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Life cycle assessment of biogas digester in small scale tapioca industry

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Abstract. Biogas was mentioned to be the source of sustainable energy, but the digester materials could create environmental footprints within the manufacturing and transportation process. Hence, the sustainability of biogas digester is under questioned. The objective of this research is to analyse the environmental load effects of the biogas digester installation, maintenance and utilization from industrial wastewater of small-scale tapioca industry along with the replacement of fossil fuel as the energy source. Furthermore, this research was conducted by life cycle assessment (LCA) approach. LCA is a support tool to assist the decision-makers to understand and improve the environmental impact of a technology/service. The study started from the beginning of life until the end of the product lifespan (including the construction process, and maintenance). Hence, this study found that the emission from the installation and maintenance of small-scale biogas digester contribute to +18.5 Kt CO_2 eq. The biggest contributors of greenhouse gasses (GHG) are geomembrane HDPE and gasoline. On the other hand, the utilisation of biogas to fuel the tapioca drying process and replace fossil fuel (LPG) could significantly reduce the GHG with a total reduction of 296 Kt CO_2 eq for one life cycle (15 years).

Keywords: Biogas, Bioenergy, Sustainable energy, wastewater, life cycle assessment.

1. Introduction

Anaerobic fermentation process to produce biogas is a promising method of energy production carried out from renewable resources which could deliver several environmental advantages [1]. Biogas technology reduces the methane releases into the atmosphere as one of the most dangerous gases of climate change [2]. In addition, the by-product of biogas digestion has the power to replace the artificial fertilizer for agriculture [3] due to high content of nutrient (N, P, K). This leads to a further environmental benefit by cutting the transportation pollution with regards to the decreasing weight and volume of artificial fertilizer [4]. More obviously, this technology helps to reduce waste and decrease inconvenient odor [1].

Nowadays, the anaerobic digestion is widely used to treat animal manure management (dairy, poultry), municipal wastewater, food/agricultural waste, urban organic waste, industrial wastewater [1, 5-7] and many more. The various reactor type depends on some factors such as operating condition, pre-treatment, and dilution processes. High rate anaerobic reactors, up-flow anaerobic sludge blanket (UASB) reactor, anaerobic fluidized bed reactor, continuous stirred tank reactor, up-flow fixed film loop reactor are examples of the current technology being used in high strength wastewater [8]. The main factor in choosing an acceptable technology mainly depends on some requirements such as less capital, less area, minimum operation and maintenance. Based on this qualification, an anaerobic pond one option to treat the wastewater in small industrial scale with low cost and low maintenance [9].

Biogas technology has been widely applied to industrial company in Lampung province, Indonesia. Some tapioca factory which makes use cassava as a raw material has process its wastewater to harvest the biomethane. According to a research, the technology implementation has successfully removed the COD (Chemical Oxygen Demand) as much as 92% and are potential to produce energy as much as 27.76 kWh per ton of cassava [10].

The environmental impact of Biogas digester through the operation is assumed to be small. However, the indirect environmental impact for the installation process is still unknown. In detail, biogas digester installation requires activities and materials which potentially emit emission during the extraction process, manufacturing, usage, transportation and after usage, for example, the use of plastic [11]. Hence, the sustainability aspect of the Biogas reactor type is under question. This study, therefore, aims to evaluate the performance of small industrial scale of biogas by performing life cycle assessment (LCA) approach.

2. Materials and Method

Life cycle assessment (LCA) is a powerful decision support tools to evaluate the environmental performance of a system or product [12]. It quantifies the impact categories and helps to identify the hotspot area. A hotspot is a spot where the biggest contribution to the environment could be identified and has an opportunity for further improvement. LCA consist of four-step: goal and scope definition, inventory analysis, impact assessment and interpretation as shown in Figure 1 [13, 14].

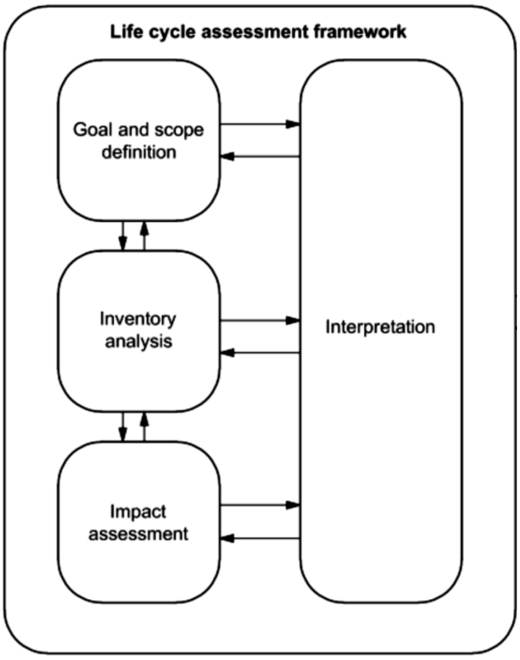

Figure 1. Overview of life cycle assessment framework [13]

2.1. Goal and scope definition

The goal and scope definition of this LCA study was to evaluate the environmental performance of a biogas plant in small scale tapioca factory. The production of biogas depends on the wastewater input to the reactor. This study assumed that the wastewater is available throughout the years. The lifetime of the biogas digester is set to be 15 years. While the working hour of the biogas installation process is set to be 8 hours per day.

2.2 System boundary and description

The case study of this research was conducted in a tapioca factory named PD Semangat Jaya, located in Desa Bangun Sari, Kecamatan Negeri Katon, Kabupaten Pesawaran, Lampung. This factory has been using the anaerobic pond to produce biogas since 2008. Until now on, the technology is still working and helped to supply energy to the owner for 10 years. Initially, they use the biogas as a kitchen fuel source to support cooking activities within the company, but in the last few years, they started to use the bioenergy as a fuel to dry the tapioca flour.

Moreover, the inventory analysis was done by listing all the input materials and products/by-products (output). The biogas reactor comprised one big covered lagoon that remained connected to a drying machine by PVC pipes. The lagoon is covered by a black Geomembrane - High-Density Poly Ethylene (HDPE) plastic. HDPE belongs as a synthetic flexible membrane liners (FMLs) which is most commonly used to manage municipal and residual solid waste [15]. HDPE has been selected to treat wastes due to its excellent chemical resistance characteristics and its endurance to leachates [16]. No degradation was found in HDPE Geomembrane although have been used for 8 years to treat municipal waste [15]. Based on lab data and field data, HDPE Geomembrane may last between less than a decade to many centuries which is depend on the oxidative degradation process of the materials [16].

Figure 2. Biogas digester at PD. Semangat Jaya

During the installation process, the HDPE was patched together by welding tools which require electricity in order to cover the big lagoon; 80 m length, 20 m width (Figure 2). As much as seven meters deep of soil was excavated to create a space for the tapioca wastewater. An excavator was used to dig the soil along with a dump truck to relocate the soil. All in all, six main input is needed to assemble one installation of an Industrial biogas digester. Therefore, the final product is the biogas itself and as stated before, the coproduct is the biofertilizer.

According to the drawn system boundary (Figure 3). The demolition phase (end of life phase) and the by-products of the biogas reactor is excluded from the system due to the complexity. The biogas maintenance process is included within the system boundary, although difficult to estimates its necessity in the future. The maintenance is in the issue of reactor leakage; plastic repatched and welding (electricity consumption). The maintenance is assumed to be done twice a year. Furthermore, methane leakage to the atmosphere is assumed to be 15% due to the gas movement through pipes to the end user and digester loss. This value is based on the conservative estimation on IPCC range 5-15% [17]. Last but not least, this research also assumed that there is an offseason of the company because of the scarcity of the raw materials (cassava) as long as two months. The offseason could affect a significant decreasing of wastewater quantity input to the digester. This assumption is based on the experience in PD Semangat Jaya via interview [18].

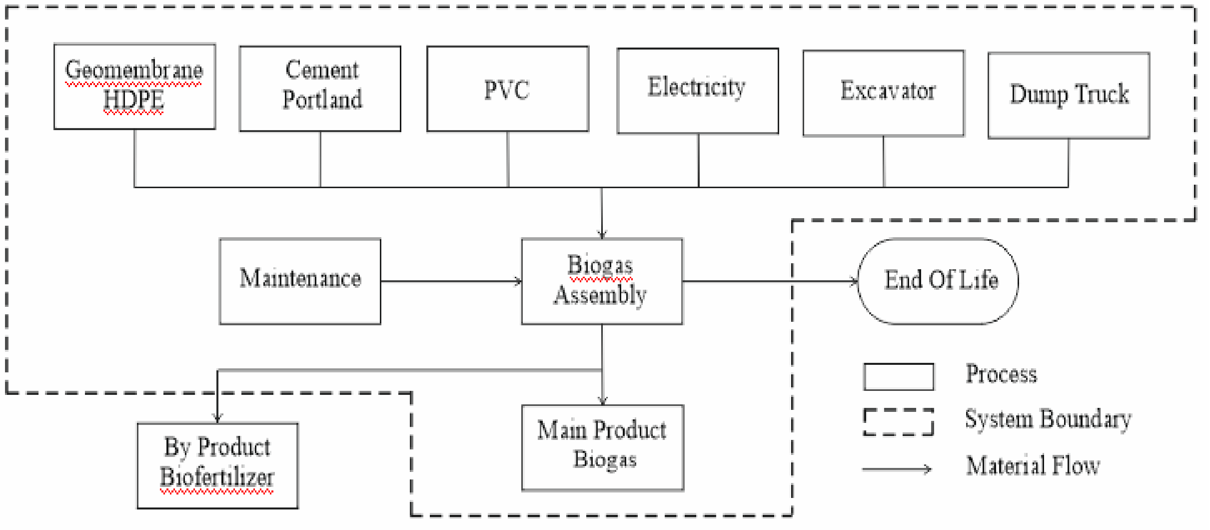

Figure 3. Flow diagram of Biogas assessment

2.3. Life cycle inventory

Inventory analysis was done by listing all the input materials and products/by-products (output). Literature review, laboratory measurement, and interview were carried out to collect the data of biogas content, biogas production, materials input weights, digestate amount and the installation process of the bioreactor. The inventory data are used to quantify the total of environmental impact based on the emission factor of the input materials. Table 1 shows the emission factor for all the input materials

2.4 Calculation and Impact Assessment

The environmental impact assessment to be calculated is the Greenhouse Gasses (GHG) emission. The final impact is the sum of each input materials multiplied by the emission factor as shown in Table 1.

Table 1. Greenhouse gasses (GHG) emission factor of input and output materials

No	Item	Unit	GHG Emission Factor (kg CO_2 equivalent)	Reference
1	Geomembrane HDPE 1 mm thick	Kg	1,9	[19]
2	Poly Vinyl Chloride (PVC)	Kg	2,22	[19]
3	Concrete	m^3	263	[19]
4	Electricity (Sumatera)	kWh	0,832	[20]
5	Maintenance			
	• Electricity	kWh	0,832	[20]
	• Geomembrane HDPE	Kg	1.9	[19]
6	Land use	m^2	NA	NA
7	Transportation fuel			
	• Dump Truck (Light fuel) Gasoline	Liter	2,75	[19]
	• Excavator (Light fuel) Gasoline	Liter	2,75	[19]
9	LPG	Kg	3	[21]
10	GWP of CH_4	Kg	21	[22]

3. Result and Discussion

3.1 Emission from installation and maintenance processes

Table 2 shows the materials input emission in regards to CO_2 eq footprints to the atmosphere. All of the inputs are within the installation stage of the small-scale biogas digester. It can be seen from the table that the biggest contributors to Global Warming impact categories are consecutively comes from the geomembrane HDPE and the gasoline (transportation) as much as 9726.34 kg CO_2 eq and 6351.79 kg CO_2 eq. These results are obvious due to the high quantity of geomembrane HDPE and gasoline used in the digester installation process as much as 5.1 tones and 2277 liters. The utilization of gasoline to fuel the dump truck is significant to add the atmospheric emission due to approximately 16800 m^3 of soil relocated. HDPE Geomembrane and Gasoline are a petroleum based material which is non-renewable, nondegradable and lead to fossil depletion [23]. Investigation based on the life cycle of HDPE Geomembrane and Gasoline showed that the extraction of the raw materials, transportation/shipping, manufacturing and utilization are the origins of the CO_2 emission hotspots [24, 25]

As much as 204 kg of polyvinyl chloride (PVC) is occupied in this installation. PVC is a thermoplastic material which makes use salt and oil as the basic raw materials. The manufacturing process of PVC is highly involving great amount of energy due to very high temperatures required to convert ethylene dichloride to vinyl chloride monomer. Furthermore, the PVC chemicals in manufacture process are hazardous to the workers and environment [26]. Excess melanomas and spinocellular cancers (skin cancers) was found to a group of workers exposed to vinyl chloride [27].

The installation and maintenance process of biogas digester relies on the occupation of electricity (639,2 kWh). Electricity production in Sumatera is 60% using domestic coal as the main materials, others fraction is fulfilled by hydropower, natural gas, geothermal energy and other renewable sources (wind power, solar power) [28, 29]. Beneath flaming situation non-condensable gasses (CO_2, H_2O, SO_2, NO_2 and CH_4) are released after the alkyl and ether linkages broken. Then the non-combustible components remain as bottom ash, but later 80% of them leaves the furnace as fly ash [30]. Those gasses and particulate matter are the sources of the harmful to people health, air pollution and climate change.

Table 2. Greenhouse gases emission from the installation and maintenance of biogas digester

No	Item	Quantity	Unit	Emissions (kg CO_2 -eq)
1	Geomembrane HDPE 1 mm thick	5119.12	Kg	9726.34
2	Poly Vinyl Chloride			
	• 3.5 Inch Pipes	204.0	Kg	452.88
	• Dope, Knee, Reducer	1.2		2.66
3	Concrete	4.4	m^3	1157.2
4	Electricity (Sumatera)	408.8	kWh	340.12
5	Maintenance			
	• Electricity	230.4	kWh	191.69
	• Geomembrane HDPE	113.75	Kg	216.125
6	Land use	3200	m^2	0
7	Transportation fuel			
	• Dump Truck (Light fuel) Gasoline	1803.2	Liters	5030.9
	• Excavator (Light fuel) Gasoline	473.8	Liters	1321.79
			TOTAL	**18439.75**

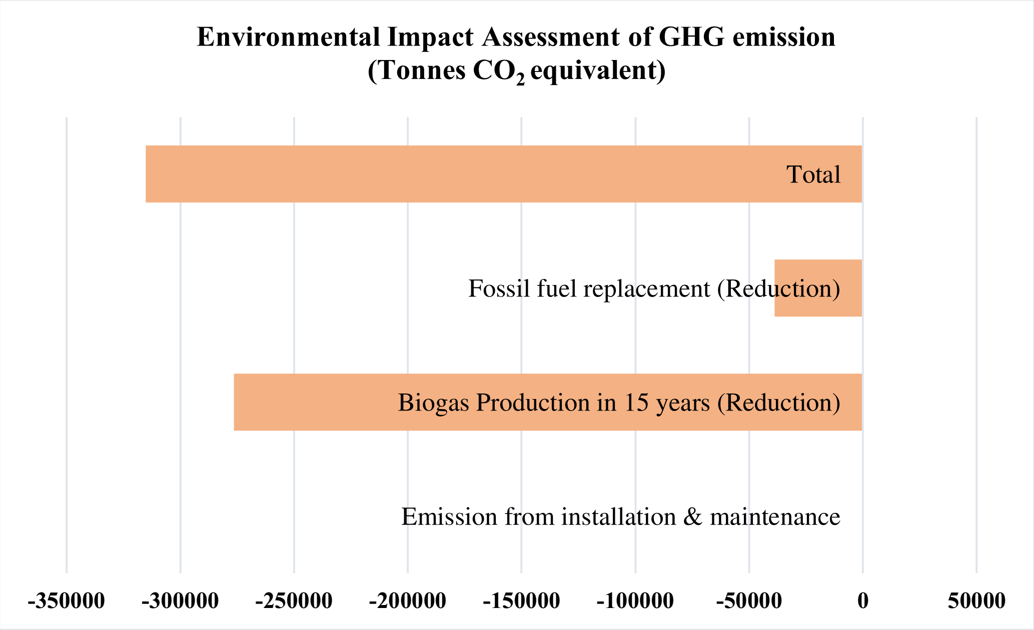

Figure 4. Greenhouse gasses emission and reduction of small industrial scale of biogas in regards to its installation, maintenance and utilization to replace fossil fuel (LPG)

3.2 Greenhouse gasses emission and reduction from biogas digester's life service.

According to our calculation presented in Figure 4, biogas digester of small industrial scale could potentially help to reduce greenhouse gasses emission as much as 296 Kt CO_2 eq per lifetime (15 years). The positive accumulation of greenhouse gasses is only contributed by the installation and operation of the digester (+18.5 Kt CO_2 eq). While the greenhouse gasses reduction is accumulated from the utilization of biogas within the tapioca drying process (methane burning) and fossil fuel savings as much as - 276 Kt CO2 eq and -38 Kt CO_2 eq. The fossil fuel (LPG) that could be saved from the biogas utilization is counted as much as 12,9 Kt. This is a remarkable saving that both very advantageous to the owner as an energy independent producer, and economically wise. More importantly, it contributes to create a sustainable industry which is environmentally friendly.

4. Conclusion

A small industrial scale of biogas digester with anaerobic pond system could potentially reduce greenhouse gasses production as much as 296 Kt CO_2 equivalent through one lifetime or 15 years. The installation and maintenance of digester's input material are creating GHG emission but the number is meagre compared to the overall reduction. The hotspots of GHG emission from the input materials are mainly come from the high utilization of petroleum/oil-based materials such as geomembrane HDPE, gasoline, PVC and electricity. 12,9 Kt of LPG could be replaced by the biogas.

Acknowledgments

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