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LCA GHG emissions in production and combustion of Malaysian palm oil biodiesel

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Abstract

The LCA GHG emission in the production and combustion of palm oil biodiesel at 1,601 kg CO₂/tonne of biodiesel is 2.6 times lower than that for fossil diesel. The LCA GHG emission reduction savings is, thus, 62% and exceeds the threshold value of 35% needed by EU for renewable sources to qualify for use as biofuels. Palm biodiesel has a great potential to improve its carbon balance further, exceeding 62% savings, by utilizing its waste products arising from oil palm cultivation and during palm biodiesel production.

Keywords

Palm biodiesel, fossil diesel, LCA GHG emissions, emission reduction savings, methane capture, carbon balance

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1. Introduction

Life cycle assessment (LCA) is a common tool used to study the environmental aspects of products. For example, the environmental impacts in the different parts of the supply chain of palm oil have been identified for the production in the nursery¹, fresh fruit bunch², crude palm oil³, palm kernel oil⁴, refined palm oil⁵ and palm diesel⁶ by carrying out LCA.

LCA can also be used to derive the greenhouse gas (GHG) emission values of the different activities associated with the product. These can then be used to predict the impact on global warming and resultant climate change. As a result of the usefulness of LCA to identify the environmental impact, such as sources of pollution and GHG emissions, LCA is now commonly used as a tool for environmental sustainability assessment⁷. At the international level, the principles and

framework for carrying out LCA are provided in ISO 140408.

When crops are used as biofuels, it is critical to know the total GHG emissions in their production. The substitution of biofuel for fossil fuel is meaningful only if the use of the former can reduce GHG emissions. As such, the European Union (EU) Directive⁹ for the promotion of the use of energy from renewable sources stipulates that the greenhouse gas emission savings for the purposes of biofuels should be at least 35%.

As palm oil can be used as biofuel, interest has been shown to determine the LCA GHG emissions of producing palm biodiesel^{10, 11}. This study was carried out to quantify the LCA GHG emissions for palm oil biodiesel production and to estimate the LCA GHG emission reduction savings that can be achieved.

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2. Methods and materials

In this study, palm oil biodiesel production and its combustion can be divided into five gate-to-gate boundaries. These are as follows:-

- 1) cultivation and production of fresh fruit bunches (FFB)
- 2) harvesting and transport of FFB to the mills
- 3) milling of FFB to produce crude palm oil (CPO) and its transport to Europe (Rotterdam port)
- 4) Converting CPO to biodiesel
- 5) Use of CPO directly as a biofuel.

The life cycle inventory (LCI) data are first obtained. The GHG emission associated with the activities are then calculated. The total LCA GHG emission in the production of palm oil biodiesel is then compared with the LCA GHG emission for the production and combustion of fossil diesel.

3. Results and discussions

3.1 Boundary of LCA study

The boundary for the LCA study is for a typical supply chain for palm oil produced in Malaysia and exported to Western Europe for use as a biofuel. The LCI model for palm oil biodiesel is shown in Figure 1. The FFB are collected from the field and sent to the palm oil mill. Palm oil is extracted during the milling stage. After further refining and esterification, palm oil is converted into biodiesel.

The GHG emission sources from land use changes for palm biodiesel production are identified to be:

1. CO₂ emission from displaced rubber production from rubber land converted to plant oil palm
2. CO₂ emission from land use change for new rubber plantation.

On a global scale, item 2 may be difficult to study. To establish its impact, a macro-economic analysis of the global markets for rubber, oil palm and other plantation products needs to be carried out. Besides, the LCA GHG reduction requirement for EU does not consider land use change. As such, LCA GHG emissions resulting from direct¹² and indirect^{13,14} land use changes are not considered in this study.

Figure 1 - Boundary of palm oil LCI model used for comparison with fossil fuel use

Table 1 - Main parameters for palm oil and fossil diesel supply chain analysis

Parameter	Quantity
Average palm tree density	143 palms/ha
Average FFB production	19.6 t/ha/year
Products generated from 1t FFB	
- CPO	21%
- Palm kernels	6.5%
- EFB	23%
- Fibres	14.5%
- Shells	6.5%
- POME	0.7m ³
Average oil extraction rate	20%
Average CPO yield	3.9 t/ha/a
Calorific value CPO	39.36 MJ/kg
Emission factor CPO	0 kg/kg
Calorific value diesel	43.3 MJ/kg
Emission factor diesel	73.7 kg/GJ

Notes and assumptions on palm oil calculations:

- N-fertilizer used for palm oil is assumed to be 50% urea and 50% ammonium sulphate

3.2 Parameters and assumptions used for the analysis

The main parameters used for the palm oil supply chain analysis are shown in Table 1. These are based on typical Malaysian data and common practices in the sector. This study considers oil palm to be grown on mineral soils in Malaysia.

3.3 LCA GHG emission from palm biodiesel production and use

The LCA GHG emissions for the different parts of the palm oil supply chain are shown in Table 2. A total of 1,601 kg CO₂ equivalent (CO₂ e) is emitted in the production of 1 tonne (t) of palm oil biodiesel. The biggest source of LCA GHG emission comes from methane in the effluent ponds in the palm oil mills. This source

contributes to 824 kg CO₂/t biodiesel or 51.5% of the total CO₂ e emissions. The production and use of nitrogenous fertilizers is the next biggest source of emission, causing 315 kg CO₂/t biodiesel or 19.6% of the total emissions. These two GHG sources have high global warming potentials (GWP); methane GWP is 23 while N₂O has a GWP of 296¹⁵.

The third major source of GHG emission comes from fossil fuel used for transporting fresh fruit bunches from the fields to the factory as well as that used for transporting the empty fruit bunches (EFB) back to the fields. Similar conclusions pinpointing methane, use of nitrogenous fertilizers and use of fossil fuel as the three major sources with the largest environmental impact in palm biodiesel production have also been reported^{2,3,4,5,6}.

Table 2-Total GHG emissions for the different activities to produce palm oil biodiesel

Biodiesel supply chain activity	Amount of emission (kg CO ₂ e/t biodiesel)	Percentage (%)
1. Fertilizer use	185	11.5
2. Fertilizer application (N ₂ O)	130	8.1
3. Pesticide use	34	2.1
4. Harvesting machinery	89	5.6
5. Milling process	19	1.2
6. EFB disposal/ re-use	87	5.4
7. POME disposal/re-use	824	51.5
8. CPO transport	36	2.3
9. Biodiesel production	197	12.3
Total emissions	1,601	100

Table 3-Total GHG emissions to produce and combust a tonne of fossil diesel

Activity	Amount of emission (kg CO ₂ e/t fossil diesel)
Production	419
Diesel combustion	3,809
Total	4,228

3.4 LCA GHG emission from fossil diesel production and use

The total LCA GHG emitted to produce and combust 1 tonne of fossil diesel is 4,228 kg CO₂e as shown in Table 3. This is much higher than that for the production and combustion of 1 tonne of palm oil biodiesel. As such, therefore, the use of palm oil biodiesel results in lower LCA GHG emissions. This is in line with other studies which show that biofuel production and combustion are more environment friendly than fossil fuel usage^{16,17,18}.

The amount of emission derived from the production and combustion of fossil fuel is 2.64 times higher than that derived from the production and combustion of 1 tonne of palm oil biodiesel.

3.5 Comparison of palm diesel carbon balance with European sustainability standards for biofuels

According to the EU Directive⁹, the GHG emission reduction savings is calculated as follows:-

$$\text{CO}_2 \text{ reduction} = \frac{(\text{CO}_2 \text{ emission fossil fuel chain} - \text{CO}_2 \text{ emissions biodiesel chain})}{\text{CO}_2 \text{ emission fossil fuel chain}}$$

The production and combustion of palm oil biodiesel results in a lower LCA GHG emission than the similar activities for fossil fuel. The usage of palm biodiesel emits 2,627 kg less LCA GHG CO₂e/t than fossil fuel. The LCA GHG emission reduction savings for palm biodiesel usage is, thus, 62%. This is very much higher than the 16% default GHG emission savings value for the production and combustion of 1 tonne of palm oil biodiesel (process not specified) as given in the EU Directive⁹.

Figure 2 - Main sources of pollution which can be reduced or overcome

3.6 Using best practices to improve CO₂ balance

The major sources of GHG emissions are shown in Figure 2. Methane from palm oil mill effluent ponds or lagoons contributes to the largest (52%) LCA GHG emission. The palm oil mill effluent (POME) generated in the milling process are retained in these ponds until the Biological Oxidation Demand (BOD) has been reduced to an acceptable level before it can be discharged into the waterways. Due to the very high amount of organic waste in the water and the high ambient temperature in Malaysia, much of the degradation process takes place under anaerobic conditions, leading to high emissions of methane.

Methane can be trapped and used as a fuel to generate electricity, steam or heat¹⁹. This is being done currently in some of the bigger palm oil mills in Malaysia. When this is done, the total LCA GHG emission for the production of palm biodiesel is reduced to only 777 kg CO₂ / t biodiesel. The LCA GHG emission reduction savings is then increased to 82%. It is, thus, seen that the elimination of methane emission has a very large positive impact on the carbon balance.

The second way to improve the carbon balance is to carry out composting of the EFB and POME present in the mill. The two wastes can be combined into a useable organic fertilizer. Composting is an aerobic process that will not generate GHG emissions. This

organic fertilizer can substitute and reduce the use of nitrogenous fertilizers and further lowers GHG emission in the palm oil industry, since the production and use of nitrogenous fertilizers is the second major cause of LCA GHG emission currently.

Alternatively, the EFB can also be used as a renewable energy for power generation. They can be collected and incinerated in a boiler to produce steam, which in turn drives a turbine to generate electricity. Yet another option to improve the carbon balance is to improve the oil palm yields.

3.7 Present carbon balance for palm oil biodiesel and ways to improve further the carbon balance further

Figure 3 shows that the LCA GHG emission reduction savings for palm diesel produced by using the current plantation practices is 62 % (Case B). If EFB is used as a renewable energy by incinerating them in the boilers, the emission reduction is increased to 71% (Case C). The utilization of methane as a biogas increases emission reduction savings up to 82%(Case D) while composting of EFB increases emission reduction savings even further to 87%. When the palm oil wastes are well utilized, through a combination of using EFB as boiler fuel together with trapping methane, the emission reduction increases to 99% (Case F).

Figure 3 - LCA GHG emission reduction savings of palm oil biodiesel under various scenarios

Increasing the yield of CPO yields from the current 3.9 t/hectare/annum to 6.5 t/ha/annum does not improve the emission reduction savings very much. The emission reduction savings increases by only 2%, from 62 to 64% (Case G), even though a 67% quantum yield increase is recorded. This is due to the need to increase the use of fertilizers, including nitrogenous fertilizers to sustain the high FFB yields. As pointed out earlier, the emissions from fertilizer production and N₂O emissions are not favorable to GHG reductions. Besides, the use of fossil fuel will also increase due to the need for more harvesting activities and a greater need to evacuate the FFB from the fields and bring them to the mills.

The effects of combining the various best practices with high yields are notable. A similar trend of improvement in LCA GHG emission reduction savings is also seen here whereby composting EFB with POME (Case J) gives the highest effect, with a 92% LCA GHG emission reduction savings, versus the trapping and use of methane in the palm oil mills for use as renewable energy (Case I). This latter activity yields a reduction savings of 91%. The act of burning EFB in the boilers to generate electricity results in a GHG emission reduction savings of 76% (Case H).

4. Conclusions

The LCA GHG emission to produce and combust 1 tonne of palm oil biodiesel is 1,610 kg of CO₂e. This LCA GHG emission is 2.64 times lower than that needed to extract and combust a tonne of fossil diesel which amounts to 4,224 kg CO₂e per tonne of fossil diesel. As a result, the LCA GHG emission reduction savings for the production and combustion of palm oil biodiesel is 62%. This value for palm diesel exceeds the threshold value of 35% stipulated by the EU Directive, whereby in the promotion on the use of energy from renewable sources, the greenhouse gas emission savings for the purpose of biofuels should be at least 35%.

The primary source of GHG emission in the palm biodiesel life cycle occurs in the palm oil mill effluent ponds. Here, the emission of methane due to anaerobic conditions results in 824 kg CO₂e/t palm oil biodiesel or 52% of the total GHG emission. As such, therefore, the trapping of methane for use as renewable energy can reduce GHG emission significantly. By doing this, the GHG emission reduction savings increases to 82%.

The second major source of GHG emission arises from the production and use of

nitrogenous fertilizers. This source contributes to 315 kg CO₂e / t of palm diesel, or nearly 20% of the total LCA GHG emissions.

In order to produce CPO, which is the precursor needed for palm biodiesel production, large amounts of EFB are produced. If these can be used as boiler fuel, the GHG emission reduction savings is 71%. When the EFB is used as boiler fuel and methane in the palm oil mills is trapped, this activity has the largest impact in removing LCA GHG emission in the palm biodiesel life cycle.

Yield improvement, by increasing CPO production from 3.9 to 6.5 t/ha/yr. also has an impact on emission reduction savings (up to 64% savings). When high yields are combined with the activity of EFB combustion in the palm oil mill boilers, the reduction savings increases further to 74%. Increases in LCA GHG emission reduction savings are however obtained by combining high yield with other activities, namely trapping methane and composting.

5. References

1. Halimah, M., Zulkifli H., Vijaya S., Tan Y.A., Puah C.W., Chong C.L and Choo Y.M.(2010). Life cycle assessment of oil palm seedling production (Part 1). J.Oil Palm Res,22,876-886.
2. Zulkifli H.,Halimah., Chan K.W.,Choo Y.M and Mohd. Basri, W (2010). Life cycle assessment for oil palm fresh fruit bunch production from continued land use for oil palm planted on mineral soil(Part 2). J.Oil Palm Res,22,877-894.
3. Vijaya S., Choo Y.M., Halimah, M., Zulkifli H., Tan Y.A and Puah C.W(2010). Life cycle assessment of crude palm oil (Part 3). J.Oil Palm Res,22,895-903.
4. Vijaya S., Choo Y.M., Halimah, M., Zulkifli H., Tan Y.A and Puah C.W.(2010). Life cycle assessment of crude palm kernel oil (Part 3a). J.Oil Palm Res,22,904-912.
5. Tan Y.A., Halimah, M., Zulkifli H., Vijaya S, Puah C.W., Chong C.L., Ma A.N and Choo Y.M(2010). Life cycle assessment of refined palm oil production and fractionation (Part 4). J.Oil Palm Res,22,913-926.
6. Puah C.W., Choo Y.M and Ma A.N (2010). Life cycle assessment for the production and use of palm biodiesel (Part 5). J.Oil Palm Res,22,927-933.
7. Jergensen A., Hermann I.T and Mortensen J.B.(2010) Is LCC relevant in a sustainability assessment. Int. J Life Cycle Assessment,15,6,531-532.

8. ISO14040(2006). Environmental Management-Life Cycle Assessment-Principles and Framework. International Standards Organization (ISO), Geneva.
9. Commissioner of the European Communities. (2007) Directive of the European Parliament and of the Council,pp.61.
10. Schmidt,J.H (2007) Life cycle assessment of rapeseed oil and palm oil. Dept Dev & Planning, Aalborg Univ, Denmark, pp66.
11. Chen S.S(2008)The LCA approach to illustrate palm oil's sustainability advantage, International Palm Oil Sustainability Conference, Kota Kinabalu,Sabah, pp8.
12. [http://www.bioenergywiki.net/index.php/Talk: Direct land use](http://www.bioenergywiki.net/index.php/Talk:Direct_land_use) .Accessed on 17th March.
13. Panichelli L and Gnansounou E (2008) Estimating greenhouse gas emissions from indirect land-use changes in biofuel production: concepts and exploratory analysis for soybean-based biodiesel production. Bioenergy & Energy Planning Group,pp9.
14. Edwards R., Mulligan D and Marelli L (2010) Indirect land use change from increased biofuels demand. JRC.pp147.
15. [IPCC \(2001\) Third Assessment Report \(TAR\) page on Global Warming Potentials and Direct GWP.](#)
16. von Blottniz H, Curran M.A(2007) A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas and environmental life cycle perspective. J Cleaner Prod 15: 607-619.
17. Kim,S and Dale B.E.(2005) Life cycle assessment of various cropping systems utilized for producing biofuels: bioethanol and biodiesel. Biomass Bioenergy 29,426-439.
18. Yusof Basiron (2005) Biofuel: an alternative fuel in the Malaysian scenario. Palm Oil Developments, 42,1-4.
19. Jason Yapp H.H (2008) Clean development mechanism (CDM)-Market based solution in greening the palm oil industry. International Palm Oil Sustainability Conf., Kota Kinabalu, Sabah,pp22.