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Role of Biogas and Biochar Palm Oil Residues for Reduction of Greenhouse Gas Emissions in the Biodiesel Production

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Abstract

Greenhouse gas (GHG) emissions which related to palm oil production are tend to increase due to the increasing of palm oil demand and the expansion process of oil palm production worldwide. The specific objective of the study was to assess the contribution of innovative biomass processes as effort to improve the energy balance and reduce the greenhouse gas emissions (GHG) associated with biodiesel made from palm oil. The GHG was calculated that GHG emission savings up to 63.14 % in total. GHG emissions from biochar using empty fruit bunches (EFB) resulted to 2.95 % from total GHG emissions, and biogas from palm oil mill effluent (POME) produced 74.22 % of the total GHG emissions from palm oil based biodiesel production. Innovative technologies and processes for the treatment of by-products can contribute significantly for meeting the emission targets. Build upon the research, resulted to the recommendation to use biochar and capturing methane from POME. The research result was also concerned that emission savings are annulled in the case of land use change (LUC) and oil palm production on peatland. Based on this research resulted to recommended that the utilization of waste from oil palm cultivation on peatland which was disuse and the capturing of methane from POME

Keywords: Biochar; biodiesel; biogas; biomass; climate change; mitigation

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Nomenclature

CO_2	Carbon dioxide
CH_4	methane
EFB	Empty Fruit Bunches
FFB	Fresh Fruit Bunches
EU	European Union
GHG	Greenhouse Gas
ha	hectare
h	hour
IOPRI	Indonesia Oil Palm Research Institute
LCA	Life-cycle assessment
LUC	Land Use Change
POME	Palm Oil Mill Effluent
t	tonne = 10^3 kg

1. Introduction

Many countries have tried to reduce dependence on fossil fuels which aims to avoid any disruption during supply and price volatility by finding other renewable resources [1]. According to reference [2], several countries have set targets to reduce emissions. They have ratified international agreements for the mitigation of human impacts on natural systems through climate change (i.e.: Kyoto Protocol). In 2009, Reference [3] stated that the EU published the directive 2009/28/EC, which pointed-out criteria for the sustainability of biofuels in its articles 17, 18 and 19. These criteria relate to greenhouse gas savings, conservation of land with high biodiversity value, land with high carbon-stock and the implementation of agro-environmental. Estimation the carbon emissions avoided by the use of various biodiesel feedstocks grown on existing cropland [4]. They found that, in each case, more carbon would be sequestered over a 30-year period by converting the cropland to forest than when producing biodiesel. Despite the potential benefit of biodiesel, reference [5] showed that different biodiesel vary widely in their greenhouse gas balances when compared with fossil petrol, depending on the methods used to produce the feedstock and process the fuel, some crops can even generate more greenhouse gases than fossil fuels. For example, nitrous oxide, a greenhouse gas with a global warming potential 300 times greater than that of carbon dioxide, is released from nitrogen fertilizers [6]. Moreover, greenhouse gases are emitted at other stages in the production of bioenergy crops and biodiesel in producing fertilizers, pesticides and fuel used in farming, during chemical processing, transport and distribution and up until to final use [7]. References [8,9] indicated that energy balances are quantification and systematic representation of the physical transformation and a flow of energy sequestered in the consumption and production process of goods and involve both direct and indirect energy input. Several researcher [8,10-12] have investigated energy balances and GHG emissions from biodiesel palm oil production. They focused on analysing of energy balances in the palm oil derived methyl ester life cycle for cases in Brazil and Thailand. Reference [12] shows that studied the energy balances and accounted the GHG emission on the biodiesel palm oil production in Malaysia. The project was not focus on energy balances and GHG emission from LUC and energy content from by-product. Analysis of the energy balance of biomass production should provide in-depth understanding of the environmental compatibility, and its preservation can be used for energy efficiency policy.

In the article, the energy balances and GHG emissions for the different production stages from land-use change preparation, pre-chain processes, transportation, agricultural stages, milling, biochar production from EFB palm oil, biogas from POME, and biodiesel production were assessed and were analyzed.

The specific objective of the study was to assess the contribution of innovative biomass processes to improve the energy balance and reduce greenhouse gas emissions (GHG) associated with biodiesel made from palm oil. In a life cycle approach we assessed the reduction of GHG emissions resulting from the treatment of by-products from palm oil biodiesel production. The conversion of empty fruit bunches (EFB) into biochar and the use of biogas from palm oil mill effluent (POME) to sequester CO_2 from the atmosphere, fix CO_2 in the soil and reduce CO_2 emissions from fossil energy sources has been investigated.

2. Material and method

2.1. System boundaries, data base, and functional unit

This paper is based on the ISO 14044 standard which establishes life-cycle assessment (LCA) procedures. The primary life-cycle stages of palm oil production include the production of fresh fruit bunches (FFB), crude palm oil (CPO) extraction and transesterification. The by-products of palm oil include utilisation EFB as biochar and energy generation biogas from POME. Software Umberto® [13] was used for calculation of energy balance and GHG emission. The system boundaries are cradle to gate.

The primary information and data were obtained from palm oil plantation in Kalimantan and Sumatra of Indonesia, from 2009 to 2012 using personal interviews with the operator and manager of the palm oil mills for processing stages. Some material data were gained from a personal interview, references and other sources. The functional unit of the study is one tonne of biodiesel. Values are also given per ha and year.

2.2. Greenhouse gas emissions of biodiesel

According to reference [7], global warming and climate change have been receiving increasing attention lately, and this can be attributed to the large-scale use of fossil fuels. Biodiesel is primarily intended to replace the utilization of fossil fuels due to its unstable market price and to reduce GHG emissions. Biodiesel is produced from biomass; therefore, it is carbon neutral in principle, as its combustion only returns to the atmosphere the carbon that was sequestered from the atmosphere by the plant during its growth [14]. It is not like fossil fuels, which release carbon that has been stored for millions of years under the surface of the earth. However, assessing the net effect of biodiesel on greenhouse gas emissions requires an analysis of emissions throughout the life cycle of the biodiesel, which includes the land-use change, planting, harvesting, transporting, biodiesel processing, storing, and distributing the biodiesel [15].

In this study, the GHG emissions from palm oil production have generally been categorised as emissions arising from operations during oil palm growing and Fresh Fruit Bunches (FFB) processing, or more precisely, from emissions related to the use of fossil fuels for plantation-internal transport and machinery; emissions related to the use of fertilizers; emissions related to the use of fuels in the palm oil mill; and the use of palm oil mill by-products. The GHG emissions resulted from land-use change, fertilizers, transportation, palm oil farming, oil extraction, biodiesel production; the utilisation of EFB, palm oil used as organic material, and biogas produced from the liquid waste of palm oil.

2.3. Description of the studies

2.3.1. Palm oil biodiesel production in Indonesia

Palm oil trees (*E. guineensis*) were brought by the Dutch to Bogor (West Java, Indonesia) as ornamental plants and then spread throughout Sumatra in the early 20th century. In the 1960s, major oil palm plantations were established in Sumatra by the government of Indonesia within the frame of transmigration programs. Thirty years later, that is, from 1987 onward, oil palm plantations were introduced in Kalimantan, imitating the plantation schemes implemented in the transmigration programs in Sumatra. Despite the similar organization of oil palm production in Sumatra and Kalimantan, regional disparities persist due to different ecological environments, (e.g., mineral land and peat land composition in palm oil plantation areas), socioeconomic settings (e.g., know-how of palm oil processing), infrastructure (e.g., better sustained roads and bridges in Sumatra), and timeframes (e.g., due to longer operating experience – Sumatra's palm oil industry was developed earlier than in Kalimantan).

The establishment of new palm oil planting involves a change in land-use resulting in loss of carbon present in the previous vegetation and possibly some carbon from oxidation of soil organic matter [16]. According to reference [17], such losses are partly or wholly replaced by carbon sequestration in the palm oil trees and quantifying these changes requires information on previous biomass, the data for which are often uncertain. References [6], revealed that the total amount of GHG emissions for a reused peat land area can be determined by adding CO_2 and N_2O emission from peat decomposition after drainage, when the peat land is first drained and afterwards replanted with oil palm [6]. Farming stages of palm oil include land preparation, seedling, planting, fertilizer application, herbicides, harvesting and transportation from the palm oil plantation to the palm oil mill processing. Transportation is needed for bringing the fertilizer from the factory and for delivering the seedlings to the nursery and young palm trees.

Transportation during the farming process until milling processes is urgently required. This is because FFB palm oil has to be sent to the milling within less than 24 h to avoid any reduction of the CPO quality. Transportation of FFB to the mill in Sumatra is much easier and quicker than in Kalimantan. This is due to many rivers through which the FFB are transported by ferry in Kalimantan.

Milling is to convert the FFB into separated crude palm oil (CPO), kernel oil, and by-products. During this process, electricity is needed to produce steam for sterilization and processing, to drive the extraction and separation equipment, and for ancillary farm and domestic purposes.

At the transesterification stage, methanol, sodium hydroxide, and electricity are required for shaking the oil and the components to produce biodiesel. The biodiesel production rate is around 16 t per batch. The biodiesel is separated from the glycerol by gravity, then the remaining mixture is washed with water and acetic acid until the washing water is neutral. The methyl ester is then dried by heating. The biodiesel yield is around 87 % of the crude palm oil processed. The percentage of yield for biodiesel production can be calculated based on a stoichiometries material balance. Glycerol is a by-product that can be used to produce soap or other materials.

2.3.2. Biochar processing

Based on the research conducted by Soni et al. [18], EFB is obtained after extraction of the fruits from the fresh fruit bunches (FFB) during the milling process for palm oil production. At this stage, EFB has a moisture content of 12 %. It is stored for drying by natural convection in an open place. When the EFB reaches a moisture content of about 9 %, it is moved from the mill to the biochar plant using trucks with a loading capacity of seven tonnes. The transportation of the EFB from the mill to the biochar plant requires energy and produces emissions.

The biochar plant is fed by using screw belts to move the EFB from the trucks to the pyrolysis drums, where they are processed for further drying. The EFB is fed to the pyrolysis drums without shredding. The pyrolysis equipment comprises three ovens and three rotating drums. The drying and pyrolysis process is designed in such a way that when the drying of one batch is completed, the processing of the next batch gets started in the next drum. To start the process, the oven is heated with hot air generated in a burner using diesel fuel. The temperature used for the slow pyrolysis is between 350 °C and 450 °C. The slow pyrolysis process requires extensive use of diesel fuel for heat generation. During operation in 1st and 2nd hrs, no further diesel is required, as the heat production is supported by the syngas obtained as a by-product from the pyrolysis process. The syngas produced during slow pyrolysis is utilized to generate additional heat for drying and slow pyrolysis. Excess energy is dissipated through a chimney.

The products obtained from the slow pyrolysis of palm oil EFB in the biochar facility are biochar, syngas and bio-oil. The biochar production efficiency is 20 %, i.e. one t of EFB delivers 0.2 t of biochar. In addition, 0.3 t of syngas and 0.025 t of bio-oil are obtained as by-products from each t of EFB. The biochar produced is composed of carbon (C), nitrogen (N), ash and water. Biochar also produce volatile matter which is material with evaporates readily at normal temperature, pressure and vaporized with value of 41 %. Biochar yields produced from palm oil EFB in Selangor were 20 % of the feedstock mass, while biochar yields of 35 % to 36.5 % of the feed-stock mass for other kinds of feedstock [19]. A reason for this may be the different physical and chemical properties of palm oil EFB compared to other feedstock. The water content of biochar from palm oil EFB is the smallest compared with biochar from other feedstock. Compared with other feedstocks, the biochar from palm oil EFB is relatively fine and the ash content high. This may be an advantage for transportation, application and incorporation of the biochar into the soil. This is might be because of higher density of biochar.

2.3.3. Biogas from POME

The increasing production of palm oil has raised the question of how to manage the increasing volume of POME efficiently and preserving the environment. Commonly, POME is treated in ponds under aerobic conditions. The treatment system using open ponds is simple and requires low investment and low energy input.

Alternative processes for the treatment of POME are composting, covering the ponds with a flexible membrane or constructing covered tanks and anaerobic treatment in digestion plants [20]. All treatment options aim to reduce the discharges of wastewater, to recycle POME, to capture methane for reducing GHG emissions and to substitute non-renewable fuels consumed in the palm oil and biodiesel production process.

2.4. Calculation GHG emissions

Determination of the GHG emissions from palm oil-based biodiesel production is based on a life cycle inventory, and accounts for all GHG emissions that arise between initial land conversions and final use of the palm-oil-based energy. Considered greenhouse gases are carbon dioxide (CO_2, GWP: 1), methane (CH_4, GWP: 21) and nitrous oxide (N_2O, GWP: 310) which are summed up to carbon dioxide equivalents (CO_2-eq).

To account for GHG emissions resulting from converting forests into oil palm plantations, the following equation from guidelines [6, 21] is applied:

$$LUC_{emissions} = 3.7 * \left[\frac{LUCC}{T_{LUC}Y} - \frac{C_{uptake}}{\left(T_{plant}Y\right)} \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where $LUC_{emissions}$ is the net emissions from LUC (kg CO_2-eq. MJ^{-1}), 3.7 is the molecular weight ratio of CO_2 to C (dimensionless), LUCC is the loss of carbon from LUC (kg C ha^{-1}), C_{uptake} is the carbon uptake by oil palm during the plantation lifetime (kg C ha^{-1}), T_{LUC} is the allocation time period of LUC emissions (years), T_{plant} is the plantation lifetime (a) and Y is the net energy yield (GJ ha^{-1} a^{-1}).

The environmental performance of biofuels with respect to land use change effects and overall carbon balance can be assessed and compared using the methodology of Ecosystem Carbon Payback Time (ECPT) [18,21] ECPT measures the years required to compensate for the carbon loss induced from land use change processes of the featured ecosystem by avoided carbon emission (carbon savings) due to biofuel:

$$ECPT = \frac{Carbon_{landsource} - Carbon_{biofuelcrop}}{Biofuel_{carbonsavings}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where $Carbon_{landsource}$ is the carbon stock of the converted land source (t C ha^{-1}), $Carbon_{biofuelcrop}$ is the carbon stock of the biofuel crop land (t C ha^{-1}), and $Biofuel_{carbonsavings}$ is the annual carbon saving from using biofuels in place of fossil fuels (t C ha^{-1} yr^{-1}). The Commission the European Union states that greenhouse gas emission savings from biofuels are to be calculated using the following equation [22]

$$SAVING = \frac{E_F - E_B}{E_F} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where E_B is total emission from the biofuel and E_F is the total emission from fossil comparator.

3. Results and discussion

Table 1 below shows the result of GHG emissions for different activities to produce palm oil biodiesel. There are two GHG emissions added as consequences of the by-products utilized in the palm oil biodiesel production. These are GHG emissions from biochar production and GHG emissions biogas from POME.

Table 1. Total emission emitted from activities to produce palm oil biodiesel

Biodiesel supply chain activity	Amount of emission (kg CO_2-eq)	Percentage (%)	
Emission		Including LUC	Excluding LUC
1. Land-Use Change (LUC)	19 529.35	65.65	-
2. Pre-chain	391.27	1.32	3.83
3. Transportation	86.69	0.29	0.85
4. Agricultural phase	377.93	1.27	3.70
5. Oil extraction	60.37	0.20	0.59
6. Transesterification of biodiesel	1 506.23	5.06	14.74
7. Biochar production	211.60	0.71	2.07
8. POME ponds	7 583.39	25.49	74.22
Total GHG emissions including LUC	29 746.83	100.00	
Total GHG emissions excluding LUC	10 217.48		100.00

In GHG emission processes as seen in Table 1 above, there are two types of emission calculations i.e. GHG emission calculation including LUC and that excluding LUC. The following are details of both GHG emissions.

3.2.1. GHG emissions including LUC

Total GHG emission including LUC is 29 746.83 kg CO_2-eq. The LUC emits the biggest GHG emission with total of 65.65 % of total GHG emission (19 529.35 kg CO_2-eq). It is followed by emission from POME ponds with 25.49 % of total GHG emissions (7 583.39 kg CO_2-eq). Furthermore, GHG emission from biodiesel trans-esterification emits the fourth biggest emissions with 5.06 % of total emission, followed by emission of pre-chain and agricultural works with 1.32 % and 1.27 % respectively. The emission from biochar is only 0.7 % of total emissions with 211.60 kg CO_2-eq.

3.2.2. GHG emission excluding LUC

When the LUC is not included, the biggest source of GHG emission is resulted from methane in the effluent ponds. This source produces 7 583.39 kg CO_2-eq or 74.22 % of the total CO_2 emissions. The transesterification of biodiesel causes 1 506.23 kg CO_2-eq or 15 % of the total emissions. The third source of GHG emission from pre-chain processing contributes 391.27 kg CO_2-eq or 3.85% of total emissions. The contribution of agricultural activities is 377.93 kg CO_2-eq or 3.70 % of total emission. Biochar production emits 211.60 kg CO_2-eq or 2.07 % of total emissions. This value is less than GHG emission produced by the biogas of POME.

3.3. Contribution biogas and biochar for reduction of GHG emissions

The best practices to improve carbon balance are to produce biochar of the EFB and production biogas by utilizing POME. The following are details in below.

3.3.1. Biochar production from EFB

Biochar production from EFB has been taken in this study. However, the product of biochar was not applied yet to the agriculture soil when the study was conducted. The application of biochar from EFB palm oil to the soil has been conducted by Tan et al. [23]. It is reported that biochar from EFB palm oil has benefit not only to sequester carbon for climate change and mitigation but also to improve soil health and crop performance [23]. Accordingly, it is believed that the biochar will reduce the use of nitrogenous fertilizer and further will lower GHG emissions since the production and use of nitrogenous fertilizer are currently the third major causes of GHG emissions (see Table 2, item no 2). When the biochar is applied to the soil, it is crucial to quantify the possible GHG emissions (CO_2, N_2O and CH_4) because a positive carbon sequestration effect could be diminished, or even reversed, and reduction of N_2O as stated in referenc [24, 25].

3.3.2. Biogas production from POME

Based on data in the Table 2, when the total emission including LUC is applied, POME pond contributes the second largest amount of emissions with 25.49 % of total emission compared with other emissions after emission of LUC which contributes 65.65 % of total emissions. However, when LUC is excluded from the total emissions calculation, the POME pond emits the largest portion of the emissions of 74.22 % of total emissions. This is because very high number of organic wastes in the ponds and the high ambient temperature takes place under anaerobic conditions, leading to the high emissions of methane.

Methane can be trapped and used as a fuel to generate electricity, steam or heat [26] as conducted in the research area. The total GHG emission for the production of palm oil biodiesel is reduced to 33.74 %. However, when the biogas produced from the methane captured is applied, the GHG emissions reduction savings increases by 63 % as shown in Table 2. It is seen that the methane emission has a very positive impact to the carbon balance. Based on this result, biodiesel production from palm oil in Indonesia meets the European target emission savings as stated by reference [3].

When the emission reduction calculation is applied at the including LUC, it is proved that there are no savings as written in the Table 2. It means that that to achieve GHG mitigation using palm oil biodiesel, it is essential to avoid peatland deforestation and drainage as emphasized by several researchers [17,17].

Therefore, it is important for palm oil biodiesel industries in Indonesia to utilize methane captured from the palm oil mill effluent ponds and to involve law enforcement for proving that palm oil biodiesel of Indonesia is not produced and must not originate from peatland to meet the EU emissions savings target as stated in the EU Directives 2009 Annex V.

Table 2. Emission reduction over fossil oil excluding and including LUC emissions and Ecosystem Payback Time

	Parameter	**Results** (kg CO2-eq t^{-1} biodiesel)
1	Emission reduction excluding LUC	
	E_F	3 323
	E_B	1 225
	Saving	2 097
	Saving (%)	63.14 %
2	Emission reduction including LUC	
	E_F	3 323
	E_B	5 671
	Saving	No savings
	Saving (%)	No savings
3	Ecosystem payback time (ECPT)	
	Sum of LUC (t C ha^{-1})	143.81
	Saving $^{*)}$	4.03
	ECPT	36 years

Remarks:
E_F = total emission from fossil fuel comparator (fossil diesel)
E_B = total emission from biodiesel
Saving = $(E_F – E_B)/E_F$
$^{*)}$ Avoided direct emissions from fossil fuel use (calculated from biofuel yields ha^{-1} that substitute fossil diesel with EF = 0.87 t C t^{-1} fossil diesel) as quoted from [28]
Density biodiesel = 0.88 kg L^{-1}

4. Conclusions

Based on the assessment and analysis in the study, the emission reduction savings is 63.14 % of the total GHG emissions. Therefore, it can be concluded that biodiesel palm oil in Indonesia meets the EU target emission savings by exceeding from the EU threshold (at least 35 % of total GHG emission savings) which is demanded by the EU Directives 2009 Annex V. To achieve GHG mitigation by exceeding of the EU emission savings targets, the methane captured from POME has to be obligatory for the biodiesel palm oil industries and it is essential the palm oil must not originate from the peatland.

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