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Biogas Fed-fuel Cell Based Electricity Generation: A Life Cycle Assessment Approach

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ABSTRACT

The world is currently facing a scarcity of energy resources in the electricity generation sector. The current pattern of electricity generation has brought harm to the environment. Fuel cell provides a huge potential in reducing the negative environmental impacts. Malaysia as a tropical country has abundant sources of biogas production that can be fed into the fuel to produce electricity and water. The paper aimed to identify the environmental impact towards the consumption of biogas feeding into fuel cells for electricity generation. The result showed that in this modelling of system boundary, the greenhouse gas emissions were high due to large contributions from the transportation and storage processes. Hopefully, the outcome from this study could help future researchers or stakeholders in making decisions to design fuel cells for electricity generation with minimum environmental impact contribution.

Keywords: Biogas, Fuel Cell, Electricity Generation, Life Cycle Assessment, Sustainability

JEL Classifications: C32; O13; O47

1. INTRODUCTION

Due to the unsustainability issue of fossil fuel supply, the world is urged to explore new types of energy resources. Fuel cell is among the many types of energy resources that is able to fulfil the future need of electricity. Fuel cells are more effective than the present use of combustion technologies in power plants. Therefore, they might play a significant future part in reducing the reliance on fossil fuel and increasing the electricity generation capacity from biomass supply (Wasajja et al., 2020). Currently, researchers across the globe are exploring the potential of fuel cells as an energy resource in various perspectives. In 2019, it was reported that almost 30,000 research articles were published in the field of fuel cell (Elsevier, 2020). Fuel cells use the concept of electrochemical reaction in order to obtain the outputs of electricity and water, while the inputs

to the system are gas and oxygen. Amid the wide range of fuel cell types, it is found that solid oxide fuel cells (SOFCs) offer many benefits; for instance, high functional temperature, ability to utilise numerous fuels as input, and ability to be easily combined with other electric generator devices (Mehrpooya et al., 2020). This fuel cell type offers high electrical efficiency up to 60%, minimum emission of carbon dioxide, high temperature resistance, more reliable, and technically available (Cozzolino et al., 2017; Saadabadi et al., 2019). According to (Aziz and Hanafiah, 2020; Cozzolino et al., 2017), the SOFC system has a small value for economic investment due to the huge levelised cost of energy (LCOE) value, is more lenient to pollutants, and has the lowest energy cost.

As a tropical country, Malaysia has a huge potential of biogas production. A high expectation has been set by the biogas production and processing industry for Malaysia to be developed as

a biogas hub in Asia. It is estimated that by 2022, the biogas market will accumulate to RM8.3 billion (USD2.3 billion) (Bioeconomy, 2015). Utilising biogas from the anaerobic digestion process along with SOFCs is assumed to result in a significantly direct and efficient probability to combine SOFCs and biomass (only if cell degradation risks are decreased). This system combination is more convenient and less costly, as well as has low temperature gas cleaning (Leone et al., 2010). Generally, microgas turbines, internal combustion engines, or high temperature fuel cells, such as SOFC, are regarded as appropriate for combined heat and power (CHP) systems (Papurello, 2014).

Singapore is vigorously progressing towards using fuel cells in the generation of electricity. The Ministry of Home Affairs is reported to have declared in 2015 that the new prison headquarters will be fueled with polymer electrolyte membrane fuel cells (PEMFC) (Chan et al., 2016) by using food waste as feedstock in generating hydrogen. Indonesia is currently applying fuel cell generated power systems with telecom operators, such as Hutchison CP Telecommunications, Telkom International, and XL Axiata (Cascadian, 2015). Meanwhile in Thailand, 10 MW of fuel cell capacity have been initially employed in Rayong province by utilising excess hydrogen ("Alkaline Fuel Cell [AFC] deals to deploy 300 MW in Dubai, 10 MW in Thailand," 2015).

Currently, Malaysia has 83 companies installed with a total capacity of 153.64 MW that are able to produce biogas for electricity generation (SEDA, 2018). A study by (Shafie et al., 2020) estimated that palm oil residues have the ability to generate electricity up to 1474 MW. Therefore, it shows that there is great potential to feed biogas into the fuel cell system. Figure 1 displays the current location of biogas plants in Malaysia. Perak has the highest amount of available biogas plants with up to 33 MW. Based on this establish technology for biogas production, Malaysia is able to create a huge potential in utilising fuel cells for electricity generation since biogas can be fed as input to the system. Anaerobic fermentation is a biological process that is able to efficiently extract hydrogen via a sustainable approach,

particularly if organic wastes are consumed (Leone et al., 2010). It is reported that almost RM40 million have been allotted to academic and research institutions in Malaysia for the study and development of fuel cells (Sin and Najmi, 2013).

Even though the technology part of fuel cells has been precisely reported in numerous articles, the environmental aspect also needs to be analysed critically. Assessing the environmental indicator would benefit policy-makers and stakeholders in choosing the most optimum management approach with the least environmental impact (Châfer et al., 2019). The Life Cycle Assessment (LCA) is a proven approach in assessing a structure's environmental indicator from end to end throughout its lifetime (Rillo et al., 2017). Currently, the pattern of LCA studies on fuel cell electricity generation only focuses on manufacturing rather than the whole cradle-to-grave system (Rillo et al., 2017). Therefore, this paper aims to estimate the environmental impact of electricity generation based on biogas-fed fuel cells by using the LCA method.

2. METHODOLOGY

The current LCA study has been conducted in compliance to the ISO 14040 and ISO 14044 standards. The goal and scope of study were identified, followed by inventory data analysis and assessment of impacts. LCA is a cradle-to-grave method that consists of the overall process from raw material mining and chemical fuel production to electrochemical reaction (Bicer and Khalid, 2020).

Figure 2 shows the system boundary applied in this study. The aim of this study is to generate 1 kWh of electricity. The processes involved were palm oil plantation, waste treatment, storage, transportation, and solid oxide fuel cells (SOFCs).

The life cycle inventory analysis (LCIA) includes a compilation of the inputs such as energy, raw materials, and input resources, emission output, disposal amounts per unit process, and end-of-life recycling rate, all of which are reflected in the system boundary of LCA. The data was obtained from recognised databases such as GaBi, related

Figure 1: Current location of biogas plants in Malaysia for each state

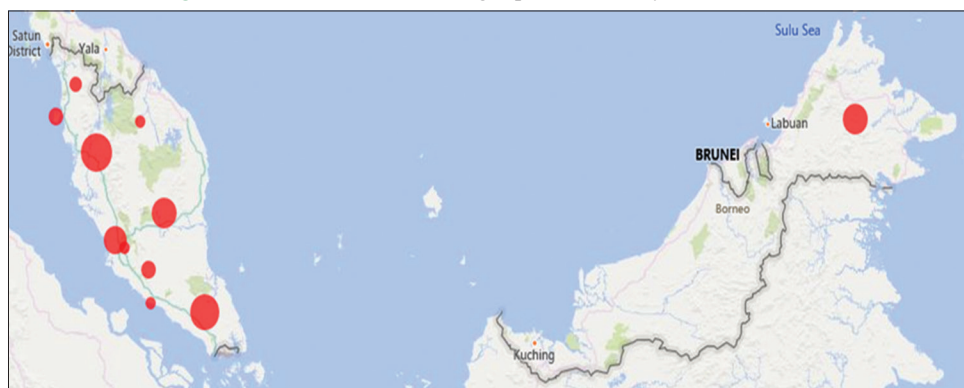
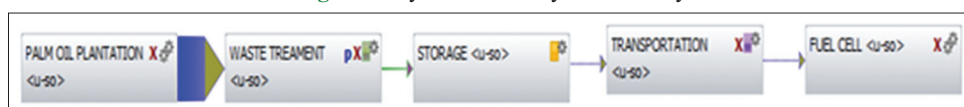


Figure 2: System boundary of this study



industries or literature review. The biogas production process of palm oil plantations was taken from interviews and observation at Setia Kawan Kilang Kelapa Sawit Sdn Bhd. Meanwhile, the SOFC process was adapted from the New Energy Externalities Development for Sustainability (NEEDS) project (NEED, 2020).

In this analysis, it was estimated that 1430 kg of fresh fruit bunches were processed to produce 290 kg of crude palm oil (CPO) and 1000 kg of palm oil mill effluent (POME) (Aziz and Hanafiah, 2020). As for the biogas production, it was calculated that 1000 kg POME could produce 16.63 kg of biogas (Aziz and Hanafiah, 2020). The transportation process was assumed to use gas trucks with a distance of 50 km to fuel cell power plants. It is reported that the most practical methods in Malaysia involve compressing hydrogen in pressure vessels and transporting via trailers and trucks (Mah et al., 2019). Biogas is capable of being compressed as liquefied biogas (Begum and Nazri, 2013) for transportation purposes. Despite the fact that pipeline transport is a cheaper choice of transportation, the pipeline compressors eventually build up the cost, resulting in it being less feasible in contrast to truck transportation (Begum and Nazri, 2013). Diesel consumption is calculated using Equations (5) and (6). SOFC is considered to be used in this analysis since this fuel cell type is the most established in the industry (Table 1). Table 2 indicates the input data to the system.

3. RESULT AND DISCUSSIONS

The most concerned parameter is global warming. In this study, the life cycle of global warming emission is 564 g CO_{2EQ}/kWh. Figure 3 shows the GHG emission in the function of electricity

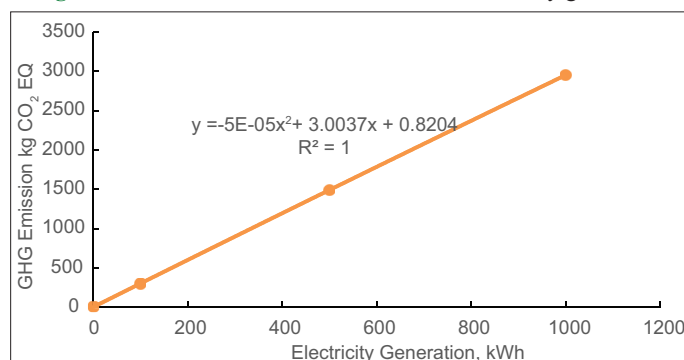
Table 1: Heating value applied in this study

Heating value POME	Calorific value	References
17,044 KJ/kg	53,000 kcal/m ³	(Begum and Nazri, 2013)
	21-23 MJ/m ³	(Mohtara et al., 2017)

Table 2: Input data to the system

Process	Sources	References
Plantation	FELCRA Kubang Kenyeng, Naka	
Milling	Setiakawan Kilang Kelapa Sawit Sdn Bhd	
Treatment	GLT Eco Sdn Bhd	
Storage	Literature review	(NEED, 2020)
Transportation	Literature review	(IRENA, 2018)
Fuel cell	Literature review	(NEED, 2020)

Figure 3: GHG emissions in the function of electricity generation



generation. According to the study from (Bicer and Khalid, 2020), natural gas-fed SOFC has the lowest environmental impact with 0.41 kg CO_{2EQ}/kWh. This is due to the fact that natural gas is able to be extricated and processed in the power plant. Nevertheless, Rillo (Rillo et al., 2017) discovered that GHG emissions are calculated at 552 kg CO_{2EQ}/kW. The relationship between GHG emission and electricity generation can be expressed in Equation (1). Where parameter X is for electricity generation in kWh. Even though the graph shows an increasing pattern of GHG emission, it is still lower as compared to the conventional electricity generation system. It is found that coal emits electricity amounting to 1,036 g CO_{2EQ}/kWh, whereas the global warming potential (GWP) for oil and gas is equivalent to 868 and 646 g CO_{2EQ}/kWh, respectively (Gaete-Morales et al., 2019). The most common GWP is found from the combustion of fuel such as lignite, hard coal, and gas, with GWP values of 97%, 83%, and 74%, respectively (Atilgan and Azapagic, 2015). This is in contrast with fuel cell-based electricity generation, where transportation and storage play the key roles in contributing towards GWP. By adjusting the type of transport, distance, and type of storage, carbon dioxide emissions can be minimised.

$$\text{GHG} = -5\text{E-}05x^2 + 3.0037x + 0.8204 \quad (1)$$

Figure 4 displays the percentage of each process that contributes towards the overall GHG emissions in this study. About 48% of emissions came from the transportation process.

The CML indicator-based technique provides a comparative environmental impact assessment result by employing a cradle-to-gate assessment. Subsequently, this approach exposes environmental effects for ten impact categories: Global warming, acidification, eutrophication, ozone depletion, abiotic depletion, freshwater aquatic eco toxicity, human toxicity, marine aquatic toxicity, photo ozone creation, and terrestrial eco toxicity. Figure 5 shows the LCIA results for 1 kWh within the system boundary. About 60% of the impact categories were from the storage process. The second highest contribution was from transportation. Reducing the distance of palm oil mills and fuel cell plants should reduce this percentage. It is suggested for the system boundary to be remodeled for minimum output of environmental impacts.

Figure 4: Process contribution toward GHG emissions

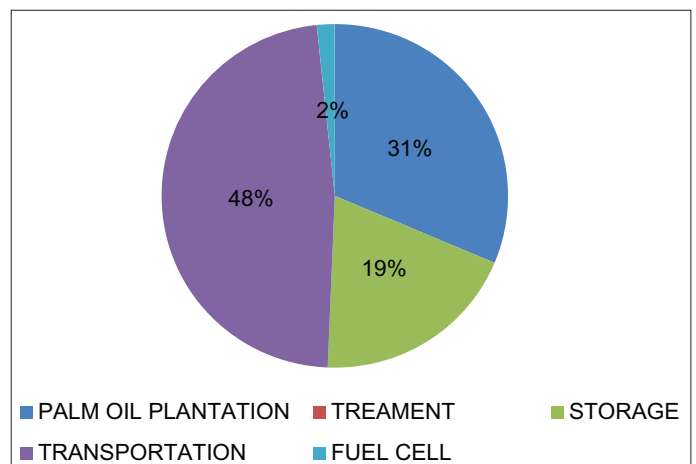
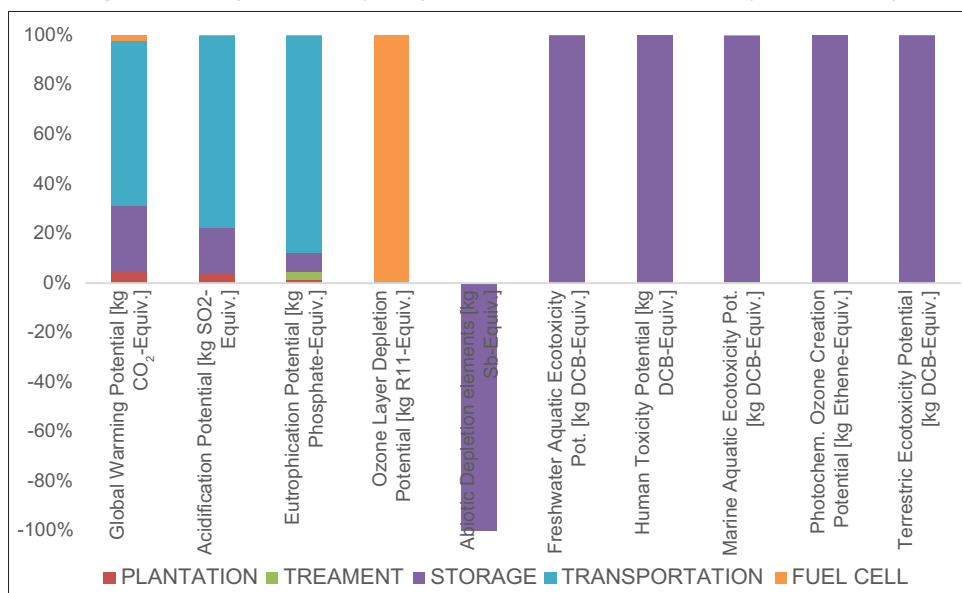


Figure 5: Life cycle inventory analysis results for 1 kWh within the system boundary

Although fuel cell application in Malaysia is minimal at this point of time, it seems that the capability of this resource due to the huge amount of biogas creates the possibility for its penetration in Malaysia. There is no suspicion that the government plays a major role in this issue. The need to increase research and development, investment in human resources, business-friendly policies and implementation beyond the mutual action plan will be the key to recognise the capability of fuel cells in Malaysia.

4. CONCLUSION

Based on this system boundary design, the result revealed that it offers high contribution towards the environmental impact. In the effort to minimise emissions and optimise the energy system, the system boundary design needs to give extra attention to the storage and transportation processes. The LCA of GHG emissions in this study are high due to the large contributions from the transportation and storage processes. Therefore, it is suggested for fuel cells to be installed inside the location of available biogas so as to reduce GHG emissions.

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