Life cycle assessment of palm oil biodiesel production in Thailand

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ABSTRACT

Biodiesel from palm oil has been considered for partial substitution of diesel fuel for transportation in Thailand. The Government of Thailand recently has set up a production target of 8.5 million liters per day of palm oil-based biodiesel by 2012. Generating biodiesel from palm oil requires a great amount of materials and energy, and during the production process several kinds of emissions are released which adversely affect the environment. Therefore, to quantify and verify the advantages and usefulness of palm oil biodiesel, it is necessary to assess its production from a life cycle point of view. The objective of this paper is to analyze the environmental impacts of palm oil biodiesel from a life cycle assessment (LCA) aspect. The SimaPro software scheme was applied in this study. This study will consider the environmental impacts from 1 liter of palm oil biodiesel; the study is divided into three processs: agriculture, transesterification into biodiesel, and utilization. The agricultural, palm oil production and biodiesel production (transesterification) facilities are all located in Krabi province, in the southern part of Thailand. EDIP method and European databases included in the LCA software SimaPro have been used for the impact calculations. The results of the study show the environmental impact per liter of palm oil biodiesel. This study indicates that the ustilization process has the greatest environmental impact, 52.09% of the total. Next are the production of biodiesel and agricultural procedures, amounting to 41.21% and 6.7%, respectively. The most significant impacts from the system are ozone formation, terrestrial eutrophication, aquatic eutrophication, and acidification. The environmental impacts take place from the emissions of CO and NO_2 during combustion.

Key Words: *Life cycle assessment, Palm oil, Biodiesel, Thailand, Environmental Impact*

1. Introduction

Biodiesel, an alternative renewable fuel made from transesterification of vegetable oil with alcohol. There are several kinds of materials that can be developed as diesel blended fuel: for example, vegetable oils, animal oils, and used cooking oils. Palm oil has been found to be an ideally suitable raw material for biodiesel production. Potential of palm oil in Thailand, oil palm has quantitatively the highest commercial production among the existing major oil crops. The palm oil harvested area, palm oil production and the price of palm oil in the years 2003–2007 are shown in Table 1. The crude palm oil (CPO) is sent mainly to refining plant; however it can be used as a feedstock for biodiesel production in Thailand.

Table 1 Palm oil harvested area and palm oil production [2]

Year	Palm oil harvested area (hectare)			Palm oil production (metric ton)		
	Central	South	Total	Central	South	Total
2003	19,023 (6.6%)	268,880 (73.4%)	287,903 (100%)	293,392 (6.0%)	4,609,183 (94.0%)	4,902,575 (100%)
2004	21,062 (6.8%)	288,553 (93.2%)	309,615 (100%)	310,358 (6.0%)	4,871,439 (94.0%)	5,181,797 (100%)
2005	22,515 (6.9%)	301,677 (93.1%)	324,192 (100%)	311,647 (6.2%)	4,691,023 (93.8%)	5,002,670 (100%)
2006	28,436 (7.5%)	351,436 (92.5%)	379,872 (100%)	428,707 (6.9%)	5,812,046 (93.1%)	6,240,753 (100%)
2007	32,718 (7.5%)	405,530 (92.5%)	438,248 (100%)	497,508 (6.7%)	6,880772 (93.3%)	7,378,230 (100%)

However during the production process, biodiesel requires material and energy inputs that contribute to adverse environmental impacts. In order to clarify the overall usefulness of biodiesel, it is necessary to apply the Life Cycle Assessment (LCA) point of view to analyze the environmental impacts from the entire life cycle of biodiesel made from palm oil.

This study will analyze the environmental impacts of palm oil biodiesel based on life cycle assessment (LCA) using SimaPro 7.1 LCA software. This tool helps evaluate the environmental burdens by identifying, quantifying the energy, materials used, the waste released into the environment, identifies and determines opportunities for environmental improvement, focusing on such areas as human health, ecology, and availability of resources for future generations.

2. Methodology

The methodology developed in this study is based on LCA. The goal of this study is to analyze the environmental impacts of palm oil biodiesel production by using the LCA method. This methodology consists of four major steps are shown in Fig 1.

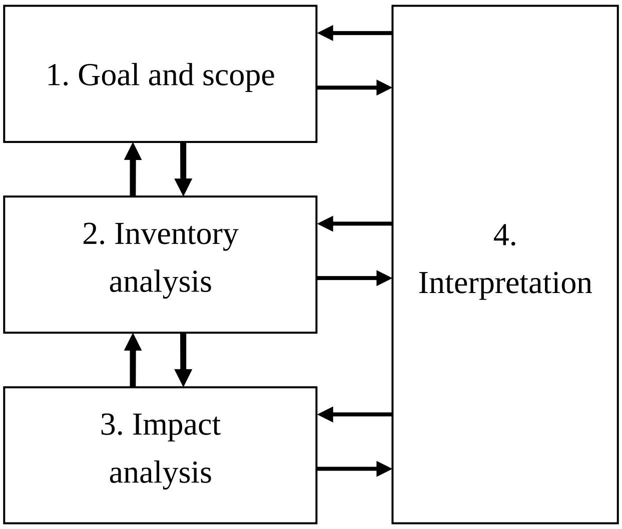

Fig 1. Phases of Life Cycle Analysis

2.1 Goal and scope

The goal and scope of this includes the definition of a reference unit: all the inputs and outputs are related to this reference, which is called the "functional unit.", the goal and scope should address the overall approach used to establish the system boundaries. The system boundary determines which unit processes are included in the LCA and must reflect the goal of the study. This provides a clear, full and definitive description of the product or service being investigated, and also enables subsequent results to be interpreted correctly.

2.2 Life cycle inventory (LCI)

The second step is inventory analysis. This is based primarily on systems analysis, treating the process chain as a sequence of subsystems that exchange inputs and outputs. Hence, in LCI, the product system is defined, which includes: setting the system boundaries; designing the flow diagrams with unit processes; collecting the data for each of these processes; and ascertaining which emissions will occur.

2.3 Life cycle impact assessment

The life cycle impact assessment is aimed at evaluating the contribution to impact categories. This includes the impacts in terms of emissions and raw material depletion. The first step is characterization, the impact potentials are calculated based on the LCI results. The next steps is normalization provides a basis for comparing different types of environmental impact categories. After into weighting step is assigning a weighting factor to each impact category depending on the relative importance, this step is necessary to create a single indicator.

2.4 Interpretation

The last step is a comparison with other processes offering a similar utility, thus allowing a critical view of these previous steps. Comparison of environmental impacts also requires the selection of impact categories.

In this paper, the authors decided to use a damage approach, using SimaPro 7.1 software based on the Environmental Design of Industrial Products (EDIP). The EDIP tool includes a comprehensive database covering materials, semi-manufactured components, and working processes.

3. Case study

Biodiesel production requires palm oil, which comes from fresh fruit bunches from oil palm plantations. It is produced from palm oil by transesterification. The life cycle of biodiesel production is divided into three processs: agriculture, biodiesel production, and biodiesel utilization. The system boundaries are shown in Fig 2. The results of the study are as follows:

3.1 Functional unit: This study will consider the environmental impacts from 1 liter of palm oil biodiesel.

3.2 Scope definition: The scope of this LCA study is divided into three phases: beginning with nursery acquisition through the utilization phase, by focusing on the extraction of raw materials, energy consumption, and the emissions during life cycle processes (as shown in Fig. 2).

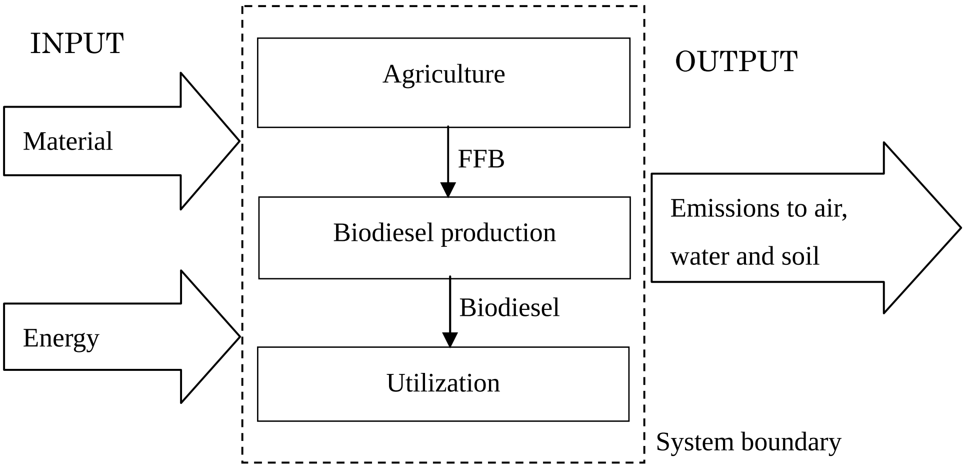

Fig 2. Life cycle diagram of biodiesel production.

The data were collected by direct measurements, plant reports and literature review. Data analysis included material and energy inputs and outputs at each process.

• The agricultural area studied is located in Krabi province, in the southern part of Thailand, suitable because of its large palm plantations. Material and energy input data constitute fertilizers, herbicides, water, and seeds. Output data are emissions to air, soil, and wastewater, as well as fresh fruit bunches (FFB). The data is an average of field data. This phase includes shipping; since the plants and factory are in the same local area, the shipping is only short-distance.

• The palm oil production facility is also located in Krabi province. Material and energy input data are: FFB, water, steam, diesel fuel and electricity. Output data are fiber, shell, decanter cake, empty fruit bunches (EFB), ash, wastewater, air emissions, crude palm oil (CPO) and kernels.

• The biodiesel production (transesterification) facility is also located in Krabi province. Material and energy input data are: palm oil, water, electricity, methanol, and sodium hydroxide. Output data are methyl ester (biodiesel), glycerol and wastewater.

• The utilization phase involved no experimentation with engines. The authors used reference data from the Research & Technology Institute of PTT Public Co., Ltd. [3]

4. Results and discussion

4.1. Agriculture

Oil palm plantations have a 25-year lifetime. Palms are planted at a density of 55 trees/acre, so a total land use of 14,805 acres would produce enough oil for biodiesel production in this case study. The fertilizers used are N from ammonium sulfate (21-0-0), P from ground rock phosphate (0-3-0), K from potassium chloride (0-0-60) and Mg from kieserite (26% MgO). These fertilizers are applied every year, but the rates of application differ depending on the age of the plants. Paraquat and glyphosate are used as herbicides between 1-3 times/year; each application is at 0.25-0.5 kg/acre and 0.75-1.25 kg/acre, respectively. Additional water is used only during the nursery stage – about 3.0-3.5 liters/tree/day (total water use is shown in Table 2). After this, most water is then acquired from natural rainfall for the remainder of the palms' lifetimes.

Oil palms start bearing bunches 2.5-3 years after planting. The usual frequency of harvesting is 15 days, and this is performed only by human labor. Young palms are harvested with a chisel, whereas old and tall palms are harvested with a long-handled sickle. The fruit bunches are generally transported to the palm oil mill on the day of harvesting – which 10 km far from the oil palm fields. A 25-ton truck is used for FFB collection. The current yield is 7.25 tons/acre/year. The average content of oil in oil palm shell is 17% (exclude oil of palm kernal). The total agricultural input and output is shown in Table 2.

Based on the inventory of agriculture in Table 2, SimaPro7.1 analysis shows the following results. The environmental impacts of agriculture are 1.03×10^{-4} Pt. (6.70%) per liter. The major impacts are release of toxic substances into the air, water and soil; radioactive waste; and global warming. All of this has occurred because of the use of fertilizers and pesticides. Nitrogenous fertilizers result in nitrite contamination of drinking water, and contribute to oxygen problems in water resource, and to greenhouse gas emissions. The environmental impacts take place from chemicals (glyphosate), and electricity from the grid that is used for the nursery. Radioactive waste is generated from chemical production, such as pesticides, glyphosate, boron and Kieserite etc.

Table 2 Total agricultural input and output

Nursery			Plantation		
OUTPUT:			**OUTPUT:**		
Palm oil seedlings	3,000 trees		Fresh fruit bunch (FFB)	2,900	kg
INPUT :			**INPUT:**		
Materials:			**Energy:**		
Polybags	83.33	Kg	Diesel	4.00	liters
Soil	49,50	Kg	**Chemicals:**		
Water	4,095,000	liters	Pesticide	0.14	kg
Energy:			Glyphosate	0.36	kg
Electric	3.13	MWh	16-16-16	33.00	kg
Diesel	56.00	liters	21-0-0	77.00	kg
Chemicals:			0-0-3	33.00	kg
Pesticide	0.56	kg	KCl	77.00	kg
Glyphosate	0.56	kg	Boron	4.40	kg
15-15-15	0.013	kg			
16-16-16	7.69	kg			
Boron	12.24	kg			
Kieserite	34.95	kg			

Estimating the effects of pollutants on human health requires not only an understanding of the intrinsic hazard of the chemical or physical agent, but also the extent of human exposure. Exposure is often determined by local pathways within a community: such as whether drinking water comes from wells or from river or water resource, or whether individuals consume vegetables grown in their backyards or those brought to market from far away. Individual activities can also alter pollutant intake; exercise, for example, increases respiratory uptake of air pollutants. Health effects due to pollutants are heavily dependent upon susceptibility factors, including age, gender, and genetic predisposition.

4.2. Biodiesel process

4.2.1. Palm oil production

In a wet-process palm oil mill, production capacity is around 45 tons of FFB per h, or around 1,000 tons of FFB per day. The mill operates 24 hr per day**.** Unit operations involved in the palm oil mill process consist of:

• *Fruit reception and storage:* The loading ramp is the place where the FFB are transported and unloaded in the mill.

• *Sterilization:* In order for the FFB to be completely cooked, sterilization is done batchwise in an autoclave for 120 min.,at 130-135 °C.

• *Threshing:* This is done to separate fruits from bunch stalks. This process generates empty fruit bunches (EFB).

• *Pressing:* The product is mashed under steam-heated conditions. The fiber and nuts from the screw press are separated in a cyclone. The fiber that passes out of the bottom of the cyclone is used as boiler fuel; the nuts that pass out go to kernel recovery.

• *Clarification:* The homogenous oil mash from the digester is pushed through a screw press, and later passes through a vibrating screen, a hydrocyclone, and decanters to remove fine solids and water. Decanter wastewater and decanter cake are the major wastes during this step. Centrifugal and vacuum driers are used to further purify the oil before sending it to a storage tank. A storage tank is maintained at 60 °C with steam coil heating before the CPO is sold.

• *Storage tank:* To keep palm oil for use in the biodiesel process.

• *Kernel recovery:* Nuts are cracked in a centrifugal cracker. After cracking, the kernels and shells are separated by clay suspension (kaolin). The shells separated from the kernels are sold to other mills as fuel. The kernels are sent to the kernel drying process in a silo dryer, to be sold later (for extraction) to other mills.

The production process in a palm oil mill is shown in Fig. 3. The results show that only 23% of the raw material input consists of valuable products (crude palm oil and kernels). Some of the remaining by-products can be reused in the palm oil production process itself – EFB (20% of raw material input) is used as fertilizer in the palm oil plantation. Other by-products can be sold to other industries, such as fibers (14%) for boiler fuel, or shell (7%). Remaining by-products also include ash (3%). However, there is a great deal of waste which must be treated properly before disposal or discharge. The wastewater (33%) is treated in a wastewater treatment pond.

Palm oil production generates enormous amounts of process residues, such as fibers (140 tons per day), shells (70 tons/d), and empty fruit bunch (EFB) (200 tons/d). The fibers are used as fuel in a boiler to produce high-pressure steam which is expanded through a steam turbine to produce electricity. Low-pressure steam is re-used in the manufacturing process for sterilization, digestion, purification, and also for temperature control. The electricity generated is used to supply almost all of the electricity requirements for the mill, which is estimated to be about 14.36 kWh/ton of FFB. The gross caloric value of fiber is 17,422 kJ/kg.

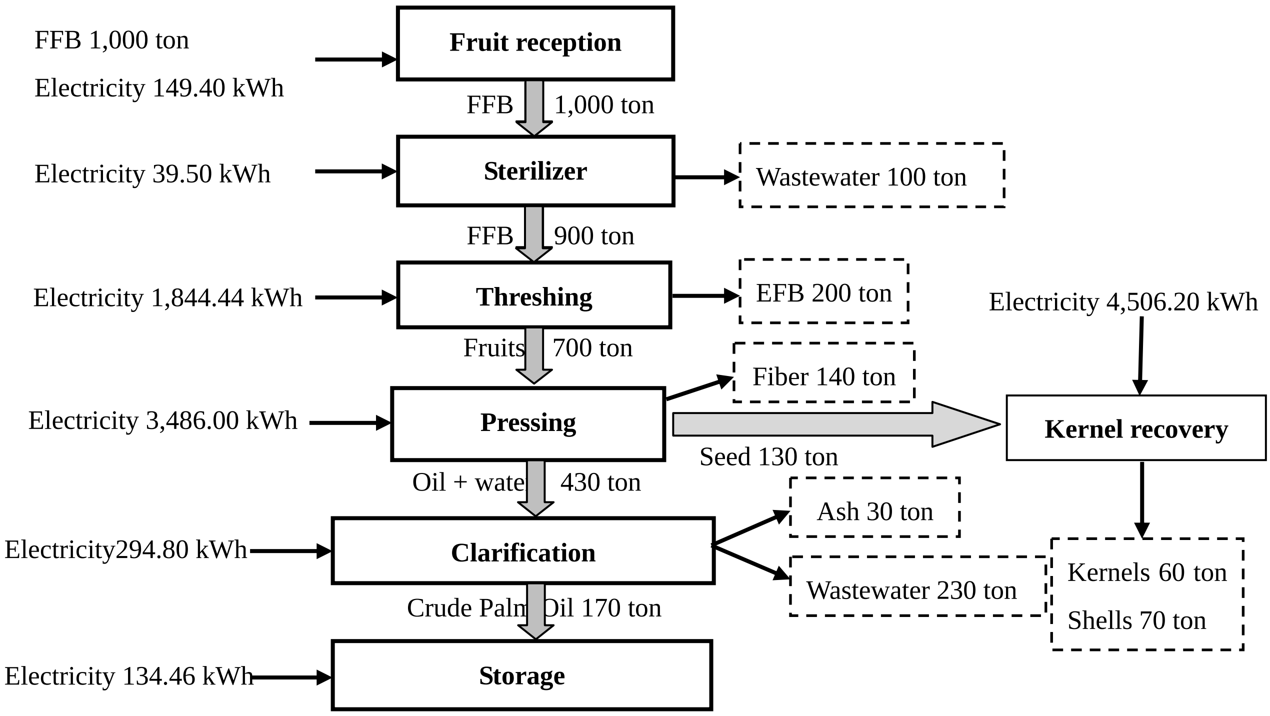

Fig 3. Flow diagram of the production process in a palm oil mill (1,000 tons per day).

4.2.2. Transesterification into biodiesel

The reactor for producing biodiesel from palm oil is a 10,000-L batch with a reactor time of 8 h/batch. In the biodiesel production phase, chemical reagents and energy are input. The amount of methanol and NaOH intake was tracked by the Specialized R&D Center for Alternative Energy from Palm Oil and Oil Crops, Faculty of Engineering, Prince of Songkla University, 2006. Transesterification of the oil produces methyl esters (biodiesel) and glycerol. The methyl ester layer is a light yellow liquid that lies on top of the glycerol layer, which is dark brown in color. The mixture may be kept overnight and allowed to separate by gravity. Otherwise, the methyl ester is separated from the glycerol and washed with water and acetic acid until the washing water is neutral. Sometimes, biodisel is purified by gently washing with warm water to remove residual catalyst. , dried, and sent to the storage. This is shown in Fig 4.

The environmental impacts of biodiesel production are 6.33×10^{-4} Pt. (42.21%) per liter. The major impacts are soil toxicity, aquatic eutrophication, radioactive waste, and global warming. These environmental impacts are primarily the result of the chemical (methanol) which is used in transesterification to biodiesel.

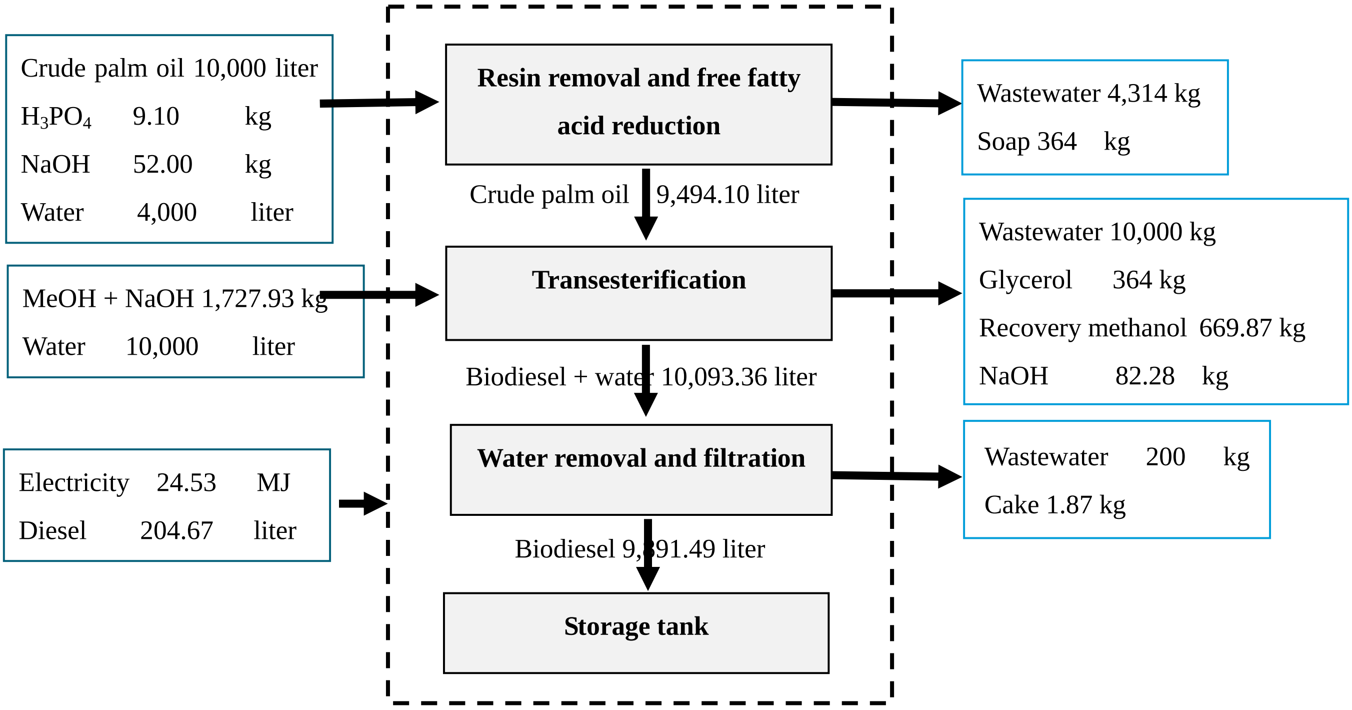

Fig 4. Flow diagram of mass and energy transesterification into biodiesel.

4.3. Utilization process

The use experiment was performed using Toyota Hilux Tiger 2.5 liter engines. Results are shown in Table 3.

Table 3 Emissions from diesel engine combustion

Emission	Quantity				Standard*
	1	2	3	Avg.	
THC (g/km)	0.681	0.673	0.667	0.674	-
NOx (g/km)	1.132	1.115	1.118	1.122	0.25
CO (g/km)	0.503	0.512	0.518	0.511	0.5
PM (mg/km)	0.160	0.154	0.152	0.155	0.025

Source: Research & Technology Institute of PTT Public Co., Ltd. (2005).

* Standard of Euro 4 for diesel engine

The environmental impacts of biodiesel utilization are 8.00×10^{-4} Pt. (52.09%) per liter. The major impacts are ozone formation, terrestrial eutrophication, aquatic eutrophication, and acidification. The environmental impacts take place from the emissions of CO and NO_2 during combustion.

The yearly net energy consumption of each part of the biodiesel production process is shown in Fig 5. The process shows biodiesel production has the highest average energy consumption, and agriculture the lowest. The energy consumption for the transportation phase is combined with agriculture, because sites have to transport products less distances. The specification of engines used for palm oil extraction is combined with the biodiesel production phase. Although the biodiesel production process does not use energy from fossil fuels, electric power in the form of electricity obtained from the central power source, some of which is fueled by palm fiber. Some electricity is also recovered from the turbine in the company.

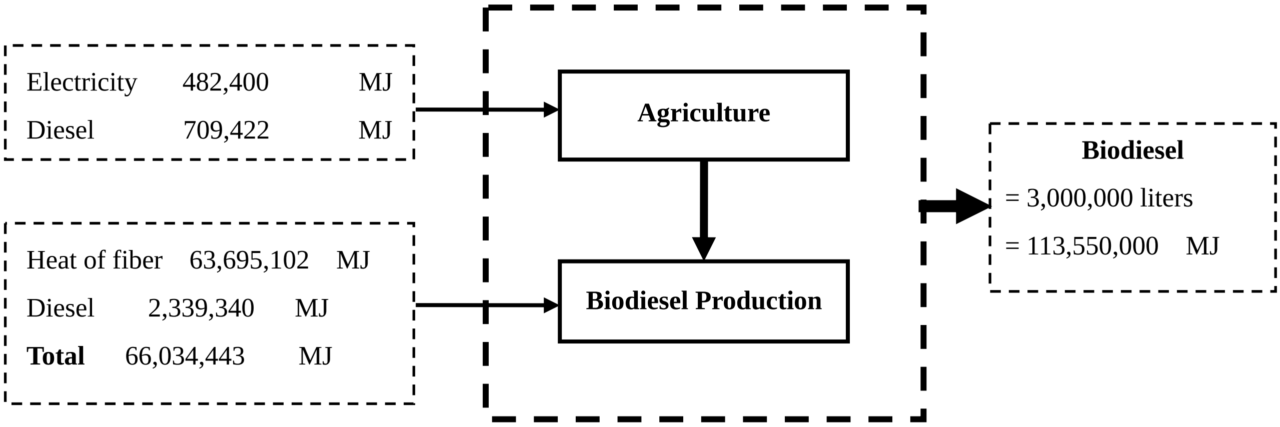

Fig 5. Yearly energy consumption by each process to produce biodiesel.

This study is based on energy consumption per liter of 22.41 MJ. Palm oil biodiesel has 37.85 MJ of heating value per liter. Therefore, the energy balance (energy out / energy in) is
37.85 / 22.41, this is equal to 1.69.

A comparison of energy requirements shows that:

• for each MJ of palm oil biodiesel production required, 0.59 MJ is required.

• for each MJ of fossil diesel produced, 1.26 MJ is required.

(From: http://www.esru.strath.ac.uk/EandE/Web_sites/02-03/biofuels/why_lca.htm)

Fossil diesel thus requires more energy to produce than it has available within it. Biodiesel, on the other hand, contains more energy than is required to produce it.

For a life cycle inventory (LCI), palm oil biodiesel production needs many kinds of materials. These can be grouped into two main processes; 1) agriculture process and 2) biodiesel production process. In agriculture process the high potential inputs are fertilizer, pesticides, and energy for water pumping in the nursery. In the biodiesel production process, chemical reagents and energy are the significant inputs. The amounts of materials and energy are shown in Table 4.

Table 4 Total materials and energy from the life cycle of palm oil biodiesel production, per 1 liter

Materials	Agriculture	Biodiesel Production
Fresh fruit bunches (kg)	5.65	-
Crude palm oil (kg)	-	0.96
Biodiesel (kg)	-	0.83
Methanol (kg)	-	0.20
Diesel (kg)	0.004	0.015
Phosphoric acid (kg)	-	0.007
Sodium hydroxide (kg)	-	0.002
Nitrogen (kg)	0.036	-
Phosphate (kg)	0.008	-
Glyphosate/Pesticide (kg)	0.0002	-
Electric from palm fiber (MJ)	-	21.26
Electricity from grid (MJ)	0.16	-

Table 5 indicates that the utilization process contributes to the highest environmental impact, which is 24.01×10^2 Pt. in total. The environmental impacts of production and agriculture are 19.00×10^2 Pt. and 3.09×10^2 Pt., respectively.

Table 5 Environmental impact from each process per year

Process	Unit	Impact	Percentage
Agriculture	Pt	3.09×10^2	6.70
Production	Pt	19.00×10^2	41.21
Utilization	Pt	24.01×10^2	52.09
Total	Pt	**46.1×10^2**	**100**

Table 6 The comparison of environmental impact between palm oil biodiesel and jatropha biodiesel per 1 liter

Process	Unit	Palm oil biodiesel	Jatropha biodiesel [6]
Agriculture	Pt	1.03×10^{-4}	2.59×10^{-3}
Production	Pt	6.33×10^{-4}	1.44×10^{-3}
Utilization	Pt	8.00×10^{-4}	1.76×10^{-3}
Total	Pt	1.54×10^{-3}	5.79×10^{-3}

5. Conclusions

Biodiesel from palm oil may have a significant adverse impact on the environment if its production is not managed properly. The results of this study show the environmental impact has the greatest of palm oil biodiesel in Thailand.

This indicates that the utilization phase has the greatest environmental impact, about 52.09% of the total. Production of biodiesel and agriculture procedures equal 41.21% and 6.70%, respectively. The comparison of palm oil biodiesel with the diesel fuel are show in Fig 6, in utilization phase the GWP can be decreased from 2.70 to 0.04 kg CO_2 eq per 1 liter

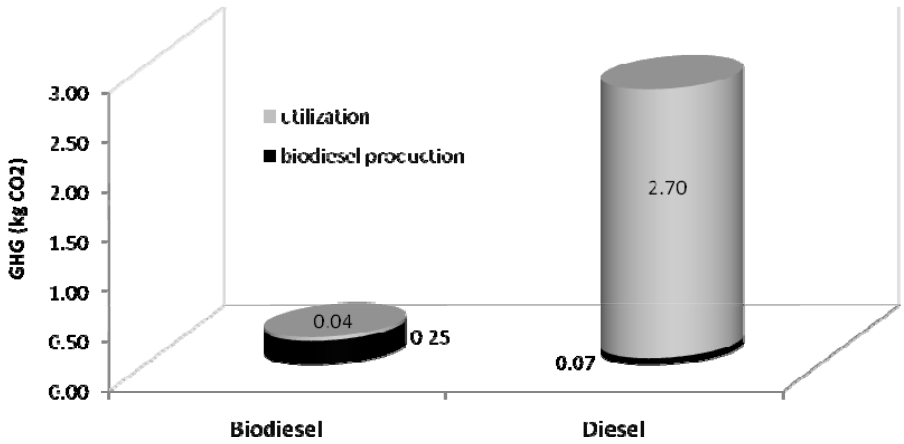

Fig 6. The comparison of GWM from palm oil biodiesel with the diesel fuel

These impact values of the utilization phase could be lower if more efficient engines were used. The energy consumption per 1 liter was calculated at 22.41 MJ, with an energy balance of 1.69. Thailand has great potential for biodiesel production from palm oil. Palm oil could provide higher yields, and still be environmentally friendly.

A combination of clean technology, industrial ecology and appropriate waste treatment would be a good approach to the improvement of the current environmental performance. Future shortages of petroleum supplies and surging prices for petroleum-based fuels should help make biodiesel production in Thailand more economically sustainable.

The results indicate that the overall system of palm oil biodiesel production in Thailand can lead to gain or loss of fossil energy depending on several factors inside the system, i.e. types of fuel used and types of chemical in biodiesel production process and efficiency of technology.

6. Life cycle improvement

Agriculture: Should provide new research to increase yield. Should study land use in the life cycle assessment of oil palm in Thailand.

Biodiesel Production: (1) The replacement of methanol by bio-ethanol (2) alcohol recovered from glycerin purification which is re-used and used as distillation equipment and (3) energy recovered from biogas in wastewater treatment at the palm oil mill.

Utilization phase: Should test various alternative engines.

Wastewater: The average quantity of wastewater generated from a CPO mill in Thailand amounts to 0.33 m^3/ton FFB, or around 330 m^3/year. This wastewater contains a high concentration of organic and suspended matter, which should be utilized for biogas production. Results from the measurements at one of the studied factories showed that the composition of the gas generated in the first anaerobic pond is about 71% methane and 29% CO_2. It is estimated that biogas generation would amount to 0.3 m^3/kg BOD.

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