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Environmental Burden Computation in White Crystal Sugar Industry using the Life Cycle Assessment Methods

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ABSTRACT

Life Cycle Assessment (LCA) is used to assess environmental impacts that can potentially result from an industrial activity, from cradle to grave. LCA assessment in accordance with the principles of ISO 14040 is carried out starting from the stage of determining the scope, collecting data, preparing the Life Cycle Inventory (LCI), formulating the Life Cycle Impact Assessment (LCIA), interpretation and presentation. At the LCI stage, data from a sugar factory studied is collected from the results of material balance analysis, exhaust gas analysis, liquid waste analysis, and solid waste calculations for the 2019 period. Life Cycle Impact Assessment characterizes each LCI data towards potential environmental impacts that are make it possible. Characterization was carried out by grouping the impacts on Energy Depletion Potential (EDP), global warming (GWP), Eco toxicity aquatic (ETA), terrestrial Eco toxicity (ETT), Abiotic Depletion Potential (ADP), Photochemical Oxydant Formation (POF), Acidification Potential (ACP), Human Toxicity Potential (HTP), Nutrification Potential (NTP), Ozone Depletion Potential (ODP). The fourth largest contribution to the environmental burden of sugar factories based on 2019 data is GWP 375,966.95 tons of CO2 equivalent, followed by ACP 89,183.03 tons equivalent to NOx, EDP worth 33,086.91 tons of fuel oil equivalent, and NTP of 14,598.66 tons equivalent to COD . In addition, it also needs attention, namely HTP 11,621.83 tonnes equivalent to phenol, ETA 11,163.18 tonnes equivalent to BOD5, and ETT 9,748.49 tonnes equivalent to ash.

INTRODUCTION

The national sugar production is considered unable to meet domestic demand. National production only reaches 2.1 million tons per year, while the need for consumption and refined sugar reaches 6.8 million tons [1]. The decline in national sugar production was due to the low productivity of 48 state-owned and 17 private-owned sugar factories as well as the decreasing number of national sugarcane plantations. Therefore, the government and the private sector are expected to revitalize sugar factories, increase the number of sugarcane fields and increase partnership programs with smallholder sugarcane farmers.

Currently, around 78.7% of sugar factories are located in Java, so that there is a struggle for factory land with residential areas. A number of people have started to complain about problems related to environmental pollution. The high environmental burden has been contributed by the sugar industry.

Sugar production in a factory during the milling season can reach 550 tons with a production of about 80 tons per day. The results of the sugar factory production process will produce solid waste, liquid waste and exhaust gas or smoke. Solid waste is generated from bagasse, sand or mud, boiler ash, boiler dust and bloth. The liquid waste produced is 1-2 m/ton of sugarcane from the washing and cooking process which results in acidity with

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high salt content, leaks of lubricating oil and soda waste. Meanwhile, exhaust gas or smoke is produced from the sugar production process, which causes a strong odor and sulfur. Analysis of environmental burden can be carried out using a Life Cycle Assessment (LCA) approach.
Research related to the LCA of the sugar industry was carried out by [2], namely the Life Cycle Assessment (LCA) in sugar cane factories, but the concentration of the discussion was more dominant in energy production and exhaust gas emissions. Research by [3] on the LCA of Sugarcane Growing Process in Fiji. The focus of this research is on the LCA of the sugarcane cultivation process in Fiji. Likewise, [4] also conducted an analysis of potential environmental impacts using the LCA approach but on sugarcane plantation. LCA research for sugar factories in Indonesia, by taking into account several important factors in the production system, has not been widely carried out so that it is an option for further research [5].

EXPERIMENTAL METHOD

Research Framework

The design of this study is a quantitative approach, by incorporating models for calculating the environmental impact of a number of identified chemicals in the activities of an industry. Techniques for examining environmental aspects and potential impacts of products through LCA, from origin to extinction. It has been developed by ISO through the ISO 14040 standard. For the direct application of LCA to products, use the ISO 14045: 2012 guidelines [6]. The research design using the LCA method is presented in **Fig 1**.

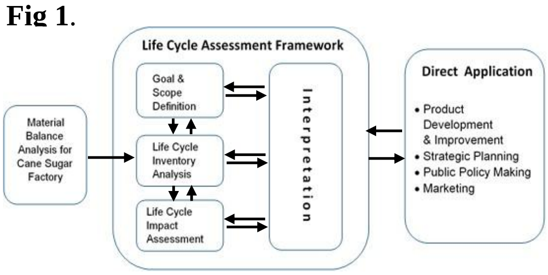

Fig. 1. Life Cycle Assessment ISO14040 Framework

Data Collection

The data used in this study are primary data and secondary data. Primary data is obtained through direct industrial emission test results, consisting of emissions to the air, emissions to land, and release to water bodies.

Industrial production data is needed to estimate the amount of environmental burden incurred by factory activities. As far as possible, obtain the latest measurement data so as to describe the latest industrial conditions.

The next step is to analyze each process unit using the normative document approach N16 formulated by Sub Committee 5 TC 207 ISO 14000 illustrating an example of a unit process description as shown in **Fig 2**.

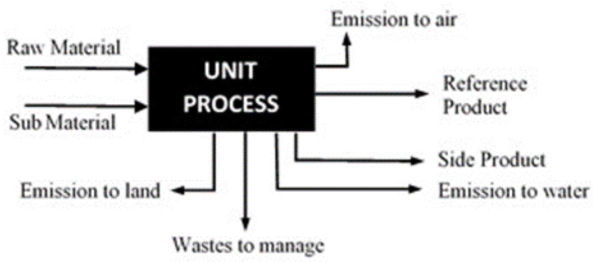

Fig. 2.Examples of descriptions of process units (ISO / TC 207 / SC 5 / WG 3: 1997) [6]

Data Analysis Technique

Several data analysis methods are used to obtain information about environmental burdens. This information is a decision material that can be interpreted to describe the environmental burden conditions caused by a sugar factory. Several data analysis methods used are shown in **Table 1**.

Table 1. Data Analysis Methods

Review	Methods Analysis	Data Resource	Output
Identify environmental burdens from production activities	• Literature review • Production analysis • Material-balance Analysis (ISO / TC 207 / SC 5 / WG 3, 1997)	• Primary and Secondary Data • Industry data • Association Data • Certain Benchmark Data	• *Production Rates* • Material balance sheet • Inventory Environmental Data

Review	Methods Analysis	Data Resource	Output
Calculating Environmental Burden	• Stoichiometric Approach • Environmental Chemical Conversion	• Waste Chemical Data	nount of Environ-mental
LCA Interpretation	• Values UNEP (1996); EDIP (2003)	• Amount of Environ-mental Burden	ormation on Industrial Environmental Condition

RESULTS AND DISCUSSION

Scope Determination

After conducting field observations, and adjusting to the availability of data from the company, it can be formulated which environmental aspects will be included in the scope. Environmental aspects can actually consist of products, activities, or services provided by the company.

Even though the LCA concept is from cradle to grave, it can be done according to a certain scope in a manufacturing system. In the case of sugar mills, the scope of this LCA study is limited to sugar mills only, even though there are sugarcane plantations and Ethanol factories. Diagrammatically, the scope of the study is presented in **Fig 3**.

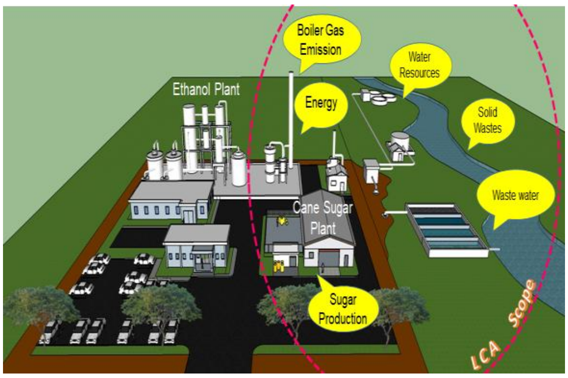

Fig. 3. Scope of the LCA

Material Balance

One of the important problems in the sugar industry is the problem of the yield that is too small, it can be interpreted that many materials do not become products so that they have the opportunity to become waste and possibly pollute the environment. Overall, since the sugarcane harvest, there is at least 69% waste.

A milling station is a term used to describe the unit of the process of milling sugar cane into juice. From this process, juice will be produced as a product, then the juice is crystallized into crude sugar crystals. The waste is bagasse, imbibition water, cake and maybe the dirt that accompanies sugarcane when it enters.

The water used in milling is between 25-30% of the sugarcane, with the milling efficiency calculated to be 95% of the extracted sucrose into juice. The final bagasse from the last station contains un-extracted sucrose, wood fiber and contains at least 55% water.

Refining Station is a term used to describe the process of refining the resulting sugar crystals and then drying them into white crystal sugar. The main waste generated from this process or sometimes also referred to as a by-product is molasses. In some sugar factories that have ethanol factories, molasses are used as raw material for the production of ethanol.

The loss of sugar during post-harvest until before milling is about 5-25%, and when it is very damaged, sugarcane can no longer be made of sugar. The indicator of damage that can be considered is reducing sugar, normally 3-5%. If sugarcane has a lot of fiber, the loss in the bagasse will be even greater, thereby causing a decrease in milled extraction. Several studies concluded that the impurities more than 3%, there was a tendency to decrease the yield by 0.194 points for every 1% increase in impurities. Losses in bagasse are large enough to reach 28-35%.

Mechanical loss, where sugar is lost with the cake. For Vacuum filter using sulfur the losses should be more than 1%, while for filter using carbonates the losses between 2-3%. The reaction is not optimal and the sugarcane impurities that is also milled, especially the soil, results in increased cakes and the loss in cakes has increased. Subsequent mechanical losses are losses due to equipment leakage or spurt into the condenser or other means through leaking pumps. Mechanical losses also often occur in old machines [7]. In summary, data on the balance of materials in the production of medium-scale sugar factories based on 2019 data are presented in **Table 2**.

Table 2. Material balance in sugar production one of the sugar factories in Indonesia

Data	Input	Output
Cane	338,291.2	
Water imbibition	96,370.4	
Non imbibition Water	4,722,149.6	
Calcium Oxide	457.1	
Flocculan	1,787.5	
Bagasse		98,928.9
Cut It off		10,990.8
The Water is Evaporated		232,935.7
Molasses		16,624.0
Sugar		31.400.0
Wastewater		105,183.0
Losses		11,551.7
Circulating Water		4,651,441.7
Balanced	**5,159,055.8**	**5,159,055.8**

Company Data for 2019, processed in tons

Life Cycle Inventory

The average value of energy production per year is obtained from the average steam energy produced from the boiler. Diesel oil is used as boiler fuel when trial /heating the boiler before milling, initial production where the bagasse has not been produced, the boiler pressure drops as an inducer so that the pressure returns to the desired pressure, and completion the milling seasons. Firewood is used as fuel for the boiler during the progress (experiment / boiler heating), completion the milling seasons, and the production of bagasse does not meet the fuel capacity of the boiler. But in the whole process, bagasse is the main fuel for the steam boiler [8].

The average production of steam produced by the Boiler per year in a medium-scale sugar factory is 381,885.98 GJ. If converted into kilo watt hours (kWh) using the assumption of 5.5 kg of steam/kWh, the average annual electric power generated by a steam boiler is 47,482,606.06 kWh [9]. According to [10], the average amount of liquid waste produced per ton of sugar production by the sugar industry is 0.15 m^3. In 2019 the liquid waste of the factory studied was calculated at 31,400 m3 or 31,400,000 liters. By [11] explain that in general the characteristics of liquid waste produced by the sugar industry have a pH value between 5.2-6.5, Chemical Oxygen Demand (COD) between 1,000-4,340 mg/L, Biochemical Oxygen Demand (BOD) between 350-2,750 mg/L and Total Suspended solid (TSS) between 760-800 mg/L. The waste is then processed first using a Wastewater Treatment Plant (WWTP) to reduce several benchmarks to meet environmental quality standards [12].

The filter cake or filter press mud is industrial waste produced by sugar factories from the sugar cane clarification process. The accumulation of these materials in large quantities will be a source of environmental pollution. The cake contains organic colloid material which is dispersed in sugarcane juice and mixed with organic and inorganic anions [13].

The environmental problem that arises from a power system that uses solid biomass fuel is ash, even its emissions often cause air pollution in the surrounding environment. Theoretically, the average ash content of Bagasse is 3.82% and wood is 5.35%, so the potential for dust solid waste from the activities of a sugar factory can be estimated as shows in **Table 3**.

Table 3. Dusts form Boiler residues in Sugar Plant

Biomass	Fuels Consumption (Ton)	Dust Estimation	
		% Ash Contents	Ash Volume (Ton)
Bagass	98,928.9	3.82	3,779.08
Wood	828.64	5.35	44.33
Total			3,823.41

Life cycle inventory is the stage of listing all possible environmental impacts that may arise from environmental aspects. These aspects can be in the form of products, activities, or services carried out by sugar factories. In accordance with the scope of the LCA that has been formulated previously, an inventory is carried out on the aspects of energy use, gas emissions from power generation, effluent wastewater and solid waste. The analysis was carried out for the 2019 data as summarized in **Table 4**.

Table 4. Life Cycle Inventory of medium-scale sugar factories

Environmental Aspects	Unit	Per Year	Remarks
Energy Resources			
PLN	MWatt	960	Maintenance
Generator	MWatt	47.482.61	Steam Turbine
Air Emission			
CO_2	Ton	131,453.25	
Particles	Ton	70	
NO_2	Ton	567.93	
SO_2	Ton	132.72	
Freon R_{22}	kg	5.6	Office
Asetyline	ton	0.08	Maintenance
Release to water			
BOD_5	ton	735.07	
COD	ton	3,012.20	
TSS	ton	592.88	
Phosphate	ton	376.8	
Sulfides	ton	15.7	
Biocyde	kg	340	
Mineral oils	ton	46.47	
Free Chloric	ton	37,523	
Solid Wastes			
Excess Bagasse	Ton	122,345.66	
Paper wastes	Ton	1.75	
Plastic wastes	Ton	0.09	
Rubber Wastes	Ton	0.16	Maintenance
Textile Wastes	Ton	0.11	Maintenance
Boiler Ashes	Ton	3823.41	
Metal	Ton	1.5	Maintenance
Filter cakes	Ton	10,990.8	

In sugar factories, during the planting period of about five to six months, it is generally used for maintenance of production machines. This period is known as the maintenance period. A number of factory-needed items, including maintenance period requirements, are listed in the research [14]. Especially for the spare parts used, were found in [15] research. During the maintenance period, the electricity used is generally a source of National Electric Supply (PLN) or diesel fueled generators.

Life Cycle Impact Assessment

Acidity

Acidic gases will cause the accumulation of acid groups on the earth's surface, often referred to as acid rain. The environmental burden of acid gas ($EB_{acid\ gass}$) of a substance is calculated by multiplying the load of material calculated by multiplying the load of material disposed of ton/ year with the acid gas factor SO_2 [16]. The discharge of acidic substances into water can lead to a decrease in pH which endangers the life of flora and fauna. The local effect of the discharge of the acid into water can be compared based on the acidity, for example by means of the H + ions released. $EB_{acidity}$ is the amount of H + ions released in ton per year. Phosphates and sulfides found in sugar mill effluent are considered as a supplier of acid to the water.

Global warming

The current global warming will endanger the changing seasons and habitat conditions. Global warming from emitted gases can be calculated based on the mass of emissions and global warming potential relative to carbon dioxide. One formula commonly used is the combined factor of the 100 year Integrated Time Horizon. The EB_{GWP} index for a ton/year substance released into the air is multiplied by the GWP. The units will be equivalent to CO_2 equivalent per year [17].

Effects of Human Health

The factors for the health effect category are derived from Occupational Exposure Limit (OEL). The use of the OEL index is possible as a basis because it represents a threshold for exposure acceptance. The OEL value is multiplied by the potential factor. The potency factor was divided by a factor for benzene compared with standard carcinogenic benzene. The $EB_{carcinogen}$ value of a substance is defined as the ton release of material per year multiplied by the factor relative to benzene.

Ozone Depletion

Depletion of ozone in the top layer of the atmosphere can increase the intensity of ultraviolet radiation to the earth's surface, thus affecting human health and other environmental impacts. Ozone depletion substances can be compared based on the Ozone Depletion Potential (ODP) index which is a number of important chemicals that can theoretically be reduced in the upper atmosphere, calculated relative to Chlorofluorocarbon-11. The EB_{ODP} index for chemical substances is the amount of material released by tons per year multiplied by the ODP. The unit is the equivalent of CFC-11 ton per year. In the case of sugar factories, the use of Freon in air conditioning is considered a contributing source of ODP gas.

Photochemical Ozone Formation

The lower limit of ozone is the precursor of tropospheric ozone. Ozone formation is influenced by respiratory problems and environmental damage to plants. The release of volatile organic matter can be compared based on the photochemical formation potential of ozone (POCP) relative to ethylene. The EB_{POCP} index for a substance is the product of the material released by tons per year multiplied by the POCP. The units are the ethylene equivalent ton per year. Analysis carried out at the sugar factory, the gas emissions of NO_2, SO_2, and the use of plastics are calculated as potential sources of POCP index, as a whole converted to ethylene equivalent.

Aquatic Eco toxicity

Discharge of substances into the aquatic environment can affect aquatic flora and fauna. When a substance is measured in an aquatic environment, it will generally be calculated as the concentration in the water medium received. One unit that can be used is for example the microgram per liter of water (μg / l). The discharge to the waters of the Eco toxic substance can be compared based on how much water is required to dissolve it before it reaches the required standard concentration. Some toxic substances have a number of concentration levels, but many of which are specifically identified to remain in water.

In the analysis of sugar factory wastewater, the metal data was not specifically identified. For the purposes of this LCA analysis, the metal data is equated with iron, given the large corrosive potential that occurs in factory machines that enter industrial wastewater. A summary of the overall environmental impact analysis, resulting in a Life Cycle Impact Assessment (LCIA). In the case of the medium-scale sugar industry which was used as a pilot, the results were obtained for three years as shown in **Table 5**.

Table 5. LCIA resume for sugar factories in the period 2017-2019

Environmental Impact	Code	Ton Equivalent	YEAR ON YEAR COMPARATION		
			2017	2018	2019
Abiotic Depletion Potential	ADP		0.53	1.03	1.46
Energy Depletion Potential	EDP	Fuels	11,580.40	24,568.09	33,086.91
Global Warming Potential	GWP	CO2	182,232.19	140,824.16	375,966.95
Photochemical Oxidant Formation	POF		1.07	0.66	2.14
Acidification Potential	ACP	NOx	30,933.86	65,611.03	89,183.03
Human Toxicity Potential	HTP	Phenol	9,731.02	11,401.03	11,621.83
Ecotoxicity Aquatic	ETA	BOD5	3,532.16	8,280.70	11,163.18
Ecotoxicity Terresterial	ETT	Ash	4,884.06	2,987.03	9,748.49
Nutrification Potential	NTP	COD	11,488.68	15,029.45	14,598.66
Ozone Depletion Potential	ODP	CFC12	0.00	0.00	0.00

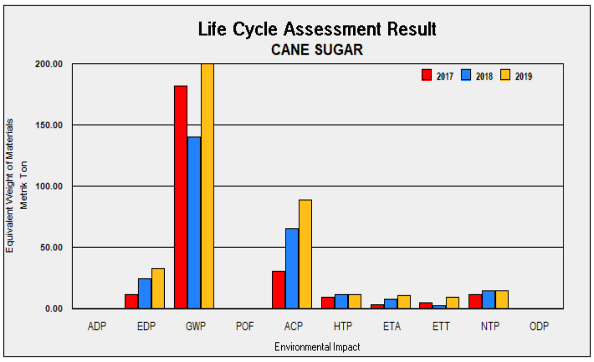

Fig. 4. LCA results of sugar factories in the

Interpretation and Presentation

The interpretation and presentation of LCA has been developed by many researchers, so it is not easy to generalize. Some researchers present in the form of comparisons between one work unit and other work units in the manufacturing system, to assess which work unit has the greatest contribution to environmental loading. The goal is to become the center for handling environmental performance improvement. Most researchers present comparisons between time periods, at least in terms of years. Presentation is done from year n to year to (n-1) or year to (n + 1). In research at this sugar factory, the interpretation model developed by SETAC was used [5].

The biggest environmental impact in the case of the 2019 data sugar factory is global warming with a load of 375,966.95 tons of CO_2 equivalent. The next environmental impact is the potential for acidification of 89,183.03 ton of NOx equivalent and the potential for energy depletion of 33,086.91 ton of fuel oil equivalent. Comparisons made to secondary data in 2017 and 2018 show that growth is getting higher from year to year even though production actually fluctuates. Figure 4 shows a comparison of the results of the LCA analysis in the last three years. The fluctuation in environmental burden from year to year appears irregular, most likely following the pattern of sugar production in the factory.

CONCLUSION

Life Cycle Assessment (LCA) is used to assess the potential environmental impacts of an industrial activity, from cradle to grave. LCA assessment can be carried out by first determining the scope of the study, in the case of one of the white crystal sugar factories the scope of sugarcane entering the factory is taken, the sugarcane milling process, the sugar production process, the steam boiler, transportation within the factory environment, and pre-activities. production or maintenance facilities. The Life Cycle Inventory (LCI) stage is carried out by collecting data related to energy use, emissions to the air, especially those generated from immovable and mobile emission sources, discharge to water bodies, as well as garbage and solid waste. Data was collected from the results of material balance analysis, exhaust gas analysis, liquid waste analysis, and solid waste calculations for the 2019 period. Life Cycle Impact Assessment (LCIA) is carried out by characterizing each LCI data towards the potential possible environmental impacts. Characterization was carried out by grouping the impact on Energy Depletion Potential (EDP), global warming (GWP), aquatic ecotoxicity (ETA), terresterial ecotoxicity (ETT), Abiotic Depletion Potential (ADP), Photochemical Oxydant Formation (POF), Acidification Potential (ACP), Human Toxicity Potential (HTP), Nutrification Potential (NTP), Ozone Depletion Potential (ODP). The fourth largest contribution to the environmental burden of sugar factories based on 2019 data is GWP 375,966.95 tons of CO_2 equivalent, followed by ACP 89,183.03 tons equivalent to NOx, EDP worth 33,086.91 tons of fuel oil equivalent, and NTP of 14,598.66 tons equivalent to COD . In addition, it also needs attention, namely HTP 11,621.83 tons equivalent to phenol, ETA 11,163.18 tons equivalent to BOD_5, and ETT 9,748.49 tons equivalent to ash. The use of LCA is to make it easier for companies to focus on controlling environmental aspects and impacts based on the priority of reducing environmental loads. Several sugar industries began to program to reduce GWP by controlling GWP gases from being released into the air, such as using CH_4 from waste treatment or using CO_2 from boilers for dry ice production. Acidification is controlled by changing the sulfitation purification technology to carbonation. Meanwhile, the use of pressing cakes is an alternative way to reduce the potential for nutrification. The results of LCA studies can actually be used to improve environmental performance by focusing on selected aspects and impacts.

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