Determination of Environmental Sustainability of Sugarcane Industry Using Life Cycle Assessment (LCA) Approach

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Abstract. This study aimed to assess the environmental impact of the sugarcane industry, focusing on the cradle-to-gate process. The research framework comprised four primary stages: defining the objectives and scope, inventory compilation, life cycle assessment, and interpretation of results. The life cycle assessment (LCA) began by cataloging the inputs and outputs associated with the desired product. Subsequently, emission data was gathered and analyzed using the openLCA software. Following this inventory compilation, an in-depth interpretation of the emission data was conducted. Sugarcane processing can be segmented into four main phases: sugar milling, clarification, crystallization, and centrifugal separation. The life cycle assessment then delved into these four stages, covering both sugarcane cultivation and sugar production.

Keywords: Sugarcane, LCA, Environmental impact, Sustainability, Industry

1 Introduction

The use of sugar is not only to meet basic needs but also the primary sweetener used as raw material in the food and beverage industry. Therefore, the national sugar industry plays an essential role in meeting the ever-increasing sugar demand level. Furthermore, sugar is made from sugar cane, one of the largest agroindustries producing sugar and ethanol [1]. As a result, the amount of sugar production has increased enormously throughout the world to meet human and industrial needs; namely, it is stated that there are 145 million tons of world sugar production annually [1].

High sugar cane production has an impact on three aspects, namely economic, environmental, and social aspects [2]. Especially on the environmental aspect the sugar cane industry has many negative impacts on the environment. For example, in planting and processing sugar cane, sugarcane production results in environmental quality degradation with loss of natural habitat caused by land use, disposal, and runoff of liquid waste. In addition, the production of air pollution, the use of chemicals, the use of large amounts of water, and the use of energy during the sugarcane production process also significantly impact environmental damage [1].

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Therefore, a scientific and thorough study is needed to determine and evaluate the environmental impact of the sugar cane manufacturing process, such as using an LCA approach. LCA method can be used to identify and evaluate environmental impacts that occur in the entire life cycle of sugar production . LCA in the sugar cane industry focuses on data and information collection factors and analyzing environmental impacts during the sugar production life cycle. Input and output data required during the sugar production life cycle is needed in conducting LCA methods such as data on raw materials, manufacturing processes, distribution, transportation, consumption, by-products, and environmental impacts [3]. This research was conducted to analyze the environmental losses caused by the sugar cane industry in the cradle-to-gate process.

2 Method

LCA is a technique used to assess the environmental impact of a product. Stage, The first stage in LCA is to compile and inventory inputs and outputs associated with the product [4]. An environmental element is any consequence of an organization's actions, products, or services that can create or avoid an environmental impact, even if it is currently under control. The environmental aspect is the cause, whereas environmental impact is the result. An environmental impact is any positive or negative change caused in whole or part by an organization's operations, goods, or services.

After executing a data inventory to determine the results of issued emission data, the program is used to conduct an Impact Assessment to determine the environmental impact of something. In this OpenLCA, the Impact Assessment utilizes the provisions of the EPD 2013 (Environmental Product Declarations) to determine the environmental impact of a product's emissions throughout its manufacture [4]–[6]. For instance, by implementing the emission reduction procedure, sugar firms can represent their products as ecologically beneficial. Once the company submits complete emission data, we can examine the compounds that may contribute to global warming and photochemical oxidation. Later, the demand for energy and natural resources utilized as the primary raw materials will be categorized into broad subjects whose data will be entered into an open LCA to study the impact on the environment and human health arising from using these raw materials. With this knowledge, we may build preventative measures to avoid pollution and the detrimental effects of production-related emissions.

3 Result and Discussion

Based on the processing process is divided into four stages in this cane sugar processing. The steps to obtain cane sugar are sugar milling, clarification, crystallization, and centrifugal separation (**Figure 1**). These four stages can be categorized into cane cultivation and sugar production. From the two stages carried out, it requires resources as a source for making sugar cane. At the cane cultivation stage, the input of natural resources is in the form of sugarcane seeds, water, fertilizer, and diesel as an energy source for the plowing machine. Then in the sugar production stage, sugar cane, lime, NaOH, and water are used. From the natural resources used, the output of the process carried out is sugar cane, air emissions in the form of CO_2, CO, NOx, and soil emissions in the form of BOD, Nitrogen, and phosphorus. The impact generated from the sugar manufacturing process can be generated from the use of natural resources that produce emissions. The resulting impact will be analyzed directly with software, namely

OpenLCA, and using analysis with EPD 2013, which can be seen to cause environmental impacts such as global warming due to air emissions in the form of CO and CO_2. CO_2. Then it causes impacts such as Photochemical Oxidation due to NOx emissions produced at the production stage.

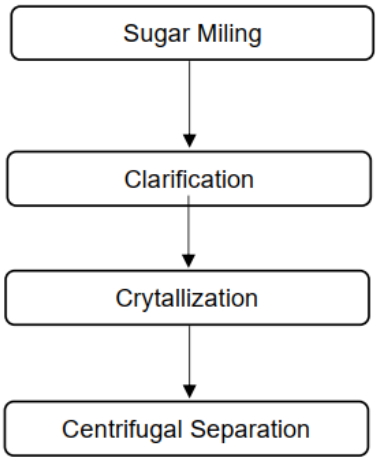

Fig. 1. Four stages in this cane sugar processing

The study adopts a cradle-to-gate approach encompassing three critical phases in the cane sugar production industry: cane cultivation, sugar production, and electricity generation. During the cane cultivation phase, for every ton of sugar cane produced, the inputs involved are 136.74 kilograms of cane seed, water, fertilizers, herbicides, and diesel. The process results in air and soil emissions as its byproducts. The sugar production phase then takes this cultivated cane and integrates additional inputs, such as lime, flocculants, NaOH, and water, to produce various grades of sugar - from unrefined to ultra-refined. Alongside these sugar outputs, the process generates wastewater and other byproducts. Lastly, industry also has an electricity production facet. In this phase, bagasse (a byproduct from the sugar production process), water, and diesel are the primary inputs to generate power. This power generation can cater to the energy needs of the sugar production process or be supplied to the grid. The life cycle inventory stage of the study meticulously details these inputs and outputs, using secondary data collected from prior research to ensure comprehensive coverage of the entire lifecycle of the product. [2].

The LCIA is a step towards classifying emissions from product production into impact categories. In our analysis, sugar products produced from sugar cane are classified by impact category, then compared by characterizing them into more general units. Data that is known to be in the form of specific units will be classified in a more general form which can later be entered into the software used, namely the OpenLCA software. This assessment using the 2013 Environmental Product Declaration (EPD) assessment method is available on the OpenLCA application. The results of the LCIA analysis can be seen in Table 1.

Table 1. Result of impact analysis

Environmental Impact	Score	Unit
Abiotic Depletion	25,013,074	MJ

Environmental Impact	Score	Unit
Acidification	103,000	kg SO_2 eq
Eutrophication	0,30586	kg PO_4 eq
Global Warming	970,000	kg CO_2 eq
Photochemical Oxidation	0,12180	kg C_2H_4 eq

The analysis has led to the development of a strategic action plan. Two core analytical methods, contribution and improvement analysis, were employed to pinpoint environmental concerns. The contribution analysis aims to recognize all the significant phases in the process, enabling targeted and effective remedial actions. From the data in Table 1, several environmental impacts associated with sugarcane cultivation and sugar production have been identified. These impacts include acidification, eutrophication, global warming, and photochemical oxidation. To alleviate these environmental effects, several improvement measures can be proposed. These encompass reducing chemical fertilizer usage, decreasing energy consumption during sugar production, minimizing fossil fuel usage during sugarcane cultivation, and eliminating the open burning of both waste and post-harvest sugarcane residues.

This measure of abiotic depletion is related to the consumption of fossil fuels (oil, coal, and natural gas) that depleted reserves. Abiotic depletion is the depletion of nonliving (abiotic) resources like fossil fuels, minerals, clay, and peat. In addition, this category describes the global reduction of nonrenewable raw materials. It addresses the broad availability of natural elements [7]. SO_2 and NOx are the acidity parameters contributing to acidification [8]. The stages that contribute to the harvest-transportation stage are examined in this study. The use of diesel fuel in sugarcane transport vehicles is the cause of harvest-transport-related SO_2 emissions. This is consistent with the findings of Chandra et al. [9], according to which the primary source of acidity in sugarcane agriculture is the use of fossil fuels. NOx emission is another factor that contributes to acidification alongside SO_2 emission. These emissions are the result of the open burning of garden waste. Postharvest trash consists of litter, dry leaves, and sugarcane shoots generated after the sugarcane harvest.

The primary pollutant sources in eutrophication are using chemical fertilizers and treating wastewater if the waste is discharged into the environment [10]. Such wastewater often contains phosphates, which are released as emissions. Nitrogen (N) nutrients are present in two primary forms: NH_4- and NO_3-. When NH_4- is transformed into NH_3, it evaporates. On the other hand, NO_3- can undergo leaching and denitrification processes, leading to the release of gases like N2O and NO. As NH_3 oxidizes, it can increase the soil's acidity. Moreover, the leaching of NO_3- can contaminate groundwater. This contamination adversely affects water quality and biodiversity due to the resulting eutrophication.

The major contributor to climate change is the release of N_2O through using nitrogen fertilizers and the open burning of agricultural trash. The resulting emissions include N_2O, CH_4, and CO_2 Greenhouse Gases (GHG) [8]. In addition, global warming is produced by the types of trucks utilized in transportation. The process of photochemical oxidation is primary contributor to photochemical oxidation is the open burning of post-harvest garbage (cane trash open burning), resulting in NO_x and CO emissions [8]. Following the findings of Nguyen and Gheewala [11], the open burning of post-harvest waste generates several air pollutants, such as carbon monoxide (CO) and volatile organic carbons (VOCs), which contribute to the effects of photochemical oxidation. For this reason, the utilization of this waste can also be done by turning it into RDF or its substitutes [12]–[15].

4 Conclusion

The LCA technique can be used to evaluate the environmental impact of sugarcane cultivation and sugar manufacturing by analyzing the consumption of natural resources and energy in these processes. The results of the LCA indicate that the cultivation of sugarcane and the manufacture of 1 million tons of sugar per year have the potential to degrade the environment. By entering input and output data during the sugarcane cultivation and sugar production processes and using the open LCA program, the environmental consequences of sugarcane cultivation and sugar production may be determined. Other environmental consequences that result from sugarcane agriculture and sugar production are abiotic depletion, acidification, eutrophication, global warming, and photochemical oxidation. Once these effects are identified, corrective measures can be taken to mitigate the environmental impact of sugarcane farming and sugar production.

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