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To cite this article: F Marendra *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **543** 012059

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A Sustainability assessment of biogas plant based on fruit waste in Indonesia: case study of Biogas Plant Gamping, Yogyakarta

F Marendra¹, A Prasetya^{1,2}, R B Cahyono^{1,2}, T Ariyanto^{1,2*}

¹Waste Refinery Center, Faculty of Engineering, Universitas Gadjah Mada, Grafika Street No. 2, Bulaksumur, 55281, Yogyakarta, Indonesia

²Department of Chemical Engineering, Faculty of Engineering, Universitas Gadjah Mada, Grafika Street No. 2, Bulaksumur, 55281, Yogyakarta, Indonesia

E-mail: teguh.ariyanto@ugm.ac.id

Abstract. The production of biogas by anaerobic digestion (AD) from fruit waste and then converting biogas to electricity is an innovative approach in the development of renewable energy. To study the sustainability of the process, it important to analysis the environ-socio-economic benefits of the technology. In this study, the life cycle sustainability assessment (LCSA) were carried out in a fruit waste biogas plant system, which located in the Gemah Ripah Central Fruit Market in Indonesia. The AD system was designed for 4000 kg/day feed and supplies 148.5 kWh/day electricity. The results of assessment of environmental, economic and social aspects are 5.00 (very good), 3.00 (moderate), and 4.00 (good). This study indicates that biogas plant from fruit waste has a significant advantage for environment, economic, and society. Overall, the sustainability of BPG is in the category of very good (grade I) with a value 4.11 from maximum value of 5.

1. Introduction

Waste fruits and vegetables is important component of household solid waste because high quantities production of agricultural activities, supermarkets and wholesale markets [1]. The number of fruit and vegetable production in Indonesia during 2016 reached 17.5 million tons [2]. With an average depreciation of 10%, the potential fruit waste in 2016 reached 1.75 million tons/year. The amount of fruit and vegetable waste in line with the amount of population and economic activity. Therefore, it is predicted that the number of food waste will increase [3]. If not processed properly, the high number of waste will give negative impacts on the environment and humans.

Waste fruits and vegetables can be processed using anaerobic digestion technology. This process benefits from energy conservation, waste management and environmentally safe products [4]. Today, anaerobic digestion is considered as the most powerful technology to convert energy from biodegradable waste [5]. Therefore, in-depth study regarding the use of anaerobic digestion to convert energy from organic waste [6] and the environmental impact of this technology [7] is needed. The AD technology has declared as the most powerful technology to convert waste to energy from biodegradable waste [8]. However, sustainability assessment includes an analysis of the environmental, economic and social of anaerobic digestion technology has not been comprehensively performed, especially in Indonesia. Also,



the previous studies mostly focused on a particular aspect, i.e. the environmental analysis performed by [9] or economic and environmental assessment as practiced by [10].

This study aimed to conduct a comprehensive sustainability evaluation for anaerobic digestion technology in the biogas power plant. The study includes analysis of the environmental, economic and social. As the case study, Biogas Power Plant Gemah Ripah (BPG) generating 148.5 kWh/day electricity with fruit waste feed, located in Gamping, D.I. Yogyakarta was chosen.

2. Methods

2.1. Description of biogas from fruit waste-generated electricity (biogas power plant)

Biogas power plant (BPG) which was analyzed in this article has a capacity of 4 tons/day, working at a pressure of 150 cmH₂O, mesophilic conditions and operating pH between 6.2 and 6.5. It is built in Gamping, Sleman, D.I. Yogyakarta, Indonesia.

The production of electricity from biogas is described as follows. Fruit waste is sorted and inserted into a temporary shelter for weighing. Fruit waste is crushed with addition of water until liquid-form known as slurry. Slurry is pumped to the two digester, and under anaerobic condition, it will produce biogas, that supplies to the power generation unit. While digestate is accommodated in the digestate storage. The unit produces biogas of 162 Nm³/day volume which generates electricity of 148.5 kWh/day and 5.7 ton/day digestate. The electricity produced is used to lighting the plant and surrounding area. The processes in the biogas power plant is described in Figure 1.

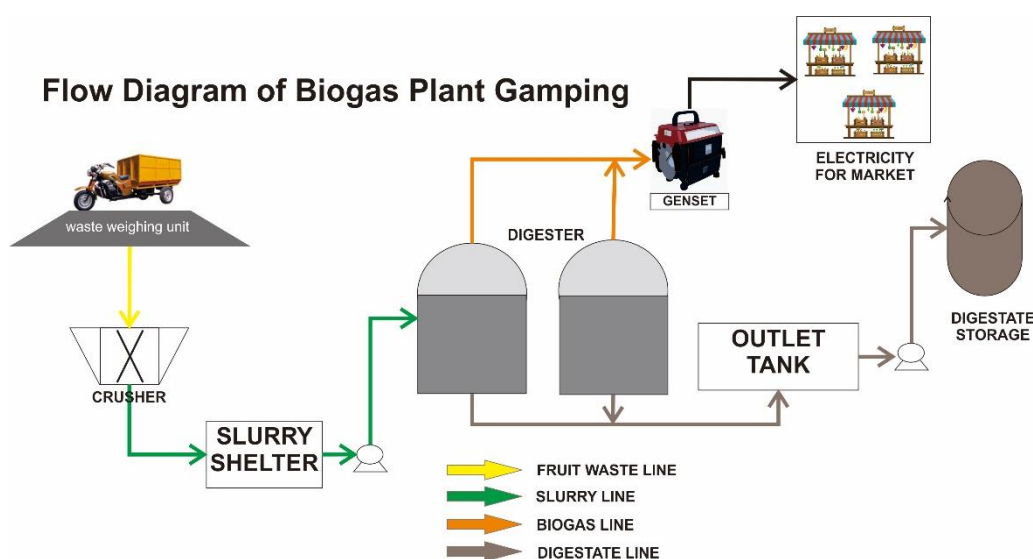


Figure 1. Process flow diagram of BPG

2.2. System boundary and basic framework of the evaluation models

System boundary and basic framework of LCSA process on BPG system is illustrated in Figure 1. The environmental assessment did not account how to obtain fruit waste but limited in start feeding fruit waste to generate electricity and digestate storage for organic fertilizer. Economic assessment is limited to the analysis of costs, benefits and the percentage of profit to the cost. Social studies was limited to the scope of the three stakeholders in BPG i.e; Worker (operator), Consumer (owners of market stalls), Local Community (private sector, organized the Gemah Ripah Fruit Market). The functional unit used in this study is a ton of processed fruit waste.

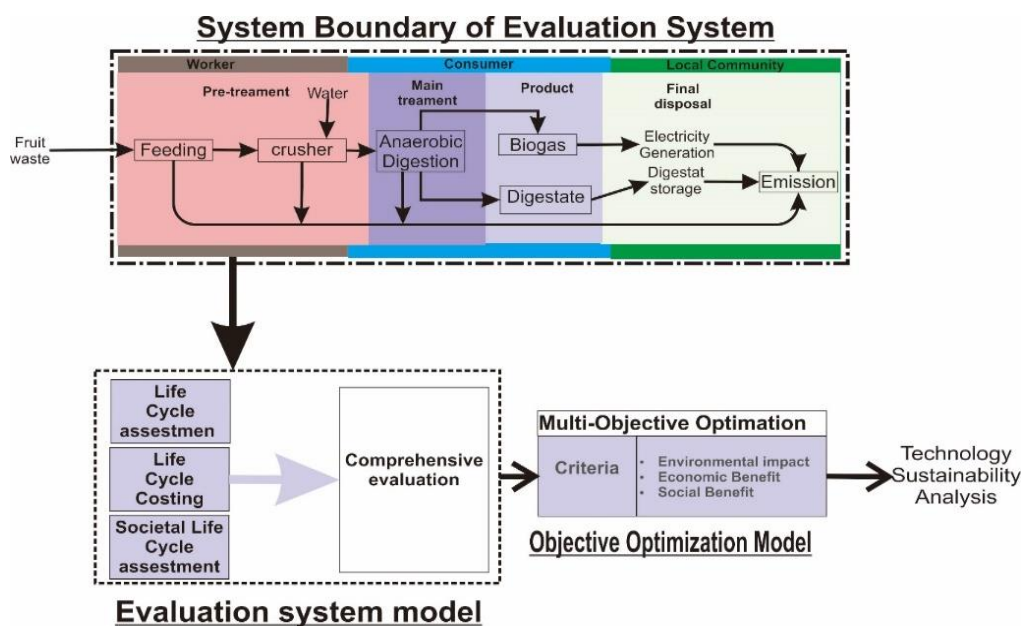


Figure 2. System boundary and basic framework of the evaluation models

2.3. Data inventory

Data inventory process was conducted by field surveys conducted from 2017-2018 year at BPG. Data collected in the form of relevant data analysis of economic, environmental and social. This data was then confirmed to the parties concerned to obtain valid data and verified. For life cycle assessment, data collected from database of Intergovernmental Panel on Climate Change (IPCC), National Environmental Research Institute (NERI), Danish Center for Environmental and Energy (DCE), Baltic Forum for Innovative Technologies for Sustainable Management and Outlook Energy Indonesia 2014.

2.4. Single factor evaluation

Data Environmental analysis was conducted using the midpoint of-life cycle assessment that refers to the operational guidelines prepared by [11]. During the process, the prediction of the environmental impact generated by BPG was divided into five categories: global warming potential (GWP, in kg CO_{2eq}), fresh water ecotoxicity potential (FAETP, in kg 1,4 dichlorobenzene (kg 1,4-DCB_{eq})), human toxicity potential (HTP, in kg 1,4 dichlorobenzene (1,4-DCB_{eq})), acidification potential (AP, in kg SO_{2eq}), and eutrophication potential (EP, in kg PO₄⁻³-eq). Each of these parameters emissions in each group was multiplied by the impact factor compiled by [12-14] to obtain the value of the operational parameters generated from BPG.

The economic analysis was performed by the method of cost-benefit analysis which refers to the way in which the [15]. In brief, the economic evaluation was divided into three categories i.e.: costs, benefits and the percentage of profit to the cost. Each category of used units per ton of processed fruit waste.

Social analysis was conducted using the product of social impact assessment refers to the operational guidelines by [16]. In this method, social impacts were divided into three categories of workers (with the highest and lowest values +24 and -24), consumer (with the highest and lowest values +4 and -4) and local communities (with the highest and lowest values +10 & -10). The question topics conducted on social assessment are as follows. For workers, topics are health and safety, wages, social benefits, working hours, child labor, force labor, discrimination, freedom of association and collective bargaining, employment relationship, training and education, work-life balance, job satisfaction and engagement. Health, safety, and experienced well-being are for consumers. Finally, health and safety, access to tangible resources, the local capacity building, community engagement and employment are for the local community.

2.5. Grades of the evaluation index

Criteria and grade of this evaluation index are very important in the study of the sustainability of the biogas power plant. The study is using grades that arranged in five grades of very good (grade I), good (grade II), moderate (grade III), poor (grade IV) and very poor (grade V). Each grade has a value in a sequence: 5,4,3,2 and 1. Each grade has a characteristic that describing per criteria on the Table 1. Environmental impact and economic benefits criteria refers to [17] while for social benefits refers to the criteria drawn up by the [18].

Table 1. Grade of evaluation index

Category		Grade I	Grade II	Grade III	Grade IV	Grade V	Ref
Level 1	Level 2						
Environmental impact	GWP (kg CO _{2eq})	≤0	246.24	402.48	738.71	984.95	[19]
	FAETP (kg 1,4-DCB _{eq})	≤0	2.92	5.86	8.77	11.69	
	HTP (kg 1,4-DCB _{eq})	≤0	0.15	0.31	0.46	0.61	
	AP (kg SO _{2eq})	≤0	0.12	0.25	0.37	0.49	
	EP (kg PO ₄ ³⁻ _{eq})	≤0	0.96	1.93	2.89	3.85	
Economic Benefit	Cost (million rupiah)	0	0.22	0.44	0.66	0.88	[20]
	Benefit (million rupiah)	4.03	3.02	2.01	1.01	0	
	The ratio profit to cost	100%	75%	50%	25%	0%	
Social benefit	worker	+24	+12	0	-12	-24	[21]
	consumer	+4	+2	0	-2	-4	
	Local community	+10	+5	0	-5	-10	

2.6. Criteria of the evaluation index

The analytic hierarchy process (AHP) method was employed to determine the weight of the evaluation index. AHP is a decision analysis method of multi-purpose labor system quantifies expert opinion using a combination of quantitative and qualitative analysis where guide the implementation process can be obtained through the article by [22].

2.7. The life cycle sustainability assessment (LCSA)

Results of single factor evaluation were employed to calculate the life cycle sustainability assessment (LCSA). First, the value of each criteria in the level 2 (V2) is multiplied by its weighting factor (WL2), hence obtaining the value of assessment level 1 (V1).

$$V1 = \sum (V2 \times WL2) \quad (1)$$

The assessment level 1 include environmental impact, economic benefit and social benefit. Total index grade (TI) of BPG is then calculated with following equation:

$$TI = \sum (V1 \times WL1) \quad (2)$$

Where WL1 is the weighting factor of level 1. The leveling and weighting factor are shown in Table 2.

Table 2. Terminology, leveling and weighting factors of assessment levels

Category		Analysis Result	Sustainability result
Level 1	Level 2		
Environmental impact	GWP (kg CO _{2eq})	0.425	
	FAETP (kg 1.4-DCB _{eq})	0.046	
	HTP (kg 1.4-DCB _{eq})	0.172	0.395
	AP (kg SO _{2eq})	0.274	
	EP (kg PO ₄ ³⁻ _{eq})	0.083	
Economic Benefit	Cost (million rupiah)	0.249	
	Benefit (million rupiah)	0.157	0.291
	The ratio profit to cost	0.594	
Social benefit	Worker	0.632	
	Consumer	0.105	0.314
	Local community	0.263	

2.8. The life cycle sustainability assessment (LCSA)

This process results interpretation and recommendation which can then be applied directly to improve the biogas power plant system. This relates to the development and improvement of products/processes, strategy and planning, determination policies etc. to support sustainability in the environmental, economic and social existence of BPG.

3. Result and discussion

3.1. Result of single-factor evaluation

3.1.1. Environmental impact

Based on the assessment of environmental impact, BPG produces a low environmental impact. It can be proved by a value of 5 in the evaluation of potential emission i.e. global warming potential (GWP), fresh water ecotoxicity potential (FAETP), human toxicity potential (HTP), acidification potential (AP) and eutrophication potential (EP) as shown in Table 3. This means that the BPG system is at grade I (very good) (see criteria in Table 1). This is consistent with the results of previous research conducted by [23]. The most prominent emission value is GWP, which reaches 81.95 kg CO_{2eq}. This value is still much smaller than that of the direct landfill (984.85 kg CO_{2eq}) as described by Chen et al. (2017). Therefore, anaerobic digestion exhibits as a proven technology which could reduce CO₂ released into the environment, when of course the methane is utilized. GWP is contributed by all subsystems BPG starting from the pretreatment, the anaerobic digestion process, electricity generation and digestate storage. For the AP, EP, HTP and FAETP, the values are low. Hence, based on this assessment, BPG shows minor contribution to fresh water ecotoxicity, human toxicity, acidification and eutrophication.

3.1.2. Economic impact

The economic analysis is shown in Table 3. The results showed that the cost required for the establishment and operation of BPG is very high due to the high instalment cost. BPG included in the grade V (very poor) with a value of 1 (see criteria in Table 1). Further analysis in advantages of BPG gives different insight. Benefit category entered in the grade 2 (good), while the amount of profit to cost

ratio reached 43%. It is shown that BPG with anaerobic digestion technology for waste treatment and energy generation gives significant economic benefits. This is consistent with the result of research by [24]

3.1.3. Social Benefit

Social benefits assessment shows the important of BPG. The social benefits have a value of 4, indicating that the BPG entered at grade II (good) (see criteria in Table 1). This means that the presence of BPG provides good social benefits for workers, consumers and local communities. The workers, consumers and local communities feel the positive impact of the presence of BPG. BPG has implemented environmental health and safety regulations with the provision of relatively comprehensive health and safety information, health and safety coverage covered by BPG managers. BPG managers also have provided first aid facilities in accidents and fire extinguishers and perform prompt and appropriate handling in the event of an accident. Consumer and local community stated that the presence of BPG provides many benefits like support their trading business and they do not feel a burden due to BPG. Furthermore, consumers are also very happy that their waste can be used as raw material of BPG. The existence of this positive impact is indispensable for the sustainability of BPG considering the social aspect as a vital aspect in the development of waste management and renewable energy in Indonesia.

Table 3. Sustainability result of single-factor evaluation

Category		Analysis Result	Sustainability result
Level 1	Level 2		
Environmental impact	GWP (kg CO _{2eq})	81.95	5
	FAETP (kg 1.4-DCB _{eq})	0.0098	5
	HTP (kg 1.4-DCB _{eq})	0.0109	5
	AP (kg SO _{2eq})	0.07	5
	EP (kg PO ₄ ³⁻ _{eq})	0.02	5
Economic Benefit	Cost (million rupiah)	1.89	1
	Benefit (million rupiah)	2.64	4
	The ratio profit to cost	43%	3
Social benefit	Worker	+7	4
	Consumer	+1	4
	Local community	+5	4

3.2. The life cycle sustainability assessment (LCSA)

Kloepffer [25] mentioned that life cycle sustainability assessment (LCSA) is the sum of the life cycle assessment, life cycle costing and societal life cycle assessment. The results of LCSA of BPG system is shown in Table 4. Overall, the technology used by BPG is categorized as a very good technology (score 4.11, grade I). The environmental benefits of BPG categorized as excellent (score 5, grade I); social benefits in the category of good (score 4, grade II); and economic benefits in the category of moderate (score 3, level III). Environmental impact assessment scores are greater than the social benefits and economic benefits. The results showed that overall the AD technology has a high sustainability, which also agrees to [26]. From the result of LSCA, it is necessary to increase economic benefits of anaerobic technology for electricity production as it is the lowest criteria. Innovative approaches are needed to be introduced for development and improvement of products/processes. For the instalment cost, for example, providing better compact digestion plant is needed, thus lowering the cost for land area. Product diversities are also required e.g. digester slurry effluent for fertilizer and a direct use of gases for cooking. Another is to introduce biogas plant as education tourism.

Table 4. Comprehensive evaluation result of sustainability assessment

Category		Sustainability results (Level 2 grade)	Level 2 weighting factor	Level 1 weighting factor	Level 1 sustainability grade	Total sustainability grade
Level 1	Level 2					
Environmental Impact	GWP (kg CO _{2eq})	5	0.425			
	FAETP (kg 1, 4-DCB _{eq})	5	0.046			
	HTP (kg 1,4-DCB _{eq})	5	0.172	0.395	5	
	AP (kg SO _{2eq})	5	0.274			
	EP (kg PO ₄ ^{-3eq})	5	0.083			4.11
Economic Benefit	Cost (million rupiah)	1	0.249			(grade I/very good)
	Benefit (million rupiah)	4	0.157	0.291	3	
	The ratio profit to cost	3	0.594			
Social benefit	worker	4	0.632			
	consumer	4	0.105	0.314	4	
	Local community	4	0.263			

4. Conclusion

The life cycle sustainable assessment was conducted for biogas power plant. The steps of the comprehensive evaluation methods include i) determination of the goal and scope of the study, ii) the analysis of inventory of data (environmental, economic, and social), iii) assessment of the impacts (environmental, economic, social), iv) determination of the criteria and grade of index evaluation, v) the determination of the weight of the evaluation index system, vi) the calculation of the value of sustainability and vii) interpretation of obtained data. Results of the assessment of environmental benefits, economic and social are 5 (grade I/very good), 3 (grade III/moderate), and 4 ((grade II/good)), respectively. In overall, the sustainability of BPG grade is in grade I with a value 4.11 (very good category). This shows that BPG can be considered as an eco-friendly program with significant socio-economic benefits.

5. Acknowledgement

The authors gratefully acknowledge the funding of the Ministry of Research, Technology and Higher Education of the Republic of Indonesia (MENRISTEKDIKTI) through Penelitian Terapan Unggulan Perguruan Tinggi (Grant No. 1870/UN1/DITLIT/DIT-LIT/LT/2018). The authors thanks to Anggun Rahmada for fruitful comments and discussion

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