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Environmental Sustainability Assessment of Sugarcane Industry Using Life Cycle Assessment.

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Abstract *The sugarcane industry is one of the industries that generated negatives impact on the environment. Therefore, it can be concluded that the sugarcane industry is not environmentally sustainable. The results of this research show that the use of electricity from bagasse cogeneration becomes the main contributor to all of damage categories. Meanwhile, the highest contribution to damage categories is human health with a total score of 59%. The results of this research are expected to reduce the environmental impact produced by PT. X so that PT. X will be more environmentally sustainable.*

Keywords*: sustainability, life cycle assessment, sugarcane industry.*

1. Introduction

The manufacturing industry has been contributed to social welfare through a supply of high-quality products that adjusted with the human needs. But on the other side, it is considered not yet environmentally-friendly [1]. So that, industrial sector required to demonstrate their responsibility to the environment by assess and reporting their performance related to the environmental impact and its sustainability. The sugarcane industry is one of the industries that not yet environmentally-friendly since it has a negative impact on the environment [2]. There are four categories of environmental impact caused by the sugarcane industry. First, water use and pollution. Second, atmospheric pollution that includes soil loss and global warming. Third, the impacts of biodiversity on the ecosystem from the discharge of contaminated effluents. Fourth, air pollution created by bagasse burning and other chemicals used in the sugarcane production process [3]. Bagasse is a waste produced by the sugarcane milling process. Bagasse is often called a by-product generated by the sugar production process and has great value as an energy source [4]. However, the burning of bagasse causes another environmental and social impact due to the produced ash. Minister of The Environment regulations No. 30 in 2009 states that ash produced by the combustion process from a boiler is categorized as a Dangerous and Toxic Material.

Consequently, further analysis of the environmental impact generated from the sugarcane industry is needed so that the impact can be minimized.

Life cycle assessment (LCA) is a method that can be used to do the environmental impact. LCA is useful in quantifying the extraction of resources and emission of a product system and their associated impacts. LCA provides a systematic analysis and address the environmental profile of a product from its material extraction stage through a disposal stage using a holistic approach. It is a comprehensive tools as far as environmental interventions and also can be used to identify the hot-spots of a life cycle of a product. LCA can be used to raise environmental awareness of employees, customers and the public. Besides, LCA can be used to compare a different products as well as alternative process to identify the best choice in terms of environmental impacts. On the other sides, LCA is a well known as the complex method. It need much of data and mostly performed using assumption (Muthu, 2014). LCA is regulated by ISO 14040-44 standards and consists of four phases namely objective and scope definition, life cycle inventory, life cycle impact assessment, and interpretation step [3].

This research was undertaken in one of state-owned company in Indonesia called PT. X which produces sugar as their main product. The results of this research show that PT. X is not environmentally sustainable due to the electricity cogeneration using bagasse still produce an environmental impact in several

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damage category. Therefore, the aim of this research is to assess the environmental impact of PT. X so that the negatives impact could be minimized an on the long term, production process in PT. X will be more sustainable.

2. Research Methodology

This research is a case study research that was conducted in a State-owned company, called PT. X in East Java. PT. X produces sugar as its main product. As stated in the previous section, the sugarcane industry was chosen as the object of the research because this industry considered has a negative impact on the environment [2]. Therefore, this research is trying to assess the environmental impact of PT. X using LCA so that the negative impact can be reduced.

This research began with the preliminary stage that is consists of a literature study and data collection. Then the next stage is the assessment process using LCA that is consists of four steps, goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation step. In this stage, simapro software was used to do the assessment. The last step is the conclusion stages which consist of defining the improvement recommendation based on the results of the previous stage and also provide the suggestion for future research. The flow of this research methodology is illustrated in Figure 1.

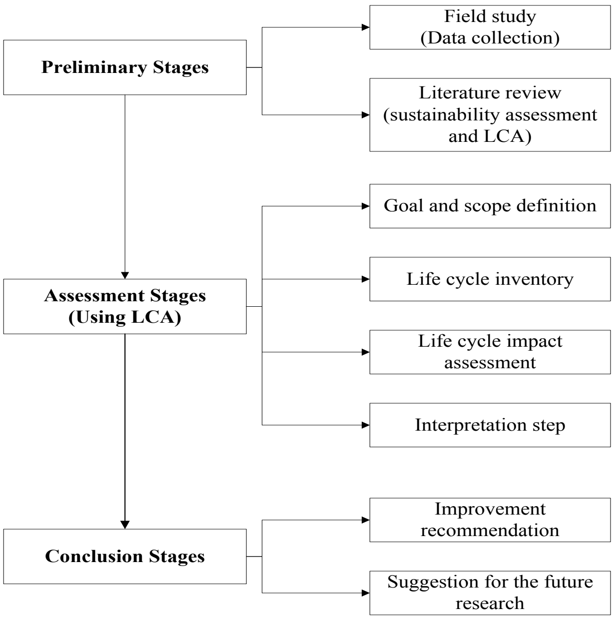

Figure 1. Flow of the research methodology

3. Sugar Production Process

The first step of sugarcane production process is called milling process. In this step the sugarcane that has been cleaned before will be milled using crusher roller the output of this process is raw juice and bagasse. The bagasse will be utilized as the fuel of boiler to conduct the electricity cogeneration process. Meanwhile the raw juice will be processed in the next step called juice clarification. The aim of this step is to remove both soluble and insoluble impurities (such as sand, soil, and ground rock) that have not been removed by preliminary screening. The process employs lime and heat as the clarifying agents. The output of this process are filter cake and clear juice. Filter cake will be sold as a fertilizer while the clear juice will be the input in the evaporation process. The aim of this process is to reduce the water through a vacuum evaporation. This process will produce a viscous syrup then will be processed in crystallization to obtain the syrup. Crystallization is a process to form the viscous syrup became the massecuite. Massecuite will be separate into raw sugar crystals and molasses using high speed centrifugal action in centrifugal separation process. The the last step is called dryer and packer when dry sugar crystals will be sorted by size through vibrating screens and packed in the packed it. Figure 2 show the flow of sugar production process in PT. X.

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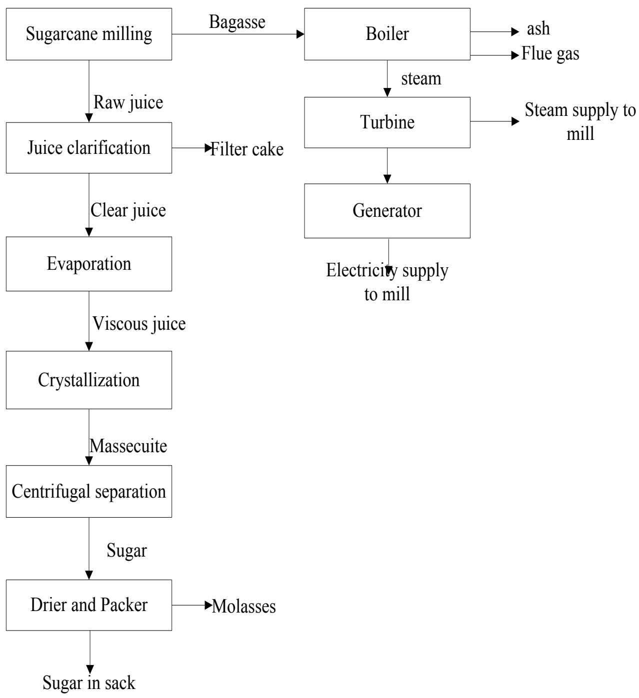

Figure 2. Sugar production process

4. Life Cycle Assessment (LCA)

LCA is a tool that can be used to assess and evaluate the environmental effects of a product, process, or activity through its life cycle [6]. There are four steps of LCA which already standardized by ISO 14040 and 14044 [7]. Each step of LCA in this research will be explained in the following chapter.

4.1 Goal and scope definition

The first step of LCA is define the goal and scope of the research. The objective of this step is to set the boundary of the research so that the research will be focused on that field. Those boundaries are including the scope, the assumption, and also the functional unit.

4.1.1 Goal : to assess the environmental impact of PT. X so that those impact could be reduced.

4.1.2 Scope : according to ISO 14040 there are four scope that can be used to conducting LCA, namely cradle to grave, cradle to gate, cradle to cradle and gate to gate. In this research, gate to gate was chosen as the scope of the research. Gate to gate includes a series of a sugar production process in PT. X.

4.1.3 Functional unit : 1 ton of sugarcane

4.1.4 Assumption : the database used in simapro software is considered to be in accordance with the conditions of PT. X.

4.2 Life cycle inventory (LCI)

The second step of LCA is called life cycle inventory. In this step, quantifies the inputs such as resource use, energy use, and other material was undertaken. Those inputs will be adjusted with the database in simapro. Energy used in PT. X was divided into two sources that is electricity generated from state-owned power plant which is using coal as the fuel and bagasse power plant that developed by PT. X. The usage percentage of coal power plant and bagasse power plant is 5% : 95%. The following are total amount of input which is adjusted with the database of simapro software.

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Table 1. The input data used in simapro software

Sugar Production Process			
No	**Input Data**	**SimaPro database**	**Amount**
1.	Sugarcane	Sugarcane (IN) sugarcane production	1 ton
2.	Water	Water ultrapure	46 kg
3.	Lime	Limestone, crushed	1,9 kg
4.	Phosporic acid	Phosphoric acid, industrial grade	0,01 kg
5.	Sulfur	Sulfur dioxide	1,5 kg
Energy Consumption			
6.	Electricity (coal)	Electricity, high voltage, heat and cogeneration of coal	53,55 kWh
7.	Electricity (bagasse)	Electricity, High Voltage, treatment of bagasse	1017,45 kWh

4.3 Life cycle impact assessment

In this step, the resources and energy used that has been listed in the previous step will be counted and assess using IMPACT 2002+. IMPACT 2002+ was chosen because it connect the input data in life cycle inventory into impact category (midpoint) then classify it in the damage category (endpoint). Figure 3 is show the tree diagram of the assessment.

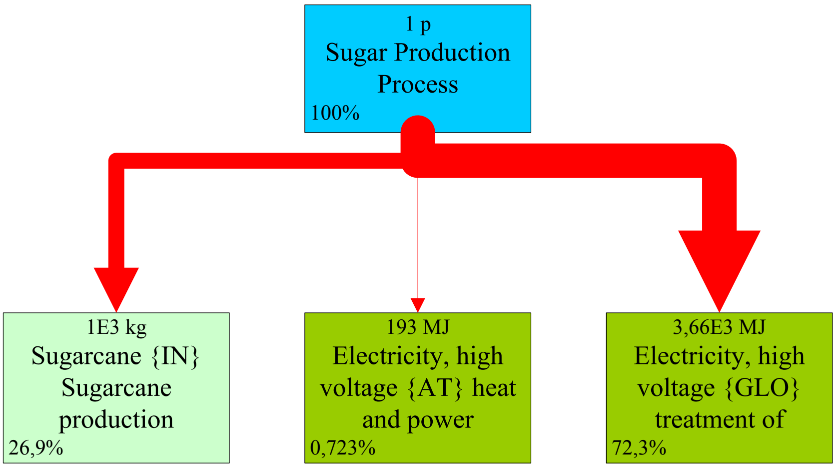

Figure 3 Tree diagram

Figure 3 shows that the environmental impacts of sugar production process in PT. X is produced by the use of electricity generated from bagasse (72,3%), the use of sugarcane as the main material of the sugar production process (26,9%), and followed up with the use of electricity that generated from the fossil fuel which is assumed using coal (0,723). Figure 4 show the results of midpoint assessment.

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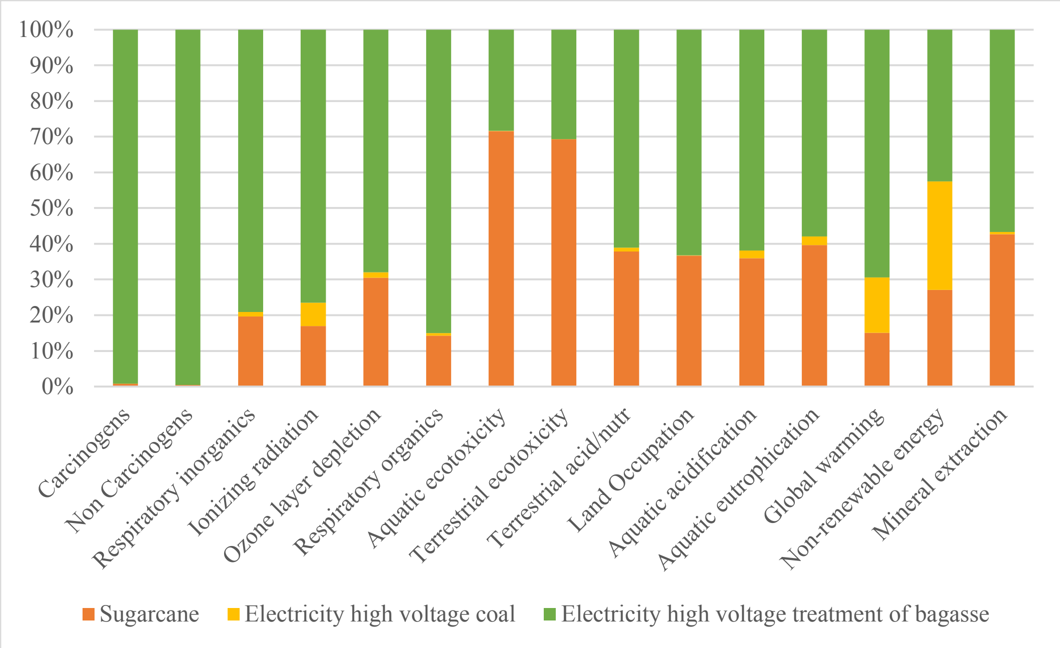

Figure 4 impact category of sugar production process (midpoint)

Figure 3 shows that the use of electricity that generated from bagasse cogeneration has a significant impact in almost all of the impact category in midpoint. As well as bagasse cogeneration, the use of sugarcane also has an impact in almost all of the impact category. The next impact category was caused by the use of electricity derived from coal. The following is the results of assessment in the damage impact (endpoint).

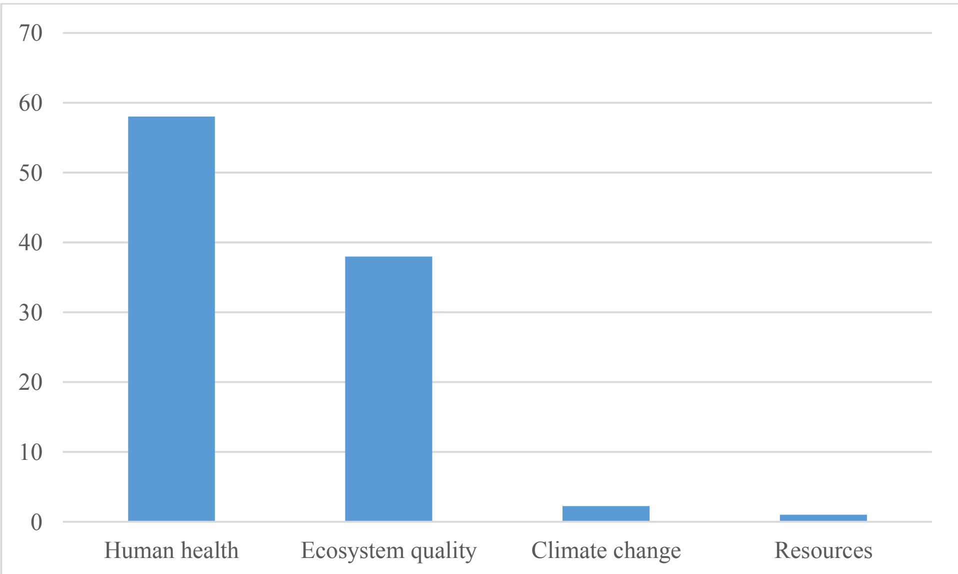

Figure 5 damage category of sugar production process

Figure 4 shows that damage category produced by sugar production process in consecutive are human health (58,7%), ecosystem quality (38%), climate change (2,26%), and resources (1,03%). From all four damage categories, the use of electricity that generated from bagasse was the main contributor of the environmental impact for each damage categories. Figure 5 will show the contribution of environmental impact for each damage categories.

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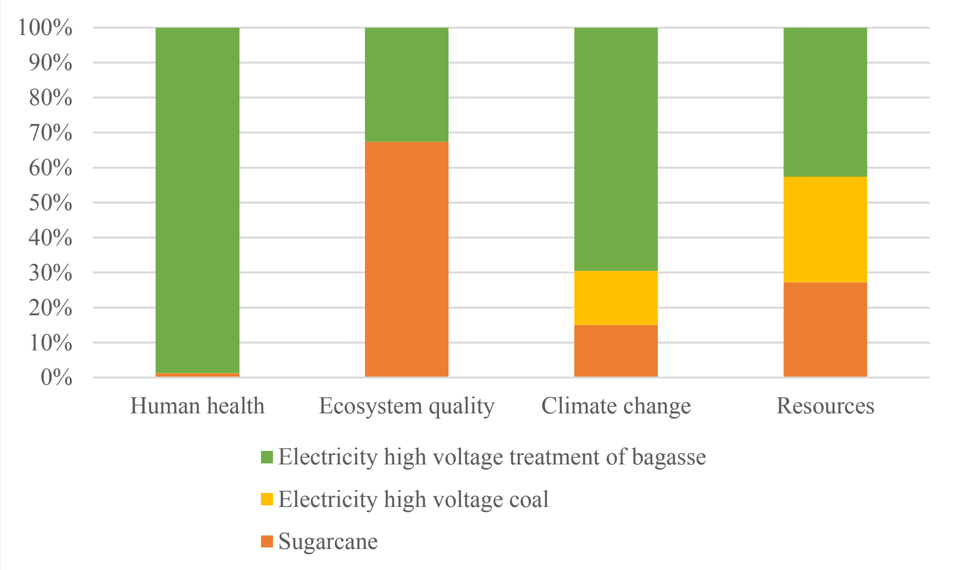

Figure 6 The main contributor of each impact categories

4.4 Interpretation step

The results of the assessment show that the hotspot of environmental impact in PT. X is the use of electricity generated from the cogeneration of bagasse. As mentioned before, PT. X utilized the waste produced from the milling process as the fuel of the boiler to produce electricity. This initiative is one of the efficiencies that can be done since it can offer economic benefits. But on the other side, it provides another environmental impact due to the produced ash that generated from combustion of bagasse. Therefore, further analysis to minimized the environmental impact of bagasse cogeneration are needed so that the sugar production process in PT. X can be more sustainable.

5. Results and Discussion

The results of a sustainability assessment in PT. X using LCA shows that the use of electricity that generated from cogeneration of bagasse is the main contributor to the environmental impact with a score of 72,3% and followed up with the use of sugarcane as the main material (26,9%), and the use of electricity that generated from coal (0,723). Those results have similar results with the research conducted by Meza-palacios et al., (2019). Meza-palacios et al., (2019) stated that the contributor to environmental impacts in consecutive is the planting and harvesting of sugarcane (52%, electricity cogeneration (27,5%), the transportation of sugarcane (12,1), and sugarcane milling (10,2%). According to Meza-palacios et al., (2019), the causes of the use of sugarcane as the main contributor to the environmental impact is due to the production process of fertilizer, the fertilization of field, the use of herbicide, and also the use of diesel machinery as the fuel to prepare the agricultural field. On the other side, Ramjewon (2004) stated that 66% of the overall environmental impact is generated from planting, harvesting and production process of fertilizer, while the production process of sugar and electricity cogeneration is contributing 20% and the 13% is generated from the transportation of sugarcane. Meanwhile, Lestari, Bohez, Ciptomulyono, & Perret (2013) predicts that the sugarcane farming contributes 86%, and the production process contributes 8,4%, while the transportation of sugarcane contributes 5,6% from the total environmental impacts.

The results of those research stated that the main contributor of environmental impacts is generated by the farming and harvesting process of sugarcane. Meanwhile, in this research, the use of electricity generated from bagasse become the main contributor to the environmental impact. The differences are caused due to the different usage of the research scope. All those three research are using cradle to gate that consist of a series of sugarcane planting processes until the production process are done and ready to distribute to the consumer. Meanwhile, in this research, the scope used is gate to gate which is covers the series of the sugar production processes. However, all those three research stated that the

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electricity cogeneration of bagasse is one of the contributor in environmental impact. Electricity cogeneration is a process of generating two kinds of different energy from the same source. The sugarcane industry is one of the industries that well known as the industry that is able to provide its own energy through a cogeneration process. Bagasse which is a waste produced from a milling process will be used as the fuel of the boiler. The combustion process will be carried out in a boiler to convert water into pressurized steam. Next, pressurized steam will flow into the turbine which will drive the generator and produce electricity energy [10].

Electrical cogeneration contributes significantly to the environmental impact due to the inefficient burning of sugarcane bagasse which produces inorganic substances that must be released into the air and cause harmful effects on human health and the quality of the ecosystem. In addition, it is also able to produce soil emissions which cause high toxicity values. Although there are environmental benefits from using sugarcane bagasse to produce energy, it is necessary to strengthen or implement effective policy measures for controlling air emissions from burning sugarcane bagasse [3]. Sugarcane bagasse is a fibrous material left after sugarcane is ground in the milling process or in other words it can be said that sugarcane bagasse is a waste produced from the sugarcane milling process [11]. Sugarcane bagasse is one example of waste that has economic value since it can be utilized. Besides, it can be used as compost and animal feed [12]. Some studies consider that the use of sugarcane bagasse as the main ingredient to produce electrical energy has various advantages, especially in economic terms, it is even possible if the needs of electricity in the company has been met, sugar industries are able to produce excess power that can be sold to the PLN electricity network [10].

On the other hand, several studies also highlight the impact arising from the utilization of bagasse waste as the main ingredient of energy cogeneration. Sahu (2018) states that producing energy produced from non-renewable energy (coal and oil) is considered more economical and environmentally friendly when compared with energy production from sugarcane bagasse. This is reinforced by research conducted by Ramjaewon (2008). The results of Ramjaewon's research (2008) showed that the use of sugarcane bagasse to produce electricity had a significant impact on the three endpoint assessment categories namely human health, ecosystem quality, and resources. Linking with this research, research conducted by Sahu (2018) dan Ramjeawon (2008) has the same results. As explained earlier, the results of this study indicate that the use of electrical energy produced by sugarcane bagasse is a major contributor to environmental impacts in each of the damage categories such as human health, ecosystem quality, climate change, and resources.

In this research, the damage categories assessed using IMPACT 2002+ method that consists of human health, ecosystem quality, climate change, and resources. The use of electrical energy using sugarcane bagasse as fuel has a significant impact on the four damage categories. It contributes 57.9% of the total impact of 58.7% in the human health category. The human health category is a grouping of assessment results in the midpoint category which includes human toxicity, respiratory effects, ionizing radiation, ozone layer depletion, and photochemical oxidation [14].. So it means that the use of electrical energy that uses sugarcane bagasse as its fuel has an impact on the environment, especially on the air so that in the long term it can cause depletion of the ozone layer, as well as being able to have an impact on human health such as the respiratory effect caused by inorganic substances. Furthermore, the use of electricity from sugarcane bagasse also produced an impact of 12.4% from 38% in the ecosystem quality damage category. Ecosystem quality is an accumulation of midpoint impact categories which include aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acid/nutrition, and land occupation [14]. So it can be concluded that the cogeneration process using bagasse in PT. X not only gave an environmental impact on human health but also gave an impact to the quality of the ecosystem that includes air, land, and water.

The third category being assessed is climate change. When compared with contributions to human health and ecosystem quality, the total contribution made in this category is only 2.26% where the value is quite small compared to the impact value of damage in the previous category. The use of electricity using bagasse contributes 1.54% of the 2.26% of the total impact given to the climate change

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category. According to Bengoa & Margni (2002) the assessment of the climate change category is the result of an assessment of the impact on global warming. Global warming is an increase in the average temperature of the earth in the long term [15]. Next in the category of damage to resources the use of electricity from sugarcane bagasse contributed 0.437. The calculation of this category is based on the use of natural resources and the consumption of non-renewable energy [14].

Linking the results of the assessment with the real conditions at PT. X, it shows that both have compatibility. Based on the field study, it was found that the residual ash produced by the burning of bagasse as a fuel of the boiler is one of the problems that had not been solved. The ashes from the combustion can cause environmental pollution in the air, land, and water so that in the long term they be able to make a significant contribution to human health and the quality of the ecosystem. This also causes the magnitude of the impact value in the category of human health damage and ecosystem quality. On the other hand, the impact value in the category of climate change and resource damage is not too large compared to the previous category. It is because the electricity cogeneration process does not consume much of non-renewable energy but instead utilizes sugarcane bagasse which is waste as a renewable energy source. Therefore, this research will focus on reducing the environmental impact produced so that the sugar production process can be more sustainable.

6. Recommendation

In this research, the given recommendations are the result of the literature review and discussion with the company. The discussion with the company aims to find out the possibility of applying the given recommendations. The given recommendations are an initial solution where is no evaluation of the recommendations obtained. The formulation of these recommendations is based on the results of the calculation of environmental impact assessment using LCA. The results of the assessment show that the process of cogeneration of electrical energy using sugarcane bagasse is a major contributor to the environment. Therefore, the improvement recommendations will be focused on the effectiveness of the use of the electricity cogeneration process using bagasse so that its negative impacts can be reduced.

PT. X as an industry that conducts the process of cogeneration of electrical energy using bagasse in practice has initiated to reduce the residual ash produced by combustion using a wet scrubber dust collector system. Wet scrubbers are effective air pollution control devices for removing particles or gases from industrial exhaust gases[16]. In many cases, wet scrubbers are the most economical way to remove particulate pollutants and gases from the gas stream [17]. The working system of this tool is to use very fine liquids on liquid droplets to wash unwanted pollutants from the gas stream. Most fine particles will stick to liquid droplets if they touch. The principle of scrubbers is to use particulate inertia and droplet forces to transfer particulates from the gas stream to liquid, particulates in the air stream are forced to come into contact with liquid droplets, liquid packing materials, liquid jets from plates.

Compared with dry scrubbers, wet scrubbers have several advantages including being able to provide gas absorption and dust collection in one unit, can control the mist, can cooling the hot gas, even the efficiency of dust collection can also be varied. Some of the research stated that wet scrubbers are generally the most appropriate air pollution control devices for collecting particles and gases in a single system [16]. Although the wet scrubber is the most appropriate tool, in practice the use of the wet scrubber has various disadvantages such as the high potential for corrosion, the discharge liquid that can cause water pollution problems, and collected particles can be contaminated and cannot be reused.

Some of these disadvantages are one of the factors causing the use of wet scrubbers at PT. X is not optimal. Therefore, some recommendations that can be formulated to optimize the performance of the wet scrubber are:

1. The replacement of the porous plate/pipe periodically

The use of wet scrubber has been proven as one of the dust collector tools with a high level of effectiveness. The effectiveness of collecting ash using a wet scrubber varies depending on particle size distribution and scrubber type. With design optimization, the

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effectiveness of separation can be greater than 99% for sub-micron particles. The effectiveness parameters of using a wet scrubber include particle size distribution, gas velocity or gas flow rate, liquid-to-gas ratio, droplet size distribution, temperature and pressure drop. In addition, the physical condition of the wet scrubber also contributes to the level of effectiveness produced [18].

Based on observations in the field, one of the factors causing the decrease in the effectiveness of the use of wet scrubber is the damage to the plate/pipe in the dust collector. As mentioned before, one of the disadvantages of wet scrubbers is that they have a high potential for corrosion, which can cause pipes and plates to become porous. Therefore, regular replacement of porous plates/pipes can be done to optimize the use of wet scrubbers. In addition, the age of the old wet scrubber is also considered to have contributed to the decreasing effectiveness of the tool.

2. Re-checking the wet scrubber design

The performance of a particular type of scrubber is very dependent on the size distribution of impurity particles in the producer gas flow. The size distribution determines the capture mechanism that dominates such as impaction, interception, or diffusion. Most wet scrubber designs rely almost entirely on inertial impaction for particle collection. Particles smaller than 0.1 μm are mostly captured through the diffusion mechanism. The wet scrubber design has an important role in the effectiveness of its use in capturing the ash produced. Re-checking the design of the wet scrubber must be based on parameters that affect the overall performance of the wet scrubber. The design parameters includes waste gas flow rate, temperature and humidity, the speed of gas and pressure drop, liquid-to-gas (L/G) ratio, residence time, and droplet size [19].

The gas flow rate is the most important measurement dimension of the wet scrubber. The higher the gas flow rate, the greater the venturi system and the volume of the scrubbing liquid needed to wash the gas. In addition, gas temperature and humidity also affect the design of the venture. When water passes through the wet scrubber, water evaporates and causes increased humidity and cools the gas stream. The amount of evaporation is determined by the inlet temperature and humidity. A high evaporation rate will increase the consumption of needed water or liquid-to-gas ratio. Besides, increasing the relative velocity between the gas and liquid droplet could increase the momentum of the particle, causing smaller particles to accumulate by the impaction mechanism. Relative speed can be increased by narrowing the throat, injecting counter-current liquid into the gas stream, or spraying liquid into the throat. However, increasing the relative speed usually increases pressure drop, energy requirements, and scrubber operation costs.

On the other sides, liquid-to-gas ratio (L/G) is the volume of liquid injected per volume of incoming gas. In general, the L/G ratio increases collection efficiency because the density of droplets along certain surface areas of the scrubber is higher. Liquid flow rates between 7 and 10 gal/1000ft3 provide maximum performance. L/G ratio in this range results in a fairly constant collection efficiency at a constant pressure drop. Although increasing the L/G ratio will increase collection efficiency to some extent, this will increase operating costs due to the use of large scrubbing liquid and the use of pumps. Increase the length of the throat and the diverging portion will increase the contact time between liquid and impurities in the gas stream. For high energy systems, it is recommended that the diverging portion of the throat be at least 4 times the width of the throat to meet sufficient contact time. Furthermore, there is an optimum droplet size to maximize particle collection. Smaller droplets have a larger surface to volume ratio, so they will capture more particles per injected volume. However, if the size of the droplet is too small, the momentum of the gas current can move to the droplet which will decrease the relative velocity between the droplet and the particle. While the relatively low speed produces a low collection efficiency as well. To sum up, it must be noted that the level of effectiveness of a wet scrubber is dependent on its design. Its design should be in accordance with all of those parameters [19].

7. Conclusion

The environmental impact produced by the sugar production process at PT. X consists of human health (59%), eco-system quality (38%), climate change (2.26%), and resources (1.03%). The main contributor to the environmental

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impact is the use of electrical energy generated from the cogeneration process using sugarcane bagasse. In addition to being able to provide economic benefits, the cogeneration process can also have a negative environmental and social impact due to the ash from the burning of bagasse in the boiler. To minimize those environmental impacts, the recommendations are given by optimizing the use of wet scrubber dust collector. The optimization includes periodically replacing the porous plate/pipe and re-checking the wet scrubber design.

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