Energy and Greenhouse Gas Implications of Biodiesel Production from *Jatropha curcas L.*

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Abstract: *Biodiesel production from Jatropha is one of the options being considered for partially substituting diesel fuel for transportation in Thailand. However, several issues such as food versus energy, energy and environmental benefits need to be addressed. Biodiesel from Jatropha meets the requirement for the first consideration because it is inedible and can be grown in waste land. However, the energy and environmental issues need further consideration. This study aims to investigate the energy consumption and greenhouse gas (GHG) emissions from Jatropha Methyl Ester (JME) production in Thailand using a life cycle approach. The selected study site for cultivation and oil extraction phase is Faculty of Agriculture, Kamphaeng Saen Campus, Kasetsart University where Jatropha is grown as an annual crop. Functional unit (FU) of this LCA study is 1 GJ equivalent of liquid fuel. Per FU, energy consumption for producing biodiesel is 0.88 GJ. The main contributors to the energy use are transesterification, irrigation, and fertilization process contributing approximately 40%, 23% and 22% respectively. The dominant global warming potential came from the production-use of fertilizer and irrigation process, about 31% and 26% respectively. Main co-products from the whole process are Jatropha residues which can be used for energy purposes and have a calorific content of about 17.88 GJ. GHG emissions from the production phase of JME are allocated based on energy content of the co-products. Compared to the production and use of diesel, GHG emissions from JME are about 77% lower.*

Keywords: Biodiesel, *Jatropha curcas L.*, Transesterification, Life Cycle Assessment, Greenhouse Gas, Biomass

1. INTRODUCTION

Thailand has been facing severe energy crisis due to present global crude oil price. Thailand mainly depends on imported oil as domestic resources are limited to lignite and natural gas. The Thai government is promoting alternative domestic energy resources development to sustain energy supply. Renewable energy is an alternative strategy option promoted by the government. The government has set a plan that the National renewable energy must be increased from 0.5% currently to 8% by the year 2011 [1]. Biodiesel is one of the important alternative energy sources. It is renewable source of energy, which can increase fuel supplies and reduce dependence on import of crude. Along with oil palm, *Jatropha curcas* L. is a potential feedstock for biodiesel production. Being a tropical plant, Jatropha can be easily cultivated in the climatic conditions of Thailand. Jatropha plantation and products have been used for many applications such as medicines, biomass, and fencing. Besides, Jatropha plantation project can create jobs and reduce the problem of labor migration to city. Cultivation of Jatropha for biodiesel production is desirable. However, there are currently concerns about the low quantity of oil yield [2]. Hence, there is no national policy measure for biodiesel production in Thailand using Jatropha plant at present. It is critical to ascertain its advantage-disadvantage for the policy decision-maker. This study is focused on evaluation of energy use and global warming potential associated with the biodiesel production from Jatropha using a life cycle approach.

2. METHODOLOGY

One of the most internationally accepted methods to determine the environmental impact over the entire period of the activities, products, process for identifying significant environmental aspects is life cycle assessment (LCA) [3]. Defined by SETAC, LCA is "an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact of those energy and materials uses and releases to the environment, and to evaluate and implement opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing; transportation; and distribution; use/re-use/maintenance; recycling; and final disposal" [4]. The LCA process under the ISO standard 14040-14044 consists of four steps: goal definition-scoping, life cycle inventory, impact assessment, and interpretation [5].

2.1 Goal-objective

The goal of this study is assess the life cycle energy use and global warming potential for biodiesel production and use as compared to conventional diesel fuel for use in transportation. The results are useful for researchers as well as decision makers in the alternative energy and transportation sector.

2.2 Scope of Work

The information from the process of Jatropha plantation to oil extraction is collected from the pilot project at the Faculty of Agriculture, Kamphaeng Saen Campus, Kasetsart University. The information for transesterification process and use of biodiesel are reviewed from an LCA study of soybean biodiesel [6]. The analysis includes 1) farming process in concept of annual crop where the jatropha plants are cut year by year for value added as biomass (leaves, bark, peels, etc.); 2) Jatropha oil extraction is operated by screw press machine; and 3) biodiesel conversion process is operated by common facility model of transesterification using methanol and sodium hydroxide (NaOH) as a catalyst. Functional unit chosen is 1 GJ of liquid fuel. JME has net calorific value of 32.80 MJ/L [7]. Therefore, 30.49 L of JME is used as reference flow for the calculations. The environmental impact category in the study is limited to global warming potential. To display the existing amount of greenhouse gas (GHG) emissions, the comparison is done with

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diesel as baseline. There is no attempt to quantify economic benefit since the market price of JME and co-products have not been set up yet. The calculation of impact potentials and energy use are based on FU and allocation of environmental burdens to co-products is done on the basis of energy. The main results included are estimates of (1) overall energy requirements (excluding the production of herbicide and insecticide due to lack of specific information); and 2) greenhouse gas emissions. The keys assumptions are 1) Jatropha biodiesel in this study meets the European biodiesel standard [7]; 2) the physical characteristics of Jatropha oil are similar to soybean oil; hence, GHG emission from jatropha methyl ester (JME) production and use are not much different with soybean methyl ester [8]; 3) 1 GJ of biodiesel and diesel can be used for driving vehicle based on diesel engine for the same distance; 4) the age of Jatropha plantation at this study site is just 3 years but the assumption (based on studies elsewhere) is that the Jatropha growing requires the process of land preparation and new cutting set every 5 years to gain the satisfactory outputs; and 5) The distance for both diesel and biodiesel production facilities from the gas station is 100 km. The system boundary of this study is shown in Fig 1.

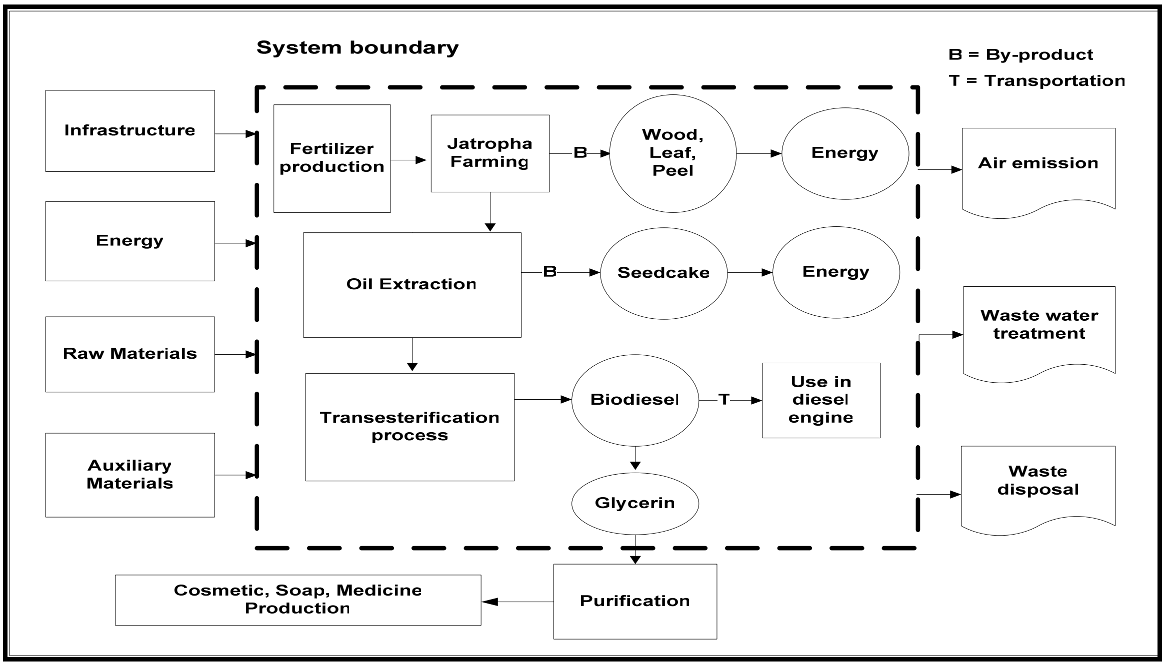

Fig. 1 The system boundary of Jatropha Methyl Ester production

2.3 Life cycle inventory and background

In order to study biodiesel production from jatropha using life cycle assessment, the site study and inventory has been performed as follows: 1) jatropha plantation; 2) oil pressing and refining; 3) biodiesel conversion; and 4) biomass co-products.

2.3.1 Jatropha plantation

Jatropha curcas Linnaeus, a shrub and toxic tree with smooth gray bark, belongs to the family Euphorbiaceae. It can grow all over the tropics as well as endures on poor soil and severe heat but the leaves drop in cold weather and arid conditions. The minimum average rainfall requirement is about 250 mm per year and it can grow well under average rainfall 900-1200 mm. The height of Jatropha is around 4 m. Within 1 year, Jatropha starts producing seeds but the maximum productivity is after 4 or 5 years. Its life span is over 20 years. The utilization of Jatropha is found in every part of the tree. The utilization of Jatropha products are for liquid fuel, biomass, fertilizer, glycerol, medicine and detoxified animal feed [9].

Information of Jatropha cultivation is collected from the Faculty of Agriculture at Kamphaeng Saen Campus, Kasetsart University in the model as follows: annual crop using cutting set in area 6.5 rai (1 rai = 1600 m^2); crop density 2 x 1 m or 800 trees per rai; land preparation comprises of ploughing, harrowing, and, furrow process with engine of tractor 75 hp to adjust soil condition for new cutting set; fertilizer chemical formula 15-15-15 at an application rate of 100 kilogram/rai/year; the chemicals used are insecticides, weedicides and medicine for the general maintenance of plantation; watering 7,200 m^3/rai/year by pumping; harvesting process is done manually. Fresh fruit yield of Jatropha plantation is about 2,500 kg/rai/year. The approximate weight of each fresh fruit and seed are around 10-15 and 2-4 g, respectively. Fig. 2 shows the unit process of Jatropha plantation.

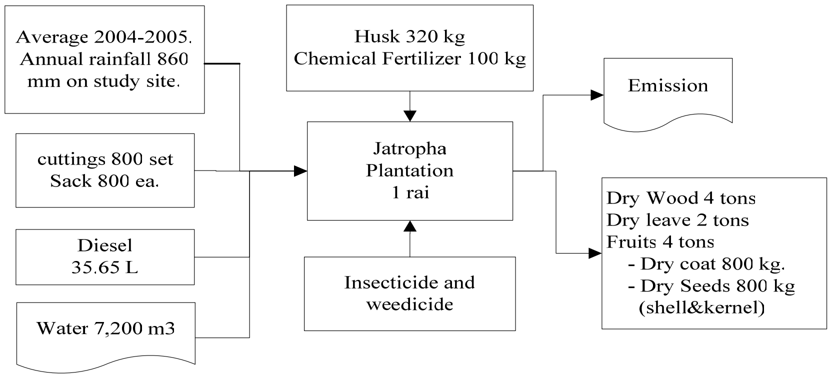

Fig. 2 Unit process of jatropha plantation; 1 rai = 1,600 m^2

2.3.2 Oil pressing and refining

After drying by sunlight, weight of dry fruit would be approximately 2,000 kg per rai. The dry fruit is placed into a 1 hp cracking machine with capacity 120 kg of seed/hour to carefully remove coats. This operation yields Jatropha seed about 800 kg per rai. Jatropha oil is extracted by 7.5 hp screw pressing engine with capacity 25 liters Jatropha oil/hour. 200 liters/rai of Jatropha oil is purified by filtering with a 2 hp machine capacity 150 liters/hour before being passed to the biodiesel conversion machine. Fig. 3 shows the unit process of Jatropha oil production.

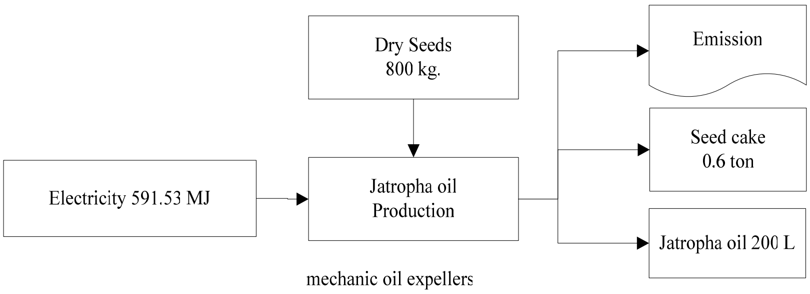

Fig. 3 Unit process of Jatropha oil production

2.3.3 Biodiesel production

Jatropha crude oil can be directly used in agricultural machinery without oil and engine modification. However, the quality of oil will be better and there will be less long term problems if it is first converted into biodiesel [10]. The procedure of biodiesel production from Jatropha is very similar to the biodiesel production from other plant oils like palm or soybean. The test results of JME have shown that its properties meet the Australian fuel standard [11]. Fig. 4 presents the unit process of biodiesel conversion in common batch of transesterification using methanol, sodium methoxide, hydrogen chloride and sodium hydroxide [6]. Efficiency of the process reaches 95% by weight of conversion rate.

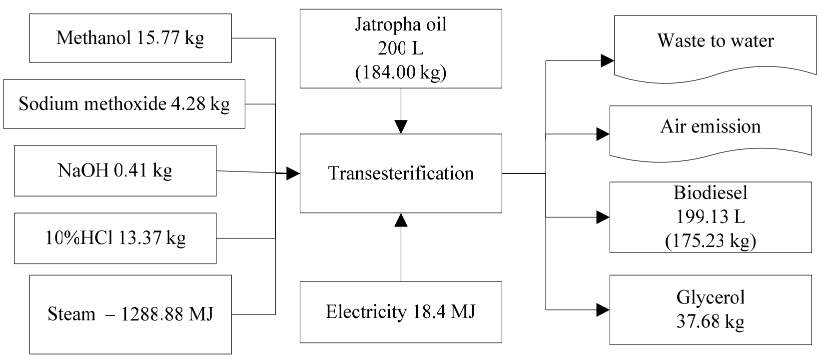

Fig. 4 Unit process of biodiesel conversion

2.3.4 Jatropha co-products as biomass.

Co-products from JME production can be converted into various useful forms. The study views those products as co-products which will be used for energy purposes. Per FU, the co-products obtained are wood, leaves, and coat having dry weight 4,000, 2,000, and 800 kg respectively from the process of plantation. Press cake, dry weight 91.5 kg, is obtained from the oil production process.

3. RESULTS AND DISCUSSION

3.1 Net energy results of Life Cycle Impact Assessment

The energy consumption in each process to produce 1 GJ of biodiesel is shown in Fig. 5. The highest energy consumption was in the process of transesterification from energy used for producing steam (about 0.197 GJ). Next is the energy consumption from irrigation and fertilization process which contributed 0.205 and 0.198 GJ respectively. The calculations of primary energy for using diesel, electricity and fertilizer production are based on the references 12, 13, and 14 respectively. The main contributor to energy used in irrigation process is the consumption of diesel for water pumping. The energy requirement for fertilizers is from both the production process as well as using 100 kg of fertilizer with the chemical formula 15-15-15 (energy consumption for transportation of fertilizer is excluded). Jatropha plantation requires the process of land preparation 1 time every 5 years as the stems are cut every year but the new plantation is made every five years. Distance of transportation for carrying cutting sets to land by pick up car is around 10 km. Energy consumption for manual labor is not included in the analysis. Also, electricity used in office, which is in the same area of oil production and biodiesel conversion, is not included because the office is utilized for many activities not related to biodiesel production and thus the allocated value for only biodiesel is small. Besides, energy used for producing raw materials as sack for propagation, husk, cutting sets, herbicide, and insecticide are not included because of lack of data. The energy output is not only from the biodiesel but also from the wood, leaves and coat from the jatropha plants as also from the pressed cake. The total energy amounts to 17.883 GJ as shown in Fig. 6. The highest energy of 10.289 GJ is from wood.

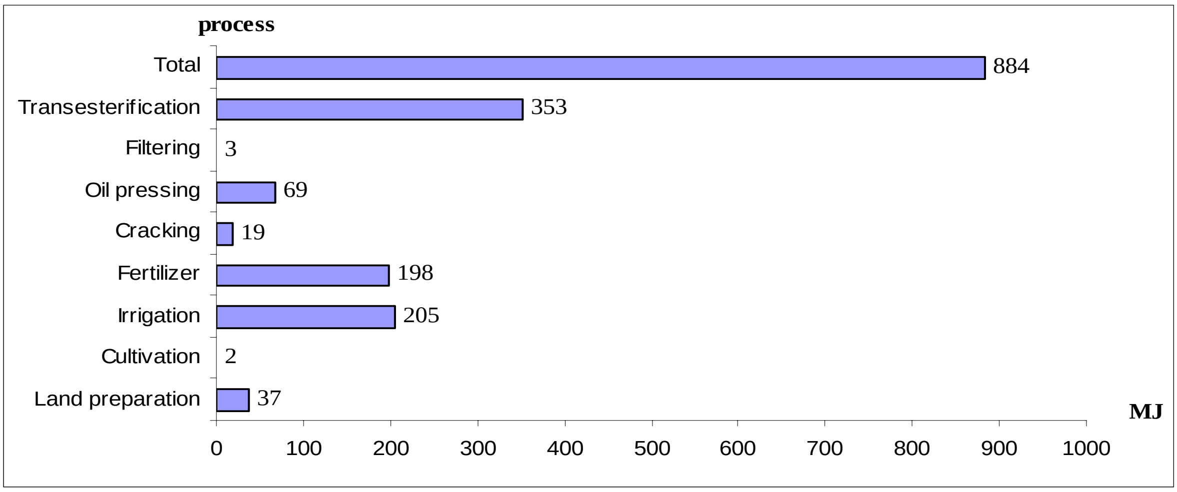

Fig. 5 Energy consumption for producing Jatropha methyl ester and co-products per FU (1 GJ of JME)

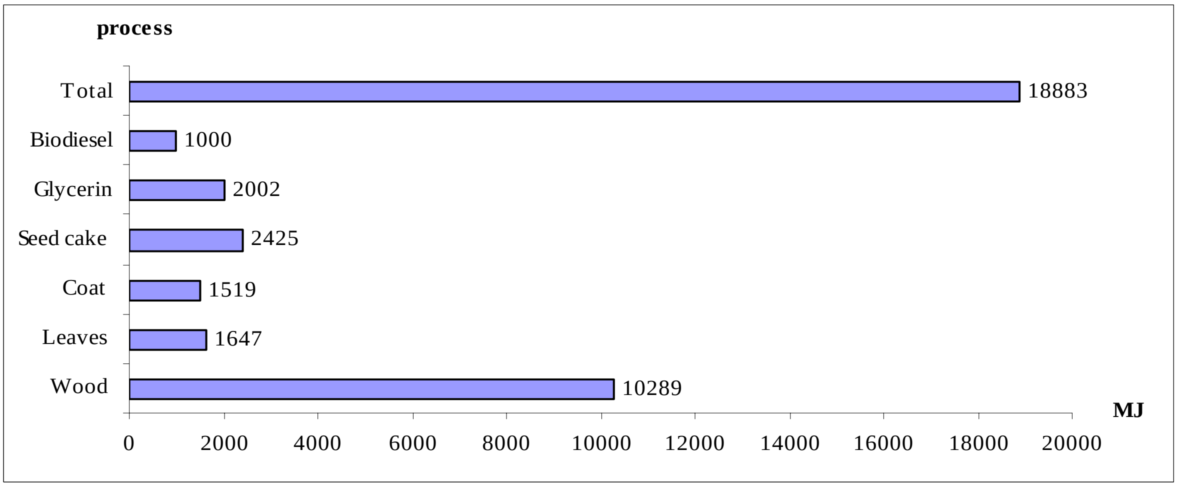

Fig. 6 Energy gain from the whole process of Jatropha Methyl Ester production per FU (1 GJ of JME)

3.2 Global warming potential of JME

The proportion of greenhouse gas emissions from each process is shown in Fig. 7. The calculation of GHG emissions from biodiesel conversion phase; electricity production for cracking, oil pressing, and filtering; fertilization; and diesel consumption for land preparation, cultivation, and irrigation are based on the references 6, 13, 14, and 15, respectively. The equivalence factors for the greenhouse gases are estimated from IPCC and EDIP for 100 year period [16, 17]. The main contributions came from the fertilizer production and use; diesel consumption for irrigation; and transesterification at 31, 26, and 24% respectively. It is interesting to note here that the energy consumption for transesterification is higher than fertilization but the highest rates of greenhouse gas emissions are from fertilization. That is because N-compounds from the process of N fertilizer production and use are the source of N_2O creation which is a highly potent greenhouse gas.

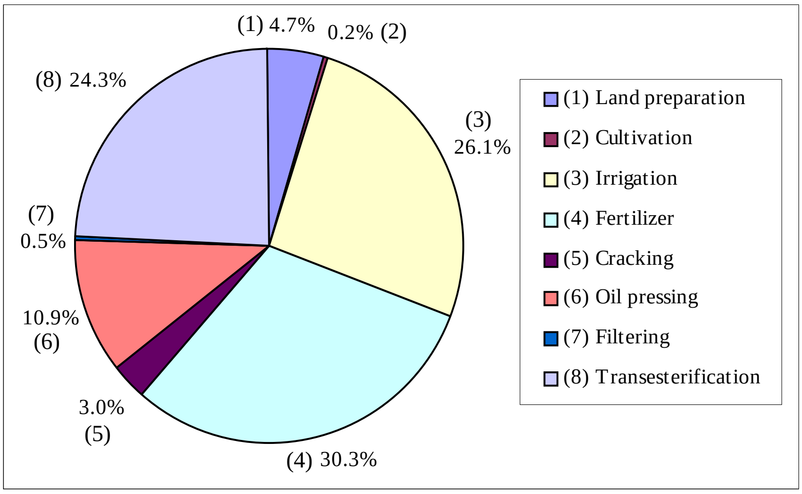

Fig. 7 Representative carbon dioxide outputs for producing biodiesel from Jatropha by transesterification

One of the advantages of a life cycle approach is that it allows a fair comparison between two products and is thus useful for evaluating the benefit of Jatropha biodiesel regarding to environmental impact as compared to petro-diesel. The calculation of GHG emissions from diesel production and use is based on the reference 6. Fig. 8 is the comparison of GHG emission from life cycle of biodiesel and diesel based on FU [3]. Over 90% of GHG emissions from the life cycle of both diesel and biodiesel are from the use phase. Rate of total global warming potential from biodiesel production and use is just 23% of diesel. This is because the CO_2 emissions from combustion of biodiesel in the engine during the use phase are considered GHG-neutral as they are of biomass origin and thus absorbed from the atmosphere by the jatropha plants during growth.

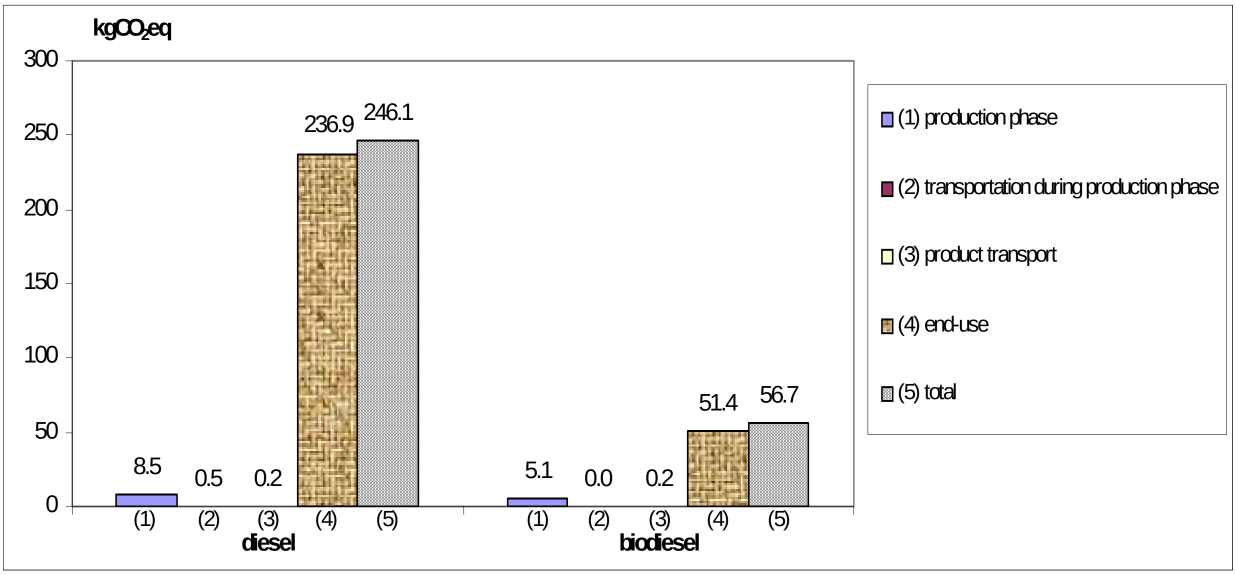

Fig. 8 Comparison of life cycle GHG emissions of biodiesel and diesel

3.3 Interpretation

Actually, quantity of GHG from JME production should be about 20 times higher than in the Fig. 8. However, energy output from the production of Jatropha biodiesel using the concept of annual planting gains energy value both from main product which is biodiesel and co-products which are peels, leaves, wood, and seed cake. The main contributors of both energy consumption and GHG emissions which should be considered are from the transesterification, irrigation, and fertilization. Energy efficiency of biodiesel conversion should be given the first priority for the process improvement as it is the main contributor to both energy use as well as GHG emissions. Almost 60% of energy consumption in the transesterification step is from steam. Alteration and maintenance of engine can help to reduce that consumption. Also, the other, more efficient, biodiesel conversion technologies should be considered. As the next priority, the range of watering and fertilizing amount should be tested to find out the optimum input values. The high amount of water and chemical requirement in this method of plantation (cutting the plants every year to get co-products) may be resulting in an energy gain at the expense of resource depletion (such as water and land use), nutrient enrichment problem from fertilizer, and ecological toxicity from chemical use of weeding and insecticide. However, this needs to be further investigated. In terms of costs, the water resource depletion and land use are relatively easy to quantify while the impacts accruing from the application of fertilizer, herbicide, and insecticide are difficult to quantify.

4. CONCLUSION

The GHG emissions and net energy value of JME are assessed to evaluate the possible benefits of using it as a substitute for diesel. The results of the study show a net energy gain from JME. Also, JME production provides co-products with high energy value. In addition, as expected, GHG emissions from the production of biodiesel are less than diesel. However, this study analyses data only from one pilot plantation site and the considerations for inputs of biodiesel production are from secondary sources. Even so, the study serves as a first step in assessing the potential advantage of Jatropha and provides justification and interest for a more comprehensive study. Moreover, the depletion of resource, nutrient enrichment from fertilization, ecological and human toxicity from chemical use and Jatropha toxicity as well as the cost of investment for manual harvesting should be further studied to find out the overall assessment of biodiesel from Jatropha.

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