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Carbon Footprint of Strait Vegetable Oil and Bio Diesel Fuel Produced from Used Cooking Oil

H Fujita[1*], K Nakano[2], H Matsuo[3] and E Hambali[4]

[1] Surfactant and Bioenergy Research Center, Bogor Agricultural University, Jl. Raya Pajajaran No. 1, Bogor, 16144, Indonesia

[2]College of Policy Science, Ritsumeikan University, 2-150 Iwakura-cho, Ibaraki, Osaka, 567-8570, Japan

[3]BDF Co. Ltd., 1-2-14 Higashisumida, Sumida-ku, Tokyo, 131-0042, Japan

[4]Surfactant and Bioenergy Research Center, Bogor Agricultural University, Jl. Raya Pajajaran No.1, Bogor, 16680, Indonesia

* Corresponding Author: E-mail: fujita@nuis.ac.jp

Abstract. Carbon Footprint of two different type fuel production systems, made of/from used cooking oil, i.e., Strait Vegetable Oil (SVO) and Bio Diesel Fuel (BDF), resulted a substantial GHG emission credit on SVO, -3.45 kg CO_2e, compared with that of BDF, -2.95 kg CO_2e, predominantly due to the emissions derived from methanol and electricity used in the BDF production. The cost analyses also favoured the SVO system at 82 JPY credit if steam use was excluded, approximately 27 JPY advantageous than the BDF system, due to the extra costs of methanol, electricity and absorbent used in the BDF production.

1. Introduction

The carbon footprint is one of the major environmental informatics which calculates Greenhouse Gas (GHG) emissions of goods and services at every stage in a series of life cycles. As an example, a use of 1 kWh electricity in Japan, makes an emission of 0.607 kg CO_2 equivalent (hereafter "e"). If one life cycle of a product uses 0.1 kg of methanol, the GHG emissions can be calculated by multiplying GHG emission data of methanol production (1.55 kg CO_2e/kg-methanol) with the activity data (0.1 kg-methanol). The numerical figure of 0.607 and 1.55 are recognized as "Emission factors" surveyed by industrial authorities of corresponding countries and regions that make the informatics database.

A comprehensive life cycle inventory analysis was conducted by Siregar et. al. (2012) who made detail life cycle inventories of Fat Acid Methyl Ester, namely, biodiesel fuel (BDF) productions from *Jatropha curcas* and *Elaeis spp.* (oil palm). The inventories were consisted of land preparation, the whole processes of the oil plant cultivations, harvesting, oil extraction, and biodiesel fuel productions, using so many emission factors of various sources [1]. The analysis showed a substantial environmental advantage in the biodiesel production from *Jatropha curcas*, approximately 60% of GHG emission of one from oil palm.

The Strait Vegetable Oil (SVO) production is one of the recent industrial developments replacing the declining BDF businesses, as for the cost constraints to produce BDF from used cooking oil (UCO), and for the non-conformity of BDF to the latest generation diesel engines which have much strict emission standards. Increasing number of companies including cooperatives in Japan who once produced biodiesel fuel are now shifting to the SVO production and electricity generation under Feed in Tariff scheme [2].

Nemoto and Matsuo surveyed material and energy balances of SVO and BDF systems using UCO and conducted a life cycle inventory analysis. It indicated that a substantial energy (electricity) usage of BDF system particularly in the fuel production [3].

The process of the SVO production is a series of repeating refining processes of dehydration and purification of the UCO by high performance filters and centrifuges, which enables the direct SVO combustion by SVO/BDF compatible generators. As there is no material, chemical, absorbent necessary in the SVO production, as required in the BDF production, it seemed that the SVO production and generation might have an advantage in GHG emission compared with the BDF system. Therefore, this study compared carbon footprint of SVO and BDF systems, and discussed advantages and disadvantages of both systems.

2. Methodology

2.1. System boundary

The system boundary of the carbon footprint analysis is shown in Fig. 1. The system boundary consists of the production processes of SVO and BDF, and combustion processes of SVO/BDF in co-generators (electricity and heat). On the other hands, the collection processes of UCO were excluded as those are dependent upon the locations of SVO and BDF plants. In the same manner, the delivery processes of SVO and BDF to the final consumption, e.g. generation, were excluded. The produced fuels were treated to be used by co-generators which have the same generation and thermal efficiencies disclosed by Yanmar Energy Systems Co., Ltd., they are, 35% electric power and 48% heat, respectively. The SVO co-generation system supplies heat to the fuel circulation, therefore no electric heating equipment used in the system. The functional unit (FU) of the analyses was 1 kg of UCO treatment.

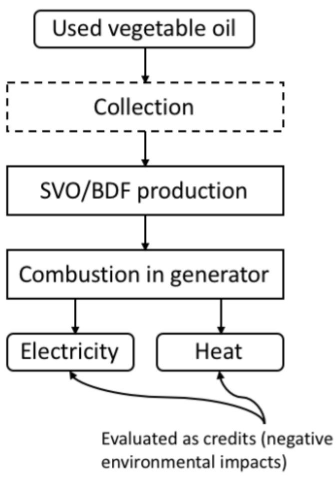

Figure 1 System boundary

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2.2. LCI analysis

The life cycle inventory (LCI) analyses were performed on the materials and energy inputs involving both in the SVO/BDF productions, and energy inputs/outputs of electricity and heat by the fuel combustion.

In the inventory analysis of BDF production, data of product (BDF), materials, electricity, by-products (crude glycerine), collected methanol of BDF Co., Ltd., was used in an actual processing of 176.7 kg of UCO on 7 and 8 June 2010. In the same manner, the actual data of SVO production of the company was used.

GHG emissions in the processes of sub-materials and energy production were derived from the IDEA v.2 [4]. The by-product of crude glycerine is being consumed as sub-fuel for construction materials production, as the company sells crude glycerine to a factory. Crude glycerine was considered containing methanol and fat acid methyl ester and others, and to be calorific value of 25.5 MJ/kg in lower heating value [5].

2.3. Impact assessment

Each GHG was converted to CO_2e value by the latest Global Warming Potential (GWP) [6]. Since CO_2 discharged from the SVO/BDF combustion was originally fixed from CO_2 in the atmosphere, the CO_2 emissions were considered as zero (carbon neutral). As in this study, only CO_2 derived from fossil fuels were evaluated, hence, the analyses deducted GHG emissions, corresponding to the generated electricity and the produced heats, both in the SVO and BDF plants. Even originated from biogenic carbon, other GHGs, such as CH_4 and N_2O, were included in this study.

3. Result

The carbon footprint of SVO system is shown in Table 1. The activity data indicates material and energy inputs/outputs of the SVO production, and energy outputs of SVO co-generations, based on the functional unit (1 kg of UCO treatment).

Table 1. Carbon footprint of SVO production and Co-generation

		Result (a*b)		Emission factor (a)		Activity data (b)	
SVO production	Electricity	4.91E-05	kg-CO_2e	6.07E-01	kg-CO_2e/kg	8.08E-05	kg
	Landfill	3.63E-05	kg-CO_2e	7.29E-03	kg-CO_2e/kg	4.98E-03	kg
SVO combustion	Diesel	1.46E-02	kg-CO_2e	7.84E-02	kg-CO_2e/MJ	1.86E-01	MJ
SVO combustion (credit)	Electricity	-2.14E+00	kg-CO_2e	-6.07E-01	kg-CO_2e/kWh	3.53E+00	kWh
	Steam	-1.32E+00	kg-CO_2e	-7.56E-02	kg-CO_2e/MJ	1.74E+01	MJ
Net GHG emission		-3.45E+00	kg-CO_2e				

The carbon footprint of BDF production and co-generation is shown in Table 2. The illustrated emissions in production and combustion states are shown in Figure 2. and Figure 3. of SVO and BDF systems respectively. The differences are three extra input and two extra outputs in the BDF production and crude glycerol combustion respectively. On the other hand, one extra input of light oil (diesel) in the SVO combustion is shown Figure 2., as starting fuel before the SVO combustion took place.

Table 2. Carbon footprint of BDF production and Co-generation

		Result (a*b)		Emission factor (a)		Activity data (b)	
BDF production	Methanol	2.39E-01	kg-CO_2e	1.55E+00	kg-CO_2e/kg	1.54E-01	kg
	KOH	8.20E-02	kg-CO2e	6.47E+00	kg-CO_2e/kg	1.27E-02	kg
	Absorbent	6.31E-02	kg-CO_2e	3.10E+00	kg-CO_2e/kg	2.04E-02	kg
	Electricity	2.77E-01	kg-CO_2e	6.07E-01	kg-CO_2e/kWh	4.56E-01	kWh
	Landfill	4.83E-04	kg-CO_2e	7.29E-03	kg-CO_2e/kg	6.63E-02	kg
BDF combustion (credit)	Electricity	-1.95E+00	kg-CO_2e	-6.07E-01	kg-CO_2e/kWh	3.22E+00	kWh
	Steam	-1.20E+00	kg-CO_2e	-7.56E-02	kg-CO_2e/MJ	1.59E+01	MJ
Glycerine combustion	Electricity	-2.86E-01	kg-CO_2e	-6.07E-01	kg-CO_2e/kWh	4.71E-01	kWh
	Steam	-1.76E-01	kg-CO_2e	-7.56E-02	kg-CO_2e/MJ	2.33E+00	MJ
Net GHG emission		-2.95E+00	kg-CO_2e				

The net GHG emission of the BDF system, which is the sum of all those carbon footprints shown in Table 2, was -2.95 kg CO_2e, whereas that of the SVO system of -3.45 kg CO_2e as in Table 1.

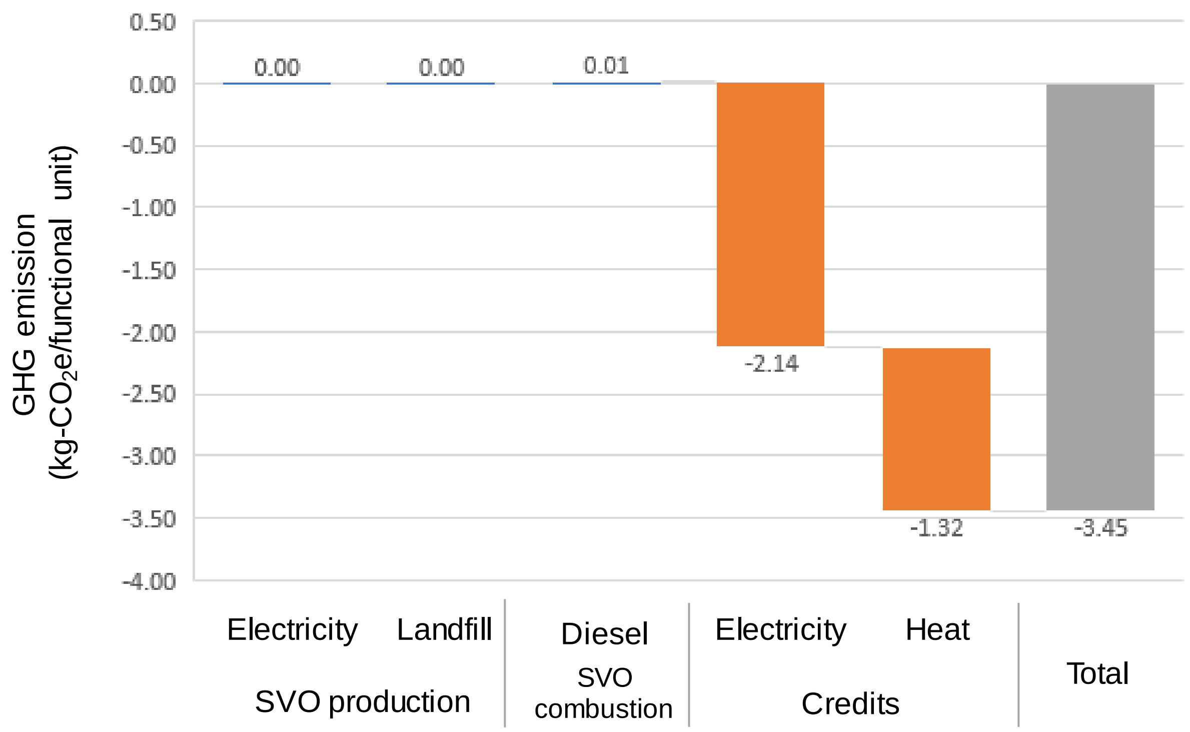

Figure 2. Greenhouse gas emission of strait vegetable oil production and co-generation (diesel oil was used for starting fuel)

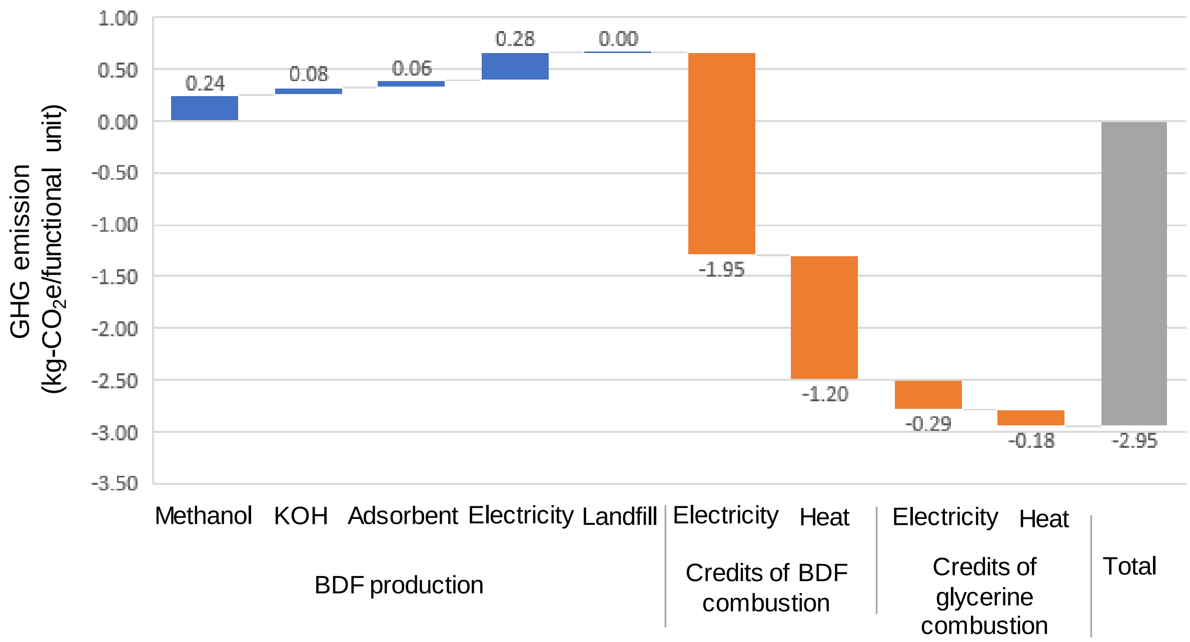

Figure 3. Greenhouse gas emission of bio diesel fuel production and co-generation

4. Discussion

The comparison in GHG emissions of SVO and BDF system is shown in Figure 4. The avoided emissions induced by the generated electricity and steam of SVO and BDF/glycerine co-generations were -3.46 kg CO2e and -3.61 kg CO2e respectively, slightly advantageous to the BDF/glycerine co-generation, as CO2e emissions of electricity and of light oil for the 1 kg SVO combustion were 0.00008 kg and 0.0146 kg respectively, whereas no energy input for BDF combustion.

The slightly higher avoided GHG emission (credit) of the electricity generated by BDF and glycerine co-generations compared with SVO co-generation was significantly reduced by the GHG emissions in the BDF production, especially the higher GHG emission induced by electricity and methanol, as shown in Fig. 2. The total GHG emissions indicate the superb environmental advantage to the SVO system due to the minimum GHG emissions, which was 0.000161 kg CO2e, for the non-material, chemical and physical processing. On the other hands, methanol, chemical, absorbent, moreover a large amount of electricity are necessary in the BDF production, the sum GHG emission was 0.662 kg CO2e, approximately 4,100 times of one of the SVO production.

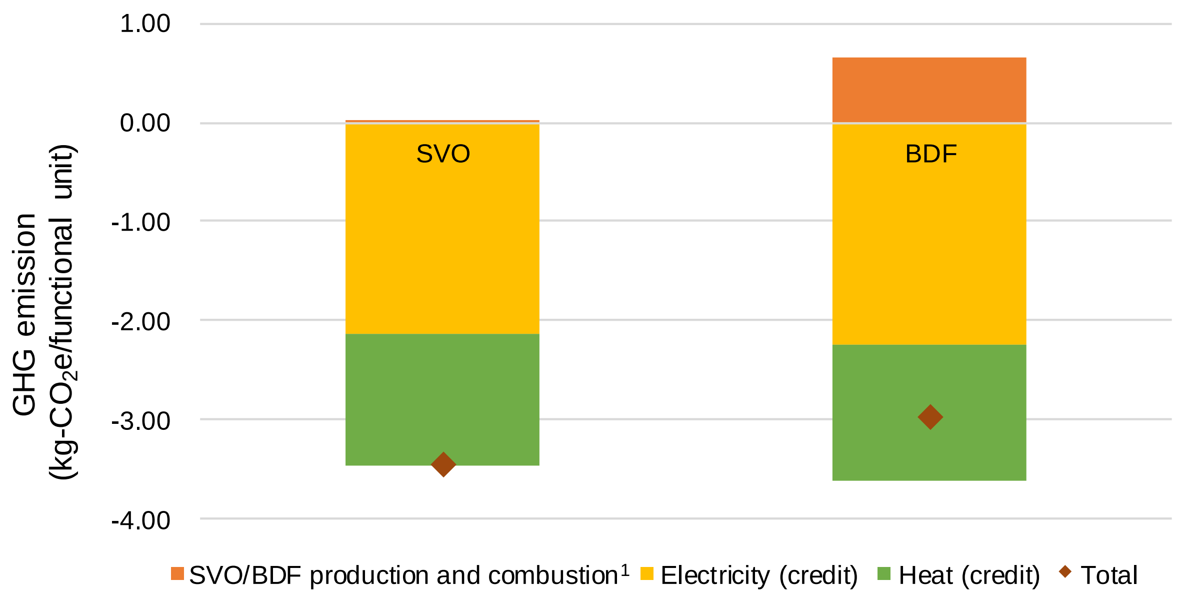

Figure 4. Comparison in greenhouse gas emissions of SVO and BDF productions/co-generations

In this study, GHG emission factor of average grid electricity mix in Japan was used. If SVO/BDF is utilized for substituting carbon-intensive energy, such as coal and heavy oil, an avoided emission will be increased.

The cost analyses were made by recent unit prices available in local markets in Japan, shown as Table 3. and Table 4. of SVO and BDF systems respectively. This cost analysis excluded capital cost, transport cost and labor cost. Furthermore, we assumed UCO was available in free of charge.

Table 3. Costs for SVO production/co-generation

		Costs (a*b)		Unit price (a)		Activity data (b)	
SVO production	Electricity	1.89E-03	JPY	2.34E+01	JPY/kg	8.08E-05	kg
	Landfill	6.46E-02	JPY	1.30E+01	JPY/kg	4.98E-03	kg
SVO combustion	Diesel	-1.94E+01	JPY	-1.04E+02	JPY/MJ	1.86E-01	MJ
SVO combustion (credit)	Electricity	-8.28E+01	JPY	-2.34E+01	JPY/kWh	3.53E+00	kWh
	Steam	-1.18E+02	JPY	-6.77E+00	JPY/MJ	1.74E+01	MJ
Net costs		-2.20E+02					
Costs excluding steam credits		-1.02E+02					

Table 4. Costs for BDF production/co-generation

		Costs (a*b)		Unit price (a)		Activity data (b)	
BDF production	Methanol	4.63E+00	JPY	3.00E+01	JPY/kg	1.54E-01	kg
	KOH	7.21E-01	JPY	5.69E+01	JPY/kg	1.27E-02	kg
	Absorbent	3.67E+00	JPY	1.80E+02	JPY/kg	2.04E-02	kg
	Electricity	1.07E+01	JPY	2.34E+01	JPY/kWh	4.56E-01	kWh
	Landfill	8.60E-01	JPY	1.30E+01	JPY/kg	6.63E-02	kg
BDF combustion (credit)	Electricity	-7.54E+01	JPY	-2.34E+01	JPY/kWh	3.22E+00	kWh
	Steam	-1.08E+02	JPY	-6.77E+00	JPY/MJ	1.59E+01	MJ
Glycerine combustion	Electricity	-1.11E+01	JPY	-2.34E+01	JPY/kWh	4.71E-01	kWh
	Steam	-1.58E+01	JPY	-6.77E+00	JPY/MJ	2.33E+00	MJ
Net cost		-1.89E+02					
Costs excluding steam credits		-1.73E+02					

The cost analyses resulted the nearly no material and energy costs in the SVO production, which supports the current business shift to the SVO production from the cost involved BDF production with 27.8 JPY for every 1 kg of UCO. The costs excluding steam credits in Table 3. and Table 4. showed the realistic credits of generation only, 82 JPY of SVO system and 55 JPY of BDF system from 1 kg of UCO, as the steam can be utilized only where heat demand is constantly existing.

An impact of the same processes in SVO and BDF systems were excluded from our study because our aim was to compare SVO and BDF systems; however, the impacts of these excluded processes, such as transportation, should be included in a study if an aim is to evaluate net GHG reduction and profitability of the UCO recycling system. Especially, collection of UCO from household may add large amount of GHG emission and cost [7]. However, less GHG emission for BDF system, compared to conventional system, such as incineration, was reported [8-9]; therefore, the SVO system also may have an advantage on GHG emission.

5. Conclusion

The carbon footprint of SVO and BDF systems disclosed a substantial GHG emission reduction on SVO, -3.45 kg CO2e, compared with those of BDF, -2.95 kg CO2e, predominantly due to the emissions derived from methanol and electricity in the BDF production. The cost analyses also favored the SVO system at 82 JPY surplus if steam use was excluded, approximately 27 JPY advantageous than the BDF system, due to the extra costs of methanol, electricity and absorbent used in the BDF production.

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