

Application of Life Cycle Assessment (LCA) in Sugar Industries

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Abstract. Sugar is one of the main commodities that are needed for human life. The demand of sugar is very high with the trend increase from year to year. This condition makes the sugar industry become a leading industry that must be maintained sustainability. The sustainability of the sugar industry is influenced by the use of energy and natural resources and the resulting environmental impacts. Therefore, an effort is needed to analyze the environmental aspects and potential environmental impacts resulting from a product (sugar), by using Life Cycle Assessment (LCA). LCA is a very important tool for the analysis of a process/system from its cradle to grave. This technique is very useful in the estimation of energy usage and environmental load of a product/system. This paper aims to describe the main elements of sugar industries using Life Cycle Assessment.

1 Introduction

The sugar industry is one of the vital industries whose existence is needed to meet the basic needs of the community for sugar, making this industry must have a sustainability (sustainability industry). In fact, it is found that the large volume of sugar entering Indonesia through imported faucets as a concrete step of Government policy indicates that the domestic sugar industry has not been able to meet the national sugar demand. In fact, Indonesia's sugar industry is actually able to meet the national sugar demand from the potential of agro-ecosystem owned. The sugar industry is one of the industries considered as economic assets as well as social assets. This is based on the consideration that the prospect of sugar market in Indonesia is quite promising that the consumption of sugar is 4.2-4.7 million tonnes/year [1]. From the social aspect, the sugar industry is able to provide a source of income for 900 thousand sugar cane farmers [2].

The rush of imported sugar is exacerbated by the high cost of producing sugar industry when compared to production cost of other basic products [3], making sugar industry sustainability highly vulnerable. The sustainability of the sugar industry in general is also strongly influenced by the use of energy and natural resources and the resulting environmental impacts in its production process.

Therefore, an effort must be made by the sugar industry in order to achieve efficiency in the production process (sugar production) in order to support the achievement of sustainability industry. The efficiency of a production can be achieved by managing the main elements in the process of producing sugar, which includes the reduction of electricity consumption, energy

and natural resources in a single product life cycle. There are various techniques that can be done one of them Life Cycle Assessment (LCA). This technique include maximizing output with the same inputs, reducing raw material and transportation use, the implementation of pollution control, emission reduction in the environment and waste utilization [4]. The aim of this study is to describe the main elements in a sugar industries system using Life Cycle Assessment (LCA).

2 Life Cycle Assessment (LCA)

LCA is a tool used to analyze the interaction between human activity and the environment [5]. LCA is an important and comprehensive method for analyzing the environmental impact of a single product or service. One of the things that determine whether or not an efficient production process, can be seen from the using of energy in the production system. Efficient system optimization can generate significant energy and cost savings while minimizing CO₂ emissions. LCA scan be carried out with life cycle approaches and can be used for carbon accounting and to evaluate other important environmental impacts such as acidification, ozone depletion, eutrophication, smoke, and health effects on humans [6].

There are five key stages in the life cycle of a product (Figure 1):

- Raw Materials, sourcing the materials required for the product
- Production, converting raw material the products
- Distribution, getting the product to the end user
- Use, where the user derives the direct value from the product

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- End of life, what happens when the end user has finished the product.

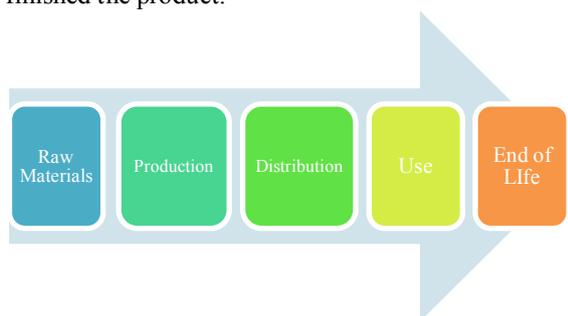


Fig. 1. Stages in The Life Cycle of a Product [7]

The methodological framework for LCA consists of four phases are definition of goal and scope, inventory analysis, impact assessment and interpretation of results as shown in Figure 2 [8].

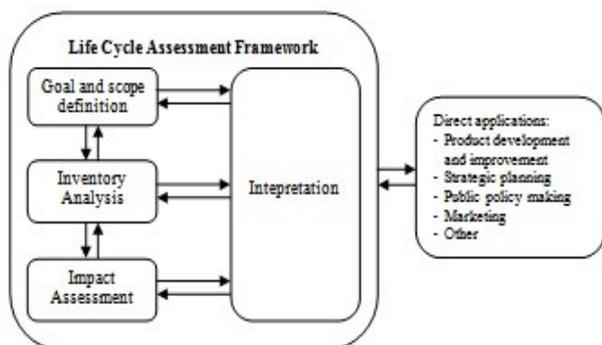


Fig. 2. The Methodological framework for LCA

3 Sugar Producing Materials

Sugar is one of the basic needs in the fulfillment of human life. Generally, sugars are produced from sugar cane crops found in tropical climates. In addition to sugarcane, sugar can also be produced from corn, beet, cassava and so on [9]. However, in some countries, sugar cane becomes the mainstay raw material in the production of sugar due to several reasons, such as several aspects as considered as over all cost, environmental effects, rate of sugar production and percentage of sucrose present in different materials [10].

4 Sugar Industries

In earlier time, the sugar industry only produced the main products of white sugar. But nowadays, besides producing sugar, sugar industries also produce other products such as cogeneration energy of bagasse, and ethanol. In general, the process of production in the sugar industry includes several main process, including the process of milling, clarification, crystallization and centrifugation [11].

4.1 Sugar milling

Initially, sugarcane is washed to remove excessive quantity of soil, rocks, and trash. After cleaning and fibrising of sugarcane, it passes through several types of mill to get extract raw juice of sugar cane. This sugar cane contains sucrose as the main ingredient of sugar making. Before milling, sugar cane will be crushed first which aim to simplify the process of sugar cane extraction. This process will produce two types of products namely bagasse and sugar cane extract. Both products are separated in different places, baggase used for energy cogeneration raw materials, while sugar cane extract is transferred to the next process, juice clarification and treatment.

4.2 Clarification

In this process, raw juice will be treated with the addition of chemicals such as sulfur (SO₂) and lime. The addition of this chemical aims to coagulate the impurities contained in the juice so easily deposited to be separated [11]. The chemical reactions of these chemicals will separate the juice into 2 parts, in liquid form (syrup), and in solid form (mud or filter cake) [4].

4.3 Crystallization

The syrup from the clarification process is then evaporate using heat. The purpose of this evaporation is to remove the water content so that it will be obtained thick syrup and ultimately produce *massecuite* that is the solution mixture of crystals of sugar and molasses.

4.4 Centrifugal separation

After crystallization, massecuite is passed through centrifugal tanks. These tanks are used to separate sugar and molasses. Molasse is the remaining massecuite that no longer contains sugar crystals. Sugar that comes out from these tanks are passed though vibrating device that addition serve as a means of transport also serves as a dryer. After drying, sugar is ready to be packed.

5 LCA of Sugar Industries

LCA in sugar industry has been done in many sugar producing countries. The LCA has different results depending on the system boundary, goal, inventory result and selected impact analysis (Figure 1). Research related to LCA aims to improve the balance of energy in sugar industry. This can be done by reducing the amount of water use, using steam in heating raw juice, using electricity from the use of baggase and heating raw juice by condensation. Analysis LCA in the sugar industry in Australia is able to contribute significantly to the environmental impact [10]. LCA study of sugar industry for different countries is shown in Table 1.

Table 1. Result of LCA Study in Sugar Industries

No	Author	System Boundary	Functional Unit	Input	Output
1	Toolseram Ramjeawon(12)	Cane production and harvest, cane burning, transportation, fertilizer and herbicide manufacture, and sugar processing, electricity generation	1 tonne of raw cane sugar	<ul style="list-style-type: none"> - Land, 0.12 ha - Water, 553 m³ - Fossil fuel, 1995 MJ - Total energy (fossil fuel and baggase), 14235 MJ 	<ul style="list-style-type: none"> - Emissions to air: 1.7 kg TSP, 1.21 kg SO₂, 1.26 kg NO_x, 1.26 kg CO, 0.065 kg VOC, 0.002 kg CH₄, 0.26 kg N₂O, 160 kg CO₂ from fossil fuel - Emissions to water: 1.7 kg N, 0.002 kg herbicides, 19.1 kg COD, 6.3 kg BOD₅, 13.1 kg TSS, 0.37 kg PO₄³⁻, 0.1 kg oil and grease - By-product: 0.27 kg molasses, 0.3 tonnes baggase (65 KWh) electricity
2	Livision Mashoko, Charles Mbohwa, and Valerie M. Thomas(13)	The growing and harvesting of sugar cane all the way to the production of sugar and co-generation of electricity from baggase	1 tonne of raw cane sugar	<ul style="list-style-type: none"> - 846 tonnes of cane - Total fossil energy 1893 MJ/tonne of raw sugar produce - Coal, 70.8 kg (1397 MJ/tonne of raw sugar produced) - Water, 17000 m³/ha - Land, 0.15 ha 	<ul style="list-style-type: none"> - 35 KWh of electricity from 1 tonne of cane crushed - Emissions from cane burning : 280 kg of tops and dry leavesat 50% moisture per metric tonne of cane harvested - Ashes and slags, 368 kg/tonne sugar - Emissions to air : 7.5 kg CH₄, 196 kg CO₂, 0.5 kg N₂O, 2.18 kg SO₂, 7.5 kg NO₂, 0.85 kg suspended particulate matter - Emissions to water : 6.6 kg BOD₅, 19 kg COD, 12 kg NO₃⁻, 0.15 kg PO₄³⁻, 0.05 kg suspended solids, 0.00126 kg Fe - By-Products : 0.56 tonne filter cake, 0.38 tonne molasses
3	Wichita Witayapairot, and Chatpet Yossapol(3)	Cane cultivation, sugar production process, electricity production, ethanol production	1 tonne of cane	<p>Cane cultivation (1 tonne):</p> <ul style="list-style-type: none"> - Cane seed, 136.74 kg - Water 138.1 m³ - Fertilizer 11.39 kg - Herbicide 0.18 kg - Diesel 3.26 L <p>Sugar Production :</p> <ul style="list-style-type: none"> - Cane, 1 tonne - Lime 1.5 kg - Flocculants 6.54 kg - NaOH 0.43 kg - Water 0.046 m³ <p>Electricity Production :</p> <ul style="list-style-type: none"> - Baggase, 280 kg - Water, 112.71 kg - Diesel, 4.85 L <p>Ethanol Production :</p> <ul style="list-style-type: none"> - Molasses, 55 kg - Water, 0.137 m³ - Yeast, 5.79 x 10⁻³ kg - Electricity 3.994 KWh - Steam 1.484 kg 	<p>Cane cultivation:</p> <ul style="list-style-type: none"> - Cane, 1 tonne - Emission to air : 9.7 kg CO₂, 3.8 kg CO, 0.9 kg NO_x, 0.4 kg SO₂, 0.114 kg SPM - Emission to soil : 0.11 kg N₂O, 0.38 kg nitrogen, 0.042 kg BOD, 0.0073 kg Phosphorus <p>Sugar Production :</p> <ul style="list-style-type: none"> - Raw sugar 60.02 kg - Refin esugar 31.71 kg - Super refine sugar 16.81 kg - Waste water : 7.65 x 10⁻³ mg/l BOD, 3.44 x 10⁻⁴ mg/l nitrate, 6.92 x 10⁻³ phosphate - By-Products : 280 kg baggase, 40.25 kg filter cake, 55 kg molasses <p>Electricity Production :</p> <ul style="list-style-type: none"> - Electricity, 69.4 KWh <p>Ethanol Production :</p> <ul style="list-style-type: none"> - Ethanol 99.5% → 14.47 L - Vinasse 6.51 x 10⁻² kg

6 LCA of by-product Sugar Industries

Besides producing sugar, the sugar industry also produces several “by-product” such as baggase and molasses which are the raw material for other plants. Baggase is used to source raw materials from power plants, while molasses are used as a source of raw materials for ethanol production. The utilization of these

two materials aims to improve the environmental profile of the industry as well as to increase the economic value of the waste. These by products from sugar industries can produce electricity, fuel, paper and organic chemicals[14]. The production of electricity from baggase and trash cane has an important role in reducing CO₂ emissions.

6.1. Baggase

As explained earlier that the sugar industries are now using the waste generated, such as baggase used as a raw material for cogeneration energy. Every 100 tons of sugar cane is capable of producing 11.8 tonnes of sugar and 28-30 tonnes of baggase which contain about 50% water[15]. In South Africa, 1 tonnes of raw sugar produced by 8.46 tonnes of sugarcane, 17.000 m³ of water, 0.15 ha of land and 71 kg of coal. However, the production process also produces byproducts of 0.56 tonnes of filter cake and 0.38 tonnes of molasses, 2.4 tonnes of baggase and 368 kg of ashes and slugs. Production of 1 ton of sugar requires 23.800 MJ of renewable and non renewable energy which 18.400 MJ renewable energy is provided from baggase[13]. While the sugar industry in Mauritius, 1 tonnes of sugar can be produced using resources of 0.12 land, 553 m³ of water, 1995 MJ fossil fuel, 14.235 MJ total energy consumption (fossil fuel and baggase)[12] In Thailand, 1 tonnes of sugar cane with 4.6 x 10⁻² m³ water is able to produce 60.02 kg raw sugar, 31.71 kg refine sugar, 16.81 kg super refined sugar and 55 kg molasses. By product that produced are 280 kg baggase and 40.25 kg of filter cake [3]. From another study, 1 tonnes of sugarcane production requires 0.017 ha of land and produced 103.6 kg of sugar, 45.2 kg of molasses, 247 kg baggase, and 16.94 kWh of electricity[16].

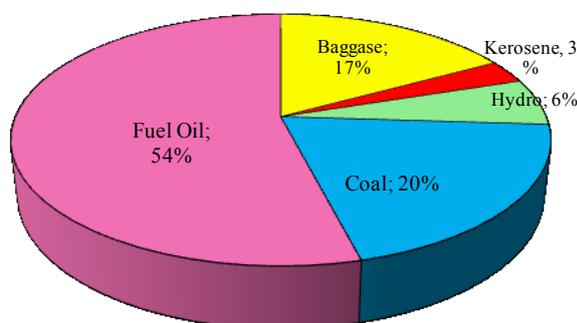


Fig. 3. Resource required of electricity in Mauritius [17]

Baggase is a by-product of the sugar industry used as inputs for power generation sources and capable of meeting industrial electricity needs. Even in some countries are able to supply electricity from the use of baggase for use outside the sugar industry. The fact that the sugarcane plant provides its own source of energy from sugar production in the form of baggase has long been a special feature of the sugar industry. In Mauritius, in traditional approach, sugar industries co-generate just enough steam and electricity to meet their on-site needs. With the availability of advanced co-generation technologies, sugar industries today can produce surplus electricity for sale to the national grid or directly to other electricity users. Such industries burn baggase during the crop season and use coal as a complementary fuel, during the intercrop. Around 44% (750 GWh) of electricity in Mauritius comes from the sugar industries,

of which 21% (360 GWh) is from baggase. Electricity generated from baggase combustion provides an environmental advantage over electricity generated from fossil fuels (oil and coal)[17]. The use of baggase as a source of raw material for electricity is able to meet 17% of electricity demand in Mauritius compared to other sources of power, as shown in Figure 3.

6.2 Molasses

Molasses is also one of the most economically important by-products of sugar industries which is used as raw material of ethanol generation. Ethanol analysis has been done either directly from sugar cane or indirectly from by product sugar industry, molasses [13]. In a day, molasses produced in the sugar industry X in Indonesia is 60.000 kg. To produce ethanol, molasses are mixed with 12.000 kg water/day, 3.000 kg of H₂SO₄ solution per day, *Saccharo mycescerevicesiae* 1.500 kg/day, 600 kg urea per day. Fermentation and distillation process produces 13.413 kg/day of bioethanol, water vapor 17.020 kg/day and vinasse 46,667 kg/day[18].

An average of 1 ton sugarcane produces 23 L of molasses. Molasses have many industrial uses i.e generation of alcohol, preparation of animal feeds, and food stuffs. Molasses containing large fractions of fermentable sugars which is diluted with water and allowed to ferment in the presence of yeast culture either by batch or continuous process of fermentation [19].

7 Conclusions

In the past, sugar industries produced only sugar crystal but nowadays sugar industries are involved in the production of sugar, electricity and ethanol. So, sugar industry is now called as the cane industry. From several studies LCA of sugar industries, it can be concluded that the main elements of sugar industries are cane cultivation and harvesting, transportation, fertilizer and herbicide use, sugar production, co-generation of electricity, and ethanol production. Electricity and ethanol are products that generate from by-products of sugar industries, baggase and molasses.

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