Life Cycle Assessment of Sugar from Sugarcane: A Case Study of Indonesia

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Abstract— **Facing rising environmental concerns in the industry sector, especially sugar industry, requires to assess environmental performances. Minimizing the environmental impact like eco design is vital to save the earth. Life cycle assessment (LCA) is applied to know the impact of sugar production from agricultural stage to industrial stage, without considering their usage and disposal phases (cradle to gate). Eco Indicator 99 (H) is used as life cycle impact assessment (LCIA) methods in this study. Life cycle of sugar from sugar cane in Kebon Agung sugar company, East Java province, Indonesia is analyzed by SimaPro 7.3.3 software. The total emission covering cradle to gate with one ton of sugar as functional unit is 508 Pt. Agricultural stage especially fertilizer usage is the largest source of emission in the whole sugar processing with dominant emissions in carcinogens and land use categories. It contributed 86% of whole impact. The contribution from de-ionsed water and burnt lime are also significant to give emission during industrial stage. It mainly affected respiratory inorganics impact category.**

Keywords—life cycle assessment;sugar production;agricultural stage;industrial stage; environmental impact

I. Introduction

Sugar is a commodity which is consumed in the world, including Indonesia. In 2012, Indonesian domestic sugar consumption reached 3.9 million tons [1]. Based on data from the directorate general of plantation, sugar plantations are located only in nine provinces in Sumatra, Java and Sulawesi [2]. In 2008, Java has the largest plantations totaling 301,343 hectares or 65.5% of the total areas of the country's sugar plantation of 460,406 hectares. In Java, East Java has the largest plantations totaling 213,914 hectares and followed by Central Java with 60,616 hectares of plantations [3]. The industrial sector in East Java is the sector that contributed output biggest economy in East Java. Output great course followed by the use of resources and discharge into the natural environment that great anyway. Kebon Agung Sugar Factory is one factory in East Java which feeds the national sugar [4].

Life cycle assessment (LCA) is a methodology for assessing the environmental aspects associated with a product over its life cycle [5]. This method covers the entire period of product life cycle starting from the extraction and processing of raw material through manufacturing with associated waste stream and storage, packaging, and marketing processes, transport and distribution, the use, re-use and maintenance and its disposal and recycling. LCA also quantifies energy and emissions flow of all stages of a product's life [6].

From a large number of wastes from sugar production in Indonesia and climate change protection to minimize environmental impacts, this study intend to reduce waste from sugar consumption in order to improve the environmental impacts. The cradle-to-gate LCA of sugar product in Indonesia will be analyzed in this study. LCA procedure of the study is mainly focused on raw material consumption, chemicals and energy consumption, solid waste, and different emissions related to sugar in production and packaging phase and disposal phase, which including transportation of each phase. In this study, LCA of sugar industry is identified in Indonesia, the developing country which the environmental friendly technology is not advance.

II. Methodology

Life Cycle Assessment (LCA) is environmental and potential impacts assessment technique related with life cycle of a product. The inventory of inputs and outputs in system of a product are constructed in LCA. The potential impacts in environmental side are also investigated [7]-[12]. Then, the results are interpreted based on inventory and impact analysis. Its associated with the objectives of the study [13]-[15]. It contains four main phases, definition of goals and scope, analysis of the inventory, environmental impact assessment, and results interpretation.

A. Goal and Scope Definition

The goal of this study is to assess the environmental impacts occuring during the cradle-to-gate life cycle of sugar industry and also identify the most significant processes or activities with contribute to environment. Scope definition of LCA includes defining the functional unit (object of the study) and identifying the limitation and the boundary of the study. The functional unit (FU) of this study consisted of the production of one ton of sugar. In this study, the unit processes included all production processes inside Kebon Agung sugar factory. These unit processes consisted of sugar cane plantation, sugar cane supply, chemical production, sugar production, energy production, and transportation.

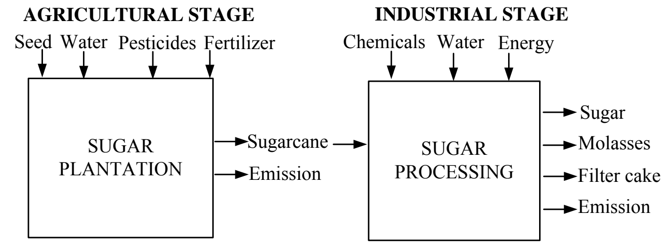

Fig. 1. Scope definition of sugar cradle to gate life cycle

B. System Boundaries

In this study, second order approach will be applied. This included all production processes during the cradle-to-gate life cycle and production of materials and transportation (upstream production). The infrastructure buildings involved and other goods such as machinery were excluded.

C. System Description

Sugar is made from sugar cane which planted in well-drained soil. When the sugar cane has been harvested, it must be transported to a sugar factory. The sugar cane will through the process in the factory, such as sugar cane milling, juice clarification, evaporation, crystallization, and centrifugal separation. The details of sugar processes production are [16]:

1) Sugar cane growing: Sugarcane is perennial grass that come from tropical and subtropical areas. Its are planted in cultivation by farmers or mechanical planters. Sugarcane need well-drained soil to grow appropriately. Fertilizing from planting up periode until ripening period are applied regularly. Fields of sugarcane need to be weeded routinely to get optimum growth. Irrigation also need in cane cultivation to improve planting intensity.

2) Sugar cane transported: Mature sugarcane are harvested by farmers. The farmers also remove the leaves and trim of the top of sugarcane. Then, harvested sugarcane are picked up and transported to sugar industry.

3) Sugar cane milling: When reaching the mill, sugarcane are entirely cleaned and cut into pieces. Then, milling machine extract juice from sugarcane stalks. It allows the hot water sprayed on to sugarcane stalks to dissolve any remaining sugar. The remains pulp as known as bagasses are dried and used in cogeneration plant as fuel to make energy for sugar processing.

4) Juice clarification: The raw juice from sugarcane milling moves to next station to be clarified. Phosporic acid, sulphur and lime milk are added to raw juice and heated to the boiling point. More over, through filters series, the juice is pumped to remove any impurities left with some chemical reactions. By clarifier, the juice is separated as clear juice and filter cake (co-product).

5) Evaporation: The clear juice that obtained from clarifying station is put under a vacuum. This process aimed to boil the juice in low temperature and begins to evaporate. It is heated until a thick form juice out, brown syrup called viscous juice.

6) Crystallization: After evaporating the remaining water in sugar syrup, crystallization is occured. Pulverized sugar called fondant as the liquid evaporates is fed into sterilized vacuum pan. It can cause crystals formation.

7) Centrifugal separation: Syrup from crystallization is pumped through centrifugal pans. In this process, a thick mass of large crystals as known as syrup is spinned and get the sugar crystals as the result. There is also co-product named molasses that sold to others for ethanol production while sugar moves to the next process.

8) Drier and packer: In the last station, sugar is dried and moved to screens to check the standard size of sugar. Then, the dried sugar are packaged in sack and well labeled.

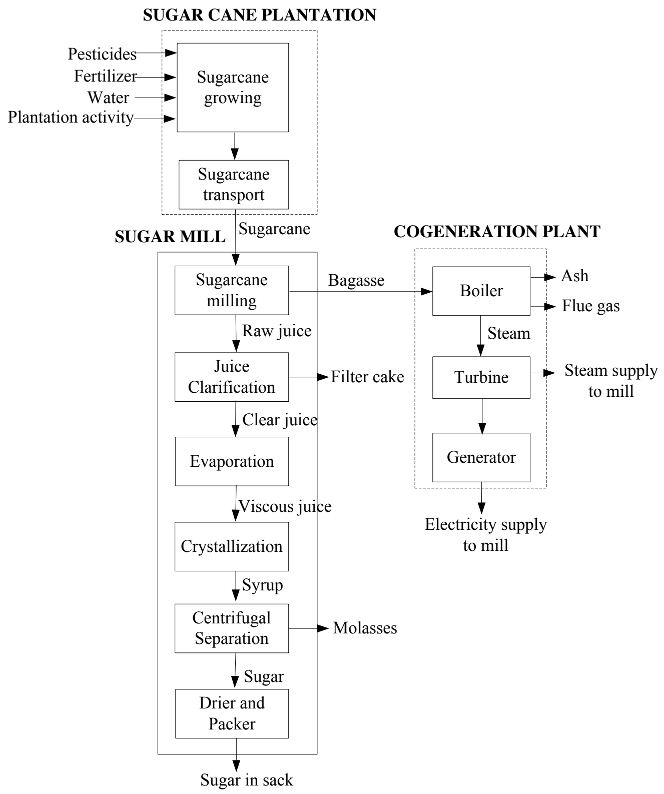

Fig. 2. Flow diagram of sugar production

D. Allocation

Allocation is an important part of LCA [17],[18]. In sugar industry, there are multiple outputs such as sugar, filter cake, and molasses. In the recent condition, the industry does not take a benefit directly from filter cake, just sell to the third party. The industry also sell molasses to the other industry who need it. On the other hand, another valuable co-product, bagasse, used in sugar industry itself for steam and electricity production [19]. So the output of sugar, filter cake, and molasses are necessery to allocated. The allocation according to mass value.

E. Inventory Analysis

In inventory phase, models are made of a complex engineering system consists of the production and transportation of products. This phase produces process flow sheet or tree with all the relevant processes. For each process, all relevant inflow and outflow collected. The hard work is actually in the life cycle inventory (LCI) is the collection and processing of the data itself. There are several sources of data: the data from the database industry, research data, such as a national database of projects that have been built in several countries, the general literature data (especially data description of the process) and data from SimaPro 7.3.3 such as water, transportation and another data that hard to find will be preferred to be used.

F. Impact Assessment

The method of Eco-indicator 99 was applied with the SimaPro software. The eleven impact categories of this indicator were evaluated using weighting based on the hierarchist cultural perspective. These impact categories are grouped into three categories of damages: human health, ecosystem quality and resources [5]. The category of damages to human health comprises the impact categories of carcinogenesis, respiratory effects of organic compounds, respiratory effects of inorganic compounds, climate change, radiation and ozone layer. The category ecosystem quality includes ecotoxicity, acidification/ eutrophication and land use while the resources category comprises mineral resources and fossil fuels. Materials, resources and products used in the evaluation were taken from the Ecoinvent database, developed by the Ecoinvent Center, Switzerland.

G. Data Collection

Majority of the data are collected from recorded data of the company. Besides, this study take the data from Simapro database and literature (books, journals, electronic database, and internet). The collection of all unit processes data were obtained by discussion and consultation with all departments in company. This study is conducted from November 2012 to July 2013. Location of data collection is in Malang Regency, East Java Province, Indonesia.

III. Result and Discussion

Implementation phases of LCA mainly for inventory analysis and impact assessment will be carried out using software SimaPro 7.3.3. By using this software, it is assumed that the impact generated described actual conditions, because the software is adopted European environment conditions.

Impact assessment was conducted to determine which parts of the life cycle of a product that contributes the largest environmental impact. Impact assessment method that is chosen is Eco indicator 99 method.

Total emission in the whole process in sugar industry is 508 Pt/one ton of sugar. The highest emission is from carcinogens (291 Pt/one ton of sugar) follow by land use category (135 Pt/one ton of sugar). That highest emission come from sugarcane from plantation. The results of the impact assessment are shown in Table 1.

TABLE I. Impact Assessment from Production of one ton of Sugar

Impact category	Impact of one ton of sugar (Pt)
Total	508
Carcinogens	291
Land use	135
Resp. inorganics	42.8
Fossil fuels	28.2
Acidification/ Eutrophication	5.47
Climate change	4.55
Ecotoxicity	1.03
Minerals	0.187
Resp. organics	0.0513
Radiation	0.018
Ozone layer	0.0136

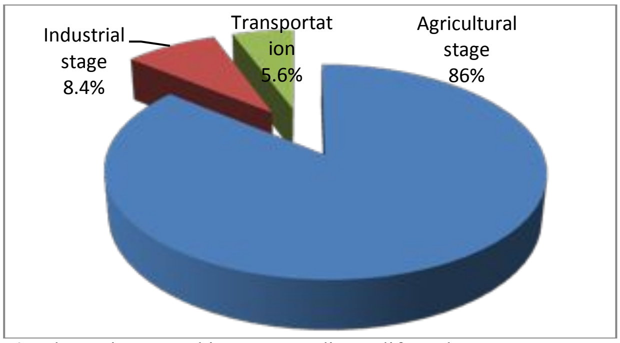

Fig. 3. The environmental impact according to life cycle stages

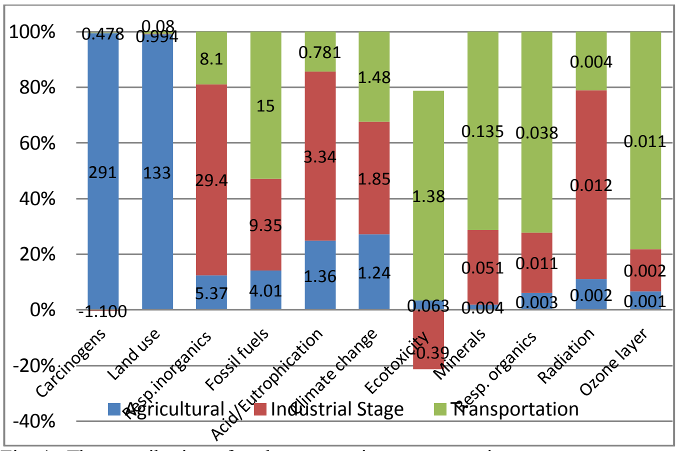

Fig. 4. The contribution of each stages to impact categories

Agricultural stage accounts for the largest environmental impact (86%) followed by industrial stage (8.4%), and transportation (5.6%). This result means that agriculture is a remarkable hot spot over the whole food processing system as mentioned in LCA of food industry [20]. Agricultural stage highly contributed to carcinogens and land use. On the contrary, industrial stage is the highest contributor to respiratory inorganics category. Different with previous both stage, transportation that carry sugarcane to mill give high contribution to fossil fuel, and followed by respiratory inorganics. All the results are shown in Figure 3 and Figure 4.

The total emission in agricultural stage is 436 Pt/12.2 ton of sugarcane. Carcinogens counted as the highest emission with almost 67% of the total emission. Fertilizer is the biggest contributor to carcinogens. Land use is a lower emission compared to carcinogens. It is only 133 Pt/12.2 ton of sugarcane or about 30% of the total emission. The farming activity such as planting, tillage are related with land use. In other words, planted sugarcane has a significant contribution to land use.

The total emission in industrial stage is 42.6 Pt/one ton of sugar. Bagasse (milling output) are biomass waste. It use as a boiler fuel to produce electricity and steam for use in sugar production process. As a result this process give negative environmental load. Both of electricity and steam which produce from bagasse can be used as a renewable energy replace Indonesia electricity and heat as steam which produce by government. Because of replacement of Indonesia electricity with electricity from biomass waste can reduce environmental impact 8.6 Pt/one ton of sugar. Simiarly, replacement of heat from Indonesia coal with steam from biomass waste can reduce environmental impact 21.6 Pt/one ton of sugar. De-ionised water and burnt lime usage affected respiratory inorganics impact category. The emission from sugarcane transportation by truck was 28.4 Pt/one ton of sugar. This stage has a major contribution to fossil fuels (53%).

IV. CONCLUSION

The cradle-to-gate life cycle of sugar from sugarcane was analyzed in this study where Kebon Agung sugar company is the location of case study. Recorded data collection of the company and interviews were conducted to obtain relevant data. SimaPro 7.3.3 with Eco-Indicator99 (H) method was used to generate the impact assessment of one ton of sugar production. Additionally, SimaPro database and data from literature was used as life cycle inventory of input and output.

The total emission from whole sugar processes with one ton of sugar as functional unit is 508 Pt. The highest emission is from carcinogens (291 Pt/one ton of sugar) followed by land use category (135 Pt/one ton of sugar). Agricultural stage was found to be hot spot of highest environmental impact over the whole process (86%) whereas industrial stage contributed 8.4% and transportation 5.6%. The emission from fertilizer and farm activity was believed to contribute significantly to the total impact assessment in agricultural stage, especially most dominant in carcinogens and land use categories. The usage of de-ionised water and burnt lime affected respiratory inorganics impact category in industrial stage. Besides, bagasses as biomass waste were combusted to generated steam and electricity in industrial stage. In consequence, the presence of negative points for ecotoxity, and carcinogens category were obtained due to avoided emissions of electricity national grid and heat from coal. Subsequently, transportation that carry sugarcane to mill related with the contribution to fossil fuel.

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