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ENVIRONMENTAL IMPACTS ASSESSMENT OF BIODIESEL PRODUCTION FROM JATROPHA AND WCO

Dinh Sy Khang[1, *], Duong Phuoc Hung[2], Phan Dinh Tuan[1]

[1]*HoChiMinh City University of Natural Resource and Environment*
236B Le Van Sy St., District Tan Binh, Ho Chi Minh City

[2]*Ministry of Natural Resources and Environment,*
10 Ton That Thuyet, Cau Giay District, Ha Noi

[*]Email: *khangds@hcmunre.edu.vn*

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Abstract. Viet Nam has advantaged conditions to produce renewable energy from agriculture products and agriculture waste. Biodiesel that is produced from renewable resources has been rising as a promising candidate to replace conventional energy in recent decades. However, developing biodiesel from agricultural product may affect food security significantly. Therefore, Jatropha that is inedible and wasted-cooking-oil (WCO) could be considered to produce biodiesel in order to diversify the biodiesel sources. One of the most important aims of using biodiesel to replace fossil diesel is to reduce environmental impacts, particularly impact on Climate Change. It is necessary to analyze the environmental performance of biodiesel through the entire life cycle. In this paper, life cycle assessment of biodiesel production and use was applied to measure the environmental performance of biodiesel produced from Jatropha oil and WCO under Viet Nam conditions. Some main emissions, such as CO_2, NO_x, PM, CH_4, VOC and land use, were computed through a cradle-to-grave analysis. The result shows that when using Jatropha biodiesel to replace diesel, global warming potential (GWP) and photochemical oxidant formation potential (POFP) could be improved, but some other impacts, such as acidification potential (AP) and eutrophication potential (EP), could tend to increase. The environmental impacts of WCO biodiesel are all reduced in comparison with fossil diesel.

Keywords: life cycle assessment**,** environmental impacts**,** biodiesel, Jatropha, waste cooking oil.

Classification numbers: 3.2.1, 3.4.1, 3.5.1.

1. INTRODUCTION

The demand of energy has been increasing rapidly while fossil fuel resources are not unlimited. Moreover, the global problems, such as global warming and environmental pollution, are rising with industrialization. So it is imperative to develop alternative resources of energy. Renewable energy has played an important role in improving energy security and environmental problem at global and national scales. Biodiesel is a renewable fuel could substitute conventional diesel to run engines directly or in blending with diesel [1]. Biodiesel has been recently produced and used commonly in some countries, such as USA, Brazil, China, Indonesia, Philippines *etc*. Using biodiesel as alternative fuel of fossil fuel may reduce the consumption of energy and obtain positive environmental impact by reducing the gases emissions. Most biodiesel is produced from edible oil such as soybean, mustard, coconut, and sunflower oil [2]. However, food security is a major concern when we choose the edible oil for biodiesel production. So it is necessary to expand the raw material for biodiesel production to non-edible oil or wasted oil. Jatropha curcas and wasted-cooking-oil (WCO) that could be used to produce biodiesel are sustainable development of this energy resource.

Viet Nam has provided a policy to produce biodiesel from Jatropha to replace diesel in the near future according to the Decision No. 1842/QD-BNN-LN of Vietnamese government [3]. Initially, from the experiences of biodiesel projects, this material could be developed in Viet Nam. Moreover, Viet Nam market also releases a large amount of wasted oil from activities of restaurants, hotels, and food productions. These are potential sources to produce biodiesel in near future. Viet Nam, with 21 percent of the total area usable in agriculture, has advantage to produce biodiesel from agricultural product or waste. Besides, Jatropha could be introduced in uncultivated or impoverished lands to avoid using the lands used for food production. So the inedible oil from Jatropha may be an appropriate material for biodiesel production. Viet Nam has promoted biodiesel as an alternative of conventional fossil fuel. There are many studies of biodiesel that have been conducted with specific conditions in Viet Nam. However, most studies on biodiesel have focused on technological aspects of biodiesel production. Another study on environmental impact should be completed to make a comprehensive overview of Jatropha and WCO biodiesel. This study carried out the investigation on the environmental impact of biodiesel in Viet Nam.

There are some studies on Jatropha and WCO biodiesel performed in several countries, such as Thailand [4], Malaysia [5] and India [2] showing the reduction of greenhouse gas. However, different condition of biodiesel production may result in different environmental impacts. It is necessary to measure the environmental performances of biodiesel from Jatropha based on the current conditions of Viet Nam. Life cycle assessment (LCA) is the most widely method for quantitative assessment of materials, energy flows and the environmental performance of products or technology from its cradle to grave. LCA is designed to evaluate input-output and potential environmental impacts of product from cradle-to-grave. LCA also has been applied to compare the processes based on different conditions, models, scenarios. It is used to define and reduce the environmental burdens from a product by identifying and quantifying energy and materials usage and waste discharges, assessing the impacts of the wastes on the environmental improvement over the whole life cycle. The environmental impacts of this product under the conditions of Viet Nam has been assessed in few studies, such as [6].

2. METHODOLOGY

2.1. Life Cycle Assessment

This study is to quantify the environmental impacts issued from biodiesel production and use from Jatropha under Viet Nam conditions. The comparison of some environmental impacts between biodiesel and fossil diesel was performed. LCA was chosen as the methodology to measure the environment impacts in this study. This is an international standardized methodology gathering the relevant inputs and outputs of product system. The total environmental impacts are measured by LCA according to the standard described in ISO 14040 shown in Figure 1. LCA method includes four steps: goal and scope definition, inventory analysis, impact assessment, and interpretation [7].

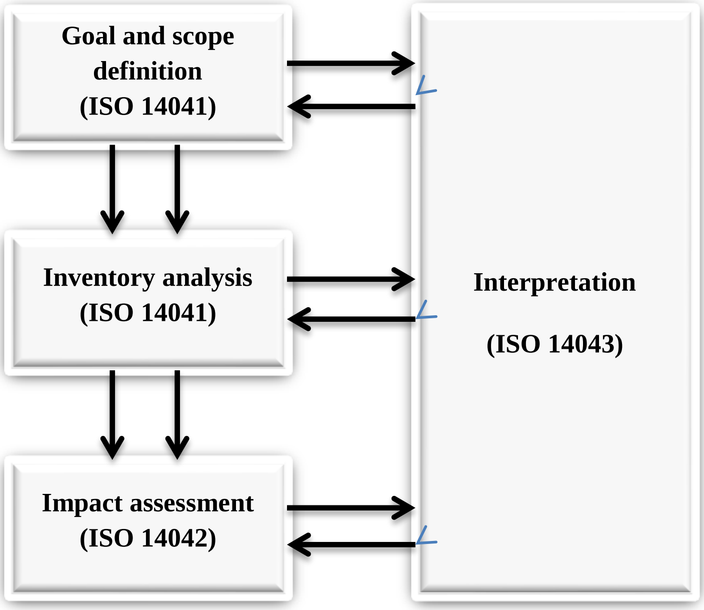

Figure 1. Life cycle assessment framework.

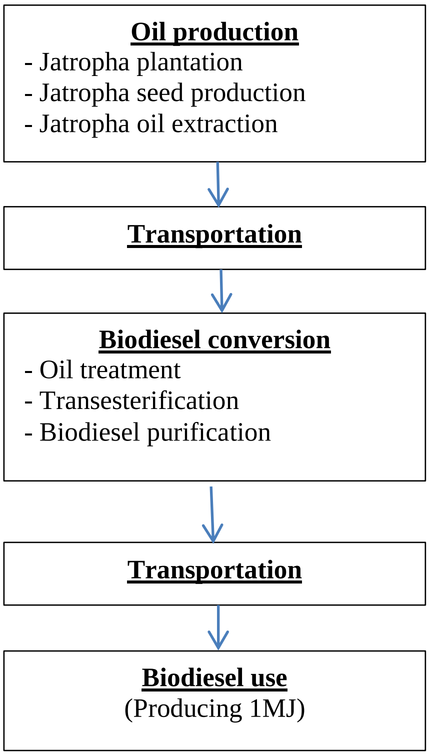

Figure 2. Life cycle of Jatropha biodiesel production and use.

2.2. System boundary

The system boundary of Jatropha and WCO biodiesel is shown in Figure 2 and Figure 3, respectively. Life cycle boundary in this study is from the raw material production to fuel combustion in vehicle engine. The life cycle of biodiesel is from Jatropha farming and ends with producing 1 MJ of power from biodiesel. It includes stage of oil production for Jatropha and oil collection for WCO, transportation, biodiesel production and biodiesel use. The first stage is decomposed to sub-stages: Jatropha plantation, harvesting and oil extraction; biodiesel production consists of oil treatment, transesterification (biodiesel conversion) and biodiesel purification; and finally biodiesel was considered to use run engine to produce power. Jatropha is planning in some selected farms in provinces of Tay Ninh, Binh Thuan, and Ninh Thuan under Vietnamese government's projects. The condition of Jatropha plantation is based on [8]. For WCO biodiesel production, oil could be collected from hotels, restaurants, or food production. WCO is considered as a waste. The system boundary of WCO biodiesel production consists of oil collection, biodiesel conversion, transportation, and biodiesel use.

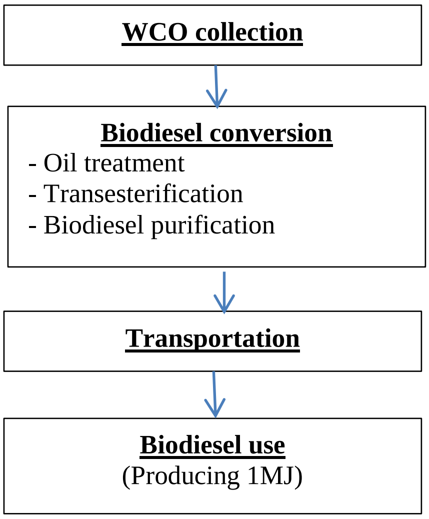

Figure 3. Life cycle of WCO biodiesel production and use.

2.3. Goal and scope definition

The objectives of this study are to analyze the environmental impacts of life cycle biodiesel from Jatropha and WCO based on the conditions in Viet Nam. The life cycle impact assessment evaluates potential environmental impacts and estimates the resource used. The ratio of biodiesel/diesel blending was verified from 10 % to 100 %. The following impacts categories have been assessed:

Global warming potential (GWP) is defined as the impact of greenhouse gases emission that includes the emissions that contribute to global warming, such as CO_2, CH_4, N_2O. The equivalent amount of carbon dioxide was used to calculate the amount of any gases that has the same amount of trapped heat. So, the unit of GWP is the number of gram CO_2 equivalent kg/emission.

Acidification potential (AP) refers to acidifying pollutants on soil, ground water, surface water, biological organisms, ecosystems, and materials. It is the result of increasing hydrogen ions (H^+) that may cause damage to organic and inorganic in medium. AP includes the emissions that cause acidification of rain, soil and water, such as SO_2, NO_x, and NH3. The unit of indicator result is in g SO_2 equivalent/kg emission.

Photochemical oxidant formation potential (POFP) is a main contributor to smog or known as summer smog. It is the reaction of chemical compounds and sunlight in the presence of pollutant gases, such as nitrogen oxide or volatile organic compounds (VOC). The unit of this impact category is the number gram of ethylene equivalents/ emission.

Eutrophication potential (EP) is the impact of exceed amount of micronutrient that contain nitrogen (N) and phosphorus (P). This may cause hypoxia, the depletion of oxygen in water that changes the nutrient concentration in lakes, rivers and soil. Ecosystem may lead to decrease the oxygen levels, because of the additional consumption of oxygen. The eutrophication impact also includes the emissions of degradable organic matter. The unit of indicator result of this category is kg PO_4 equivalent/kg emission.

These environmental impact potentials are calculated as the sums of the impact potentials for the emissions of the product system [9]:

$$EI_j = \sum_{i=1}^{n} E_i \times \varepsilon_{i/j}$$

where: EI_j: is the environmental impact category (j); E_i: is the contribution of emission (i); $\varepsilon_{i/j}$: is the effect factor of emission (i) on the environmental impact category (j).

The environmental impacts potentials depends how the emissions occur and the concentration of substances to which they contribute in environment.

2.4. Functional unit

Functional unit is provided as a reference to the inputs and outputs related. In this study, the functional unit was chosen to be 1 MJ released by engine fueled by Jatropha and WCO biodiesel.

2.5. Data sources

The data of Jatropha farming was collected from the reports of Jatropha plantation projects in Viet Nam. Other data of oil and biodiesel production were collected from previous published studies. The data for vegetable oil extraction are from [10]. The data for biodiesel production is from [11]. The data of electricity sources is from IEA [12]. The data of the emissions from biodiesel and diesel use are from [13]. The data of CO_2 emission of the production of fertilizer (N, P, K), hexane, methanol and catalyst are from [14-17] .

2.6. Life Cycle Inventory

Table 1 shows the input – output data for four stages of Jatropha biodiesel production based on the current conditions in Viet Nam. Jatropha plants were farmed in the prepared field with spacing of 2×2 m (2500 plants/ha) and could be harvested after 4 year. Fertilizers (N, P, K) were used during growing Jatropha plant. The yield of Jatropha seed is 2733 kg/ha. Hexane solvent extraction was performed to get oil and determined oil content of Vietnamese Jatropha is 32.2 %. For biodiesel production, the common technology based catalyzed transesterification of Jatropha oil and methanol was applied. And the ratio of oil/methanol/sodium hydroxide was referred from the reports of the biodiesel production projects in Viet Nam. The total distance for transportation of oil collection and biodiesel distribution assumed in this study is 20 km. The transport mode with a mileage of 3km/litter was used for oil and biodiesel delivery. A heavy-duty truck with the capacity of 25 tons and mileage of 3 km/litter of diesel was assumed [2]. The energy content of biodiesel and diesel is 37.8 and 48.1 MJ/kg, respectively. In this study, Jatropha and WCO biodiesel was assumed as fuel to run vehicle. Glycerol was assumed as a product can displace another process.

Table 1. Input – output data of life cycle system of Jatropha biodiesel production.

Stages	**Inputs/outputs**	**Jatropha biodiesel**
Oil production/ Collection	*Input*	
	N (kg/ha) *	28.8
	P_2O_5 (kg/ha) *	44.1
	K_2O (kg/ha) *	45
	Diesel (MJ)	3.33
	Hexane (to atmosphere) (kg)	5.73
	Land use (plants/ha) *	2500
	Output	
	NH_3 (to atmosphere) (kg)	3.53
	PO_4^{-3} (to fresh water) (kg)	0.165
	N_2O (to atmosphere) (kg)	0.305
	NO_x (to atmosphere) (kg)	6.37
	Biomass (kg/ha) *	2733
	Crude oil*	32.2%
Transportation	Transport distance (km) **	20
	Diesel (km/kg)**	3
Transesterification	*Input*	
	Crude oil (kg) *	1018
	Methanol (kg) *	96
	Sodium hydroxide (kg) *	7.6
	Output	
	Biodiesel (kg) *	1000
	Glycerol (kg) *	93.35
	Waste methanol (kg) **	9.6
Biodiesel use	*Using in vehicle*	
	Biodiesel (MJ)	1***

* data was collected from reports of biodiesel production in Viet Nam.** data was assumed. *** functional unit of the LCA calculation was 1 MJ.

The emissions generated from the processes to produce fertilizer (N, P, K), hexane, methanol and catalyst are based on the life cycle assessment of these products as shown in Table 2.

The data was integrated with the database of SIMAPRO 8.0 to make LCA calculation [13] for environmental impacts assessment.

Table 2. Greenhouse gases emission factor for inventory.

Inventory	**GHG emission factor**		**References**
Diesel	3.67	kg CO_2/kg	[14]
N	6.67	kg CO_2/kg	[15]
K	0.71	kg CO_2/kg	[15]
P	0.46	kg CO_2/kg	[15]
Hexane	3.93	kg CO_2/kg	[16]
Methanol	1.95	kg CO_2/kg	[17]
Sodium hydroxide	1.19	kg CO_2/kg	[17]

3. RESULTS AND DISCUSSIONS

3.1. LCA results

Figure 4 shows the life cycle emissions inventory of Jatropha biodiesel and the emission of diesel. Using biodiesel to replace fossil diesel could improve some emissions, such as CO_2, PM, CH_4 and VOC but it also increase some other emissions, such as NO_x. It is found that overall CO_2 emission, main distribution gas in GHG, could be reduced significantly. These results also could be used to calculate the emission reduction of national level according to the percentage of biodiesel and diesel blending.

3.2. Land use

The most considerable problem of using Jatropha as feedstock of biodiesel production is land use. In this study, it refers to the loss of land or it is unavailable for another purpose. It may improve the structural ecosystem if it is planted on wasteland but it could affect the functional ecosystem if it is used to replace other plants. Indirect land-use was not considered for Jatropha plantation. The land occupation impact of Jatropha in this study was 3.14E-08 ha/MJ that is quite large for an agriculture country like Viet Nam. In the case of WCO, land use of oil production stage is assumed as zero. Thus the impact of land use of WCO biodiesel that is allocated to biodiesel conversion and use stage should be minor. However, the capacity of WCO used in biodiesel production is not large. So it is necessary to consider the maximum capacity of biodiesel production or the acceptable percentage of biodiesel blending with diesel.

3.3. Interpretation

The life cycle impacts of biodiesel are shown in Figure 5. It is found that the environmental impacts of WCO biodiesel are all better than ones of fossil diesel. The main reason is that environmental impacts of the first stage of oil production the life cycle of WCO are allocated to the main product. In the case of Jatropha biodiesel, there are different trends of environmental impact categories when using biodiesel to replace diesel, GWP and POFP could be improved whereas AP and EP are increased.

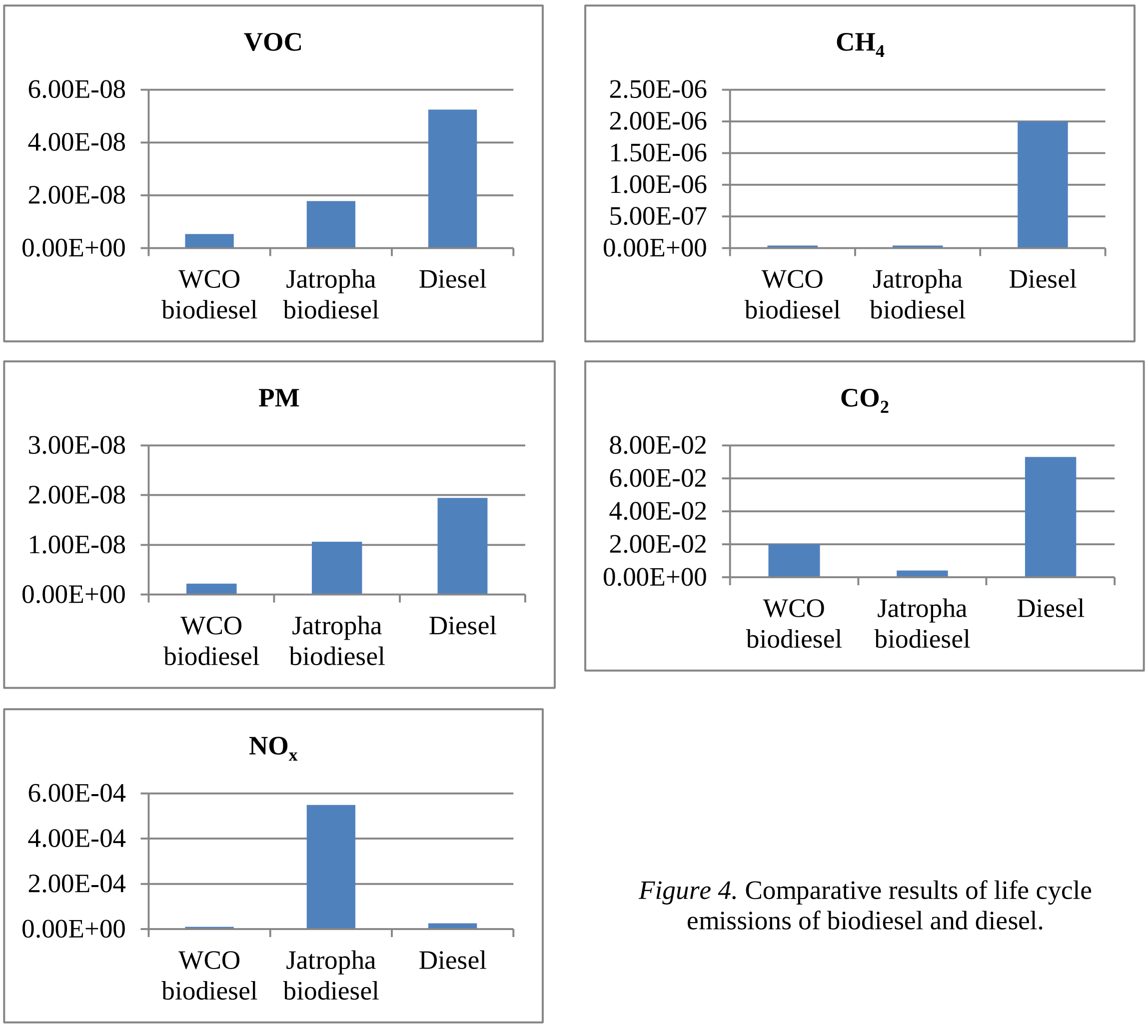

Figure 4. Comparative results of life cycle emissions of biodiesel and diesel.

Global warming potential: In this study, the GWP of Jatropha biodiesel 1.23E-02 kg CO_2 eq./1 MJ based on the conditions in Viet Nam. It could be reduced 86.56 % of the life cycle GWP of Jatropha biodiesel compared with fossil diesel. The reason of this is the large amount of CO_2 absorbed in biomass growth.

Photochemical ozone foundation potential: This impact category is expressed as kg C_2H_4 eq. In this study, POFP is associated with the emission of NO_x, CH_4 and VOC. The result shows that Jatropha biodiesel could reduce 53.63 % of life cycle POFP compared with fossil diesel.

Acidification potential: AP is calculated as kg SO_2 eq. that is associated with the emission of NH_3 and NO_x. The result indicates that the life cycle AP of Jatropha biodiesel is higher than fossil diesel.

Eutrophication potential: This offers to the emissions to the air, water and soil and is measured in kg PO_4^{3-} eq. In this study, EP includes the emission of NH_3, NO_x and PO_4. The result also indicates that the life cycle EP of Jatropha biodiesel is higher than fossil diesel. It could be the result of leaking N and P of fertilizer into the water and air.

These negative impacts (AP and EP) could be the results of using fertilizer in Jatropha plantation. So NH_3, NO_x, PO_4^{3-} may emit into the air or fresh water.

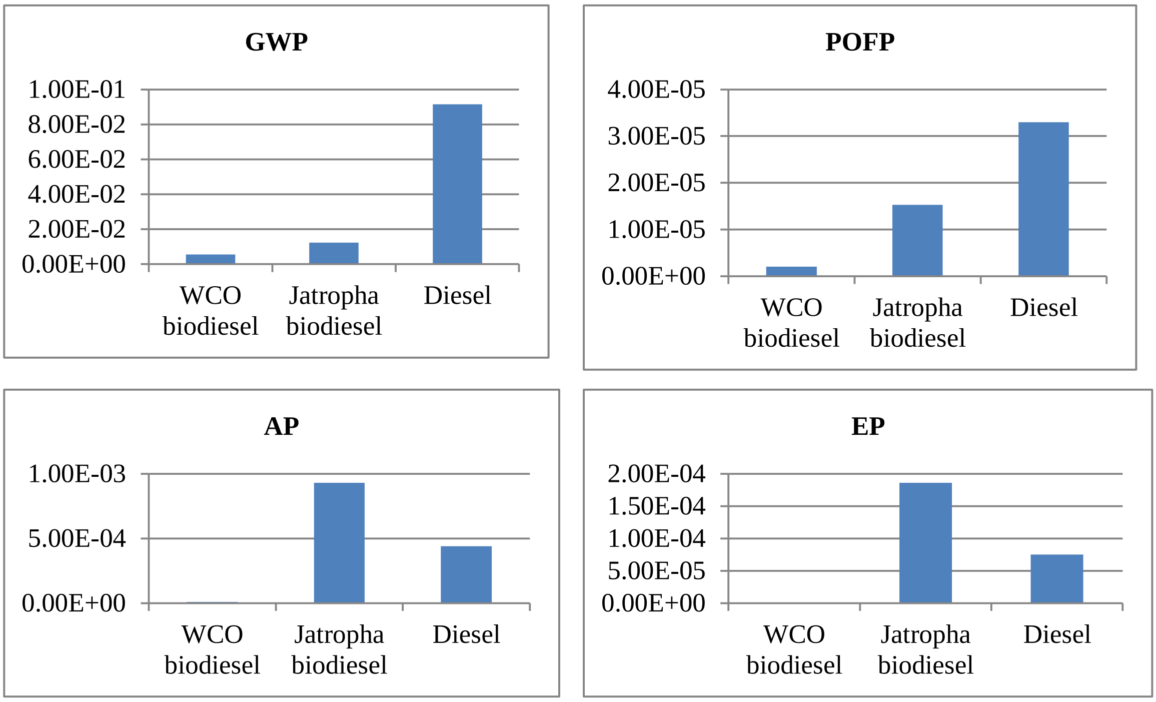

Figure 5. The life cycle impacts of biodiesel production and use.

4. CONCLUSIONS

The results of the study showed that replacing fossil diesel by biodiesel could reduce the gas emissions, such as CO_2, PM, CH_4 and VOC, but it could increase Nitrogen emissions. There are some positive impacts as well as some negative impacts issued from Jatropha biodiesel production and use in replacing fossil diesel. WCO biodiesel has positive impacts on environment. However, the most challenge of WCO biodiesel development is from the limitation of the capacity of WCO and the competition with animal feed production. Jatropha biodiesel that has large capacity could reduce 85.56 % GWP and 53.63 % POFP to fossil diesel although it could increase EP and AP. So it is necessary to consider every impacts in the decision making of biodiesel development. And the LCA also indicate the method to reduce the environmental burden through improving the technologies of material production and biodiesel conversion. For instance, the main reason of higher acidification potential and eutrophication potential is the result of the emission of nitrate and phosphate leaking to water resources and ammonia and NO_x emitted to air N and P fertilizer application. So in order to reduce these impacts, one of the possible methods is improving the technology of plantation to decrease the amount of fertilizer consumption. From the results of this study, Jatropha and WCO are found as promising feedstock of biodiesel to substitute conventional diesel in the future in Viet Nam.

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