mixing process, the use of coconut oil aims to eliminate froth when heating sap (defoaming) (Yanto dan Naufalin, 2012). The heating process produces outputs in the form of thick juice, ash and water vapor. The amount of ash produced from burning wood assumes that 95% of the wood used is burned and water vapor is assumed to be 71-72% of the water evaporated. According to Ajis *et al.* (2015) the temperature of firewood is very volatile and cannot be controlled, the temperature of deep combustion within 60 to 120 minutes is 150°C to 187°C.

The thick coconut sap is reheated using a gas stove over medium heat for 30 to 45 minutes. Heating without mixing with a gas stove aims to reduce the temperature of the thick sap gradually to avoid clumping of the sap. Mixing without heat is done after the sap has thickened and adding crystal sugar or bunch with a ratio of 1:10 (crystal sugar to coconut sugar) to accelerate the drying of coconut sugar, this is supported by research Tanjung *et al.* (2018) about the addition of sugar and the drying time of coconut sugar where the addition of 12% sugar can accelerate the drying of coconut sugar.

The grinding is done constantly to avoid the formation of hardened sugar lumps. The sieving of the crushed coconut sugar is sieved using a 16-mesh sieve. Sieving aims to obtain fine sugar grains (coconut sugar) and separate large clumps of coconut sugar that cannot be sieved, this sugar is commonly called crystal core. Data from observations and interviews were then summarized in Table 1, this aims to facilitate the input process in the SimaPro software in the environmental impact assessment carried out.

Impact Analysis

Impact analysis aims to determine the contribution of influential materials in generating impacts on each process unit. The impact analysis consists of the selection of impact categories, classification and characterization of impacts. The mandatory component is the presentation of impacts resulting from the calculation of inventory impacts that have been carried out using the CML-2016-IA Baseline. Contribution indicators include sap used, coconut oil, and energy. The energy used in production is firewood and the use of LPG. The results of the impact analysis for producing 1 kg of coconut sugar farmer scale production in Figure 4 are 4.76E-02 kg CO_2-eq for GWP impacts, 9.45E-04 kg SO_2 eq for AP impacts, 2.77E-04 kg PO_4 eq.

The most significant contributor to the GWP impact comes from the use of LPG in the heating and mixing process of 2.89E-02 kg CO_2-eq. The use of LPG aims to maintain the temperature of the sugar so that it does not decrease drastically so that clumps do not form during mixing. The most significant contribution of LPG to the GWP impact is due to the transformation process of natural gas into LPG which goes through a pretreatment process (acid removal, dehydration, and refrigeration), and fractionation. The main impurities found in natural gas are CO_2 and H_2S (Sembiring *et al.,* 2019), this is why the transformation process of natural gas into LPG is a major contributor to the GWP impact.

The most significant contributor to the AP impact is the use of firewood at 8.16E-04 kg SO_2 eq/kg coconut sugar. The burning of wood from the cooking process at high temperatures causes the reaction of nitrogen oxides (N_2) with oxygen (O_2) in the air, the result of this reaction can form nitrogen monoxide (NO) and nitrogen dioxide (NO_2) which are collectively called NO_x. (Kumar, 2017). NO_x compounds are one of the compounds that play a role in the formation of acid rain.

Table 1. Farmer's input and output inventories of granulated sugar production (1 kg basis)

Process Stages	Input		Output		Unit
	Material	Mount	Material	Mount	
Heating and Mixing	Coconut sap	4.83	Ash	1.14	Kg
	Firewood	1.21	Water Vapor	3.44	Kg
	Coconut Oil	4.74E-03			Kg
Heating	LPG	1.24E-02	Water Vapor	3.83E-03	Kg
Mixing	Crystal Sugar	1.4E-01			Kg
Grinding			Sugar Splatter	7.91E-02	Kg
Sieving			Crystal Sugar	4.51E-01	Kg
			Granulated Sugar	1	Kg

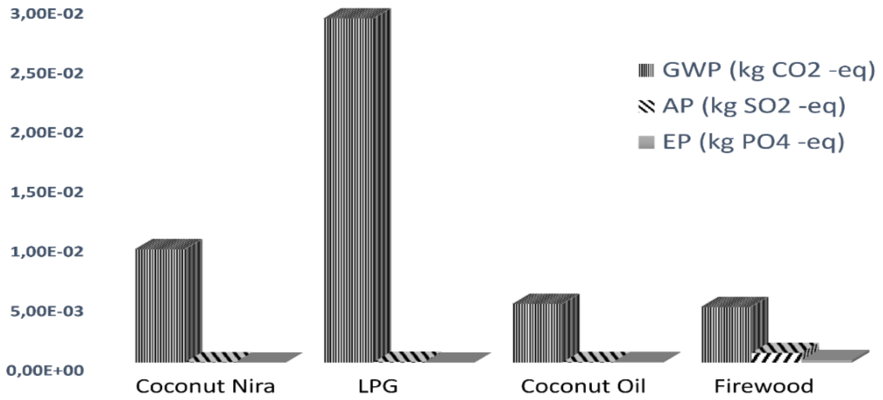

Figure 4. Characterization of coconut sugar production farmer level

According to Imam *et al.* (2021) Acid rain is atmospheric deposition in the form of rain, snow, gases, particulates, and vapors that contain acidic compounds that have a negative impact on the earth. Pollutant sources that cause eutrophication are NO_x, NO, PO_4, and nutrients (N and P) (Athirafitri *et al.*, 2021). NO_x from firewood combustion can interact with other chemical compounds and form nitric acid (HNO_3), and nitric acid (HNO_2). These acidic compounds are transported by acid rain and interact with the soil surface. Nitric acid and nitric acid provide additional nutrients in the form of nitrogen and phosphorus (Kumar, 2017).

Interpretation and Improvement

The interpretation of the results is shown based on the normalization of the assessed environmental impacts in person equivalent units. Normalization is used to check for inconsistencies in providing and conveying information from indicator results and the person equivalent represents the annual per capita global impact (Tukker *et al.*, 2004).

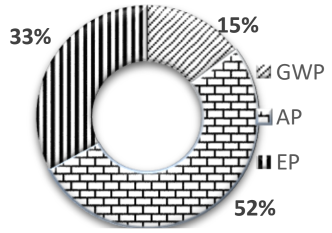

Figure 5. Contribution of indicators in generating environmental impacts

The interpretation results show the production of granulated coconut sugar at the farmer level with a total of 52% acidification impact, 33% eutrophication impact, and 15% global warming impact. The difference is quite significant from the normalization results with characterization; the highest impact in normalization is the AP impact, while in characterization, the highest impact is the GWP impact. This is because the GWP impact calculated in the characterization results is a global impact within 100 years while the person equivalent unit is an annual global impact so that the total GWP impact will be divided into yearly units. The results of this interpretation are used for discussion with experts to determine recommendations for improvement so that suggestions for improvement are proposed substituting the use of firewood.

Improvement in Firewood Usage

Based on the interpretation of coconut sugar farmer scale production, the use of firewood contributes significantly to acidification and eutrophication impacts. According to Nabawiyah dan Ahmad (2010) About the calorific value generated from burning wood ranges from 234-315 kcal/kg of wood used, so it takes a very large calorific value when compared to the calorific needs to produce 1 kg of coconut sugar. According to inventory data, the calorific value required to produce 1 kg of sugar requires 393.75 kcal. The amount of firewood used has a big effect on each impact. To reduce this impact, firewood substitution is highly recommended to minimize the resulting impact.

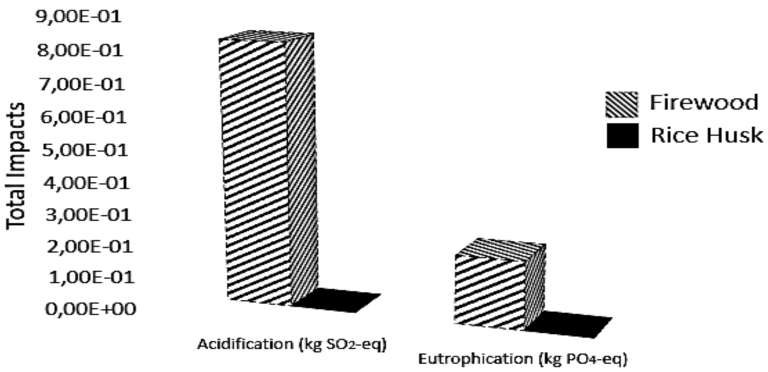

Figure 6. Comparison of the use of firewood with rice husk pellets

The selection of fuel to substitute firewood was discussed through interviews and literature studies, resulting in the selection of rice husk pellets as an alternative fuel. According to Noviyarsi *et al.* (2015) rice husk pellets have a high calorific value of around 3300 kcal/kg of rice husk, so the rice husk needed to produce 1 kg of coconut sugar farmer scale production is 1.19 kg.

The simulation results of the calculation of the use of firewood and rice husk pellets in Figure 6 reduced the initial impact of 8.16E-04 kg SO_2-eq to 2.72E0-7 kg SO_2-eq, the EP impact of 2.12E-04 kg PO_4-eq to 3.83E-07 kg PO_4-eq. So, the total impact on sugar production decreased to 1.31E-04 kg SO_2-eq from the previous impact of 9.45E-04 kg SO_2-eq for the AP impact, and 1.94E-05 kg PO_4-eq from the previous impact of 2.77E-04 kg PO_4-eq for the EP impact.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The stages of the coconut sugar production farmer level process go through a series of processes such as heating, heating and mixing, mixing, grinding and sieving. Environmental impacts are generated at the heating, and heating and mixing stages. This is because energy is only used at these stages of the process such as the use of firewood, and the use of LPG.

The environmental impact analysis using the Life Cycle Assessment approach calculates the impact per kilogram of sugar produced. The total environmental impact generated is approximately 4.76E-02 kg CO_2-eq/kg for GWP impact, 9.45E-04 kg SO_2-eq/kg for AP impact, and 2.77E-04 kg PO_4-eq/kg for EP impact. The largest contributor to generating AP and EP impacts is the use of firewood at 8.16E-04 kg SO_2 eq and 2.12E-04 kg PO_4 eq. The largest contributor in generating GWP impacts is the use of LPG at 2.89E-02 kg CO_2 eq/kg of coconut sugar which is 60% of the total GWP impact.

An improved scenario of the coconut sugar production farmer level process, by substituting the use of firewood with rice husk pellets, reduced 86% of the total acidification impact and 93% of the total eutrophication impact.

Recommendations

Complete the Life Cycle Assessment study more comprehensively by increasing the scope or boundary system with "gate to grave" or "cradle to grave" in order to know the total life cycle of the coconut sugar product, this is because there are differences in the stages of the process to produce coconut sap, the energy used in the production process, the addition of materials for the production of coconut sugar, and the marketing of coconut sugar.

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