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LIFE CYCLE ASSESSMENT (LCA) FOR THE PRODUCTION OF PALM BIODIESEL: A CASE STUDY IN MALAYSIA AND THAILAND

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ABSTRACT

Energy supply and its security issues have been a hot topic recently. Consequently, the search for alternative fuel sources is receiving much attention and biodiesel is one of the most promising where palm oil is the main feedstock for the industry. This present study compared the environmental impact resulting from the production of biodiesel in Malaysia and Thailand using the life cycle assessment method (LCA). Different scenarios that influenced the development of the biodiesel industry in the two countries were the main focus of the study. Malaysia as the world's second largest producer and exporter of palm oil and the initiatives taken by the Thai government have greatly influenced the development of the industry. The LCA includes the phase of raw material extraction (oil palm cultivation, fresh fruit bunch processing and refining of crude palm oil), and the biodiesel processing phase (transesterification process). The functional unit was the production of 1 metric tonne of biodiesel, and the life cycle impact assessment (LCIA) was determined using the SimaPro 7.2 software through the Eco-indicator 99 method. LCIA showed that the production of biodiesel in Thailand recorded higher impact values ($2.53\ 10^{-3}$ DALY for human health, 109.20 PDFm^2 yr for ecosystem quality and 3497 MJ surplus for resource depletion) compared to those of Malaysia ($6.89 \cdot 10^{-4}$ DALY, 34.87 PDFm^2 yr and 1628 MJ surplus). The use of higher quantities of fertilizers and pesticides for the oil plam cultivation process in Thailand influenced the impact values obtained compared to those in Malaysia.

Key words: biodiesel, palm oil, Life Cycle Assessment

INTRODUCTION

The escalating prices of petroleum in the world market, coupled with the diminishing levels of fossil fuel reserves, have raised concern regarding the need for renewable energy sources. The majority of the world's energy needs are obtained from petro-chemical sources, coal and natural gas. All of these sources are nite and at the current usage rate, will be exhausted in the near future (Meher *et al*., 2006). Furthermore, the utilization of fossil fuels triggers a substantial amount of greenhouse gas (GHG) emission, which subsequently pollute the environment due to the huge amount of gasses and particulates released by diesel engines (Kim *et al*., 2004). Hence, the quest for a renewable and environment-friendly source of energy has become inevitable for a sustainable future.

One of the renewable energy sources that have been getting a lot of attention lately is biodiesel, which exhibits similar properties to the petroleum-derived diesel. The increasing acceptance of biodiesel as an alternative and renewable source to replace fossil diesel is mainly due to environmental policies regarding reduction of carbon dioxide emission which is the known culprit of global warming and greenhouse effects (Yap, 2006). Biodiesel fuel is a mixture of mono-alkyl esters of long chain fatty acids (FAMEs) (Meher *et al*., 2006). Transesterication (alcoholysis) is the proposed method for biodiesel production (Kim *et al*., 2004; Ramadhas *et al*., 2005). The process involves a chemical reaction between triglycerides and alcohol in the presence of an alkaline liquid catalyst, namely sodium or potassium methoxide to produce fatty acid monoesters.

From various oil sources used as the feedstock in biodiesel production plants, palm oil has been reported to be the most promising option (Sani, 2009). Palm oil has the potential to fulfill the high demand for biodiesel in the world market due to its production rate and high oil content compared to other oilseeds (Sumathi *et al*., 2008). Malaysia is currently the world's second largest producer of

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palm oil (after Indonesia), supplying about 12.8% of the global consumption of vegetable oils in 2009 and it is imperative that Malaysia emerges as one of the pioneers in the palm biodiesel industry (Puah *et al*., 2010). With the advantage in terms of raw material supply, Malaysia is taking pro-active steps to develop strategies to expand and enhance the biofuel industry in the country (Lim and Teong, 2009). The palm oil-based B5 biodiesel programme began on the 1st of June, 2011 in Putrajaya. With its introduction, Malaysia has become the second country to implement the use of B5 (Indonesia has been using it since 2006 in selected cities and provinces), which is superior to the mandatory B2 blend which Thailand has used since April 2008.

The Thai government introduced the National Energy Policy in 2006 with emphasis on renewable energy sources such as biodiesel and bioethanol, in an effort to reduce the use of fossil fuels. In 2010, about 42% of crude palm oil produced in Thailand was used to produce biodiesel. This emphasizes biodiesel as a key enabler of crude palm oil demand, especially after the change in policy on the use of biodiesel from B2 to B5 was implemented in 2011.

It has been reported that such large-scale utilization of palm oil to produce biofuel would cause deforestation, which in turn would lead to possible loss of one of the world's largest natural carbon sink (Wakker, 1998). In some reports, the production of biodiesel is described as creating more problems instead of solving the existing environmental problems. Hence, a systematic approach to investigate all upstream and downstream processes or cradle-to-grave analysis of palm biodiesel is important to validate the benefits or 'cleanliness' of this so-called 'green energy'. One of the methods that can be used to assess the environmental merits and demerits of a product is the life cycle assessment (LCA), which entails a complete evaluation and analysis of a product throughout its lifespan (Burgess and Brennan 2001; Malgorzata, 2003).

The aim of the present study is to compile and compare the inventory input and output involved in the production of biodiesel from palm oil, in a case study carried out in Malaysia and Thailand. In addition, it will also evaluate and compare the associated potential environmental implications from the processes used in Malaysia and Thailand with the help of the life cycle impact assessment method called Eco-Indicator 99.

METHODOLOGY

The methodology can be divided into two sections *i.e* the method of obtaining data for the LCA and the LCA methods based on MS ISO 14040 standards.

Data collection

The data was collected based on the LCA scope and purpose of the study. The foreground data was obtained from responses to questionnaires, observations, and communication by telephone and through interviews. Questionnaires and request letters were sent to 12 biodiesel manufacturers (for the transesterification process) in Malaysia, but only two responded. Site visits were made to the two factories located at Selangor and Sabah, but only one (the factory in Sabah) responded to the questionnaires.

For the raw material extraction phase (oil palm cultivation, fresh fruit bunch processing and crude palm oil refining), questionnaires were distributed only to the biodiesel manufacturers. The same process was carried out in Thailand for both the raw material extraction phase and biodiesel processing. Data gaps were filled by information obtained from scientific literature, public databases and the SimaPro library database.

Method of conducting LCA Analysis

The LCA method consists of four main components namely Goal and Scope, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and Interpretation.

Goal and scope: This study determines the associated potential environmental implications from the processes involved in the production of palm from biodiesel a case study conducted in Malaysia and Thailand using the Eco-Indicator 99 method. The methodology used is aimed at identifying and quantifying inventory input and output released to the environment in all the processes. The data obtained through detailed LCI is then calculated to determine the environmental impact.

The scope includes the system boundaries and functional units of the study. The system is defined by a cradle-to-gate approach, starting from the oil palm cultivation, fresh fruit bunch processing and crude palm oil refining until the transesterification process. The transportation and the end-of-life stages had to be excluded from the study due to the lack of data. The complete system investigated is shown in Figure 1.

Life Cycle Inventory (LCI)

The inventory analysis compiles all resources and emissions that are released by the specific system under investigation and relates them to a functional unit (ISO, 1997). The LCI data for palm biodiesel production in Malaysia and Thailand were obtained through questionnaires disseminated to the biodiesel factories. Table 1 shows the LCI data for one metric tonne of palm biodiesel production.

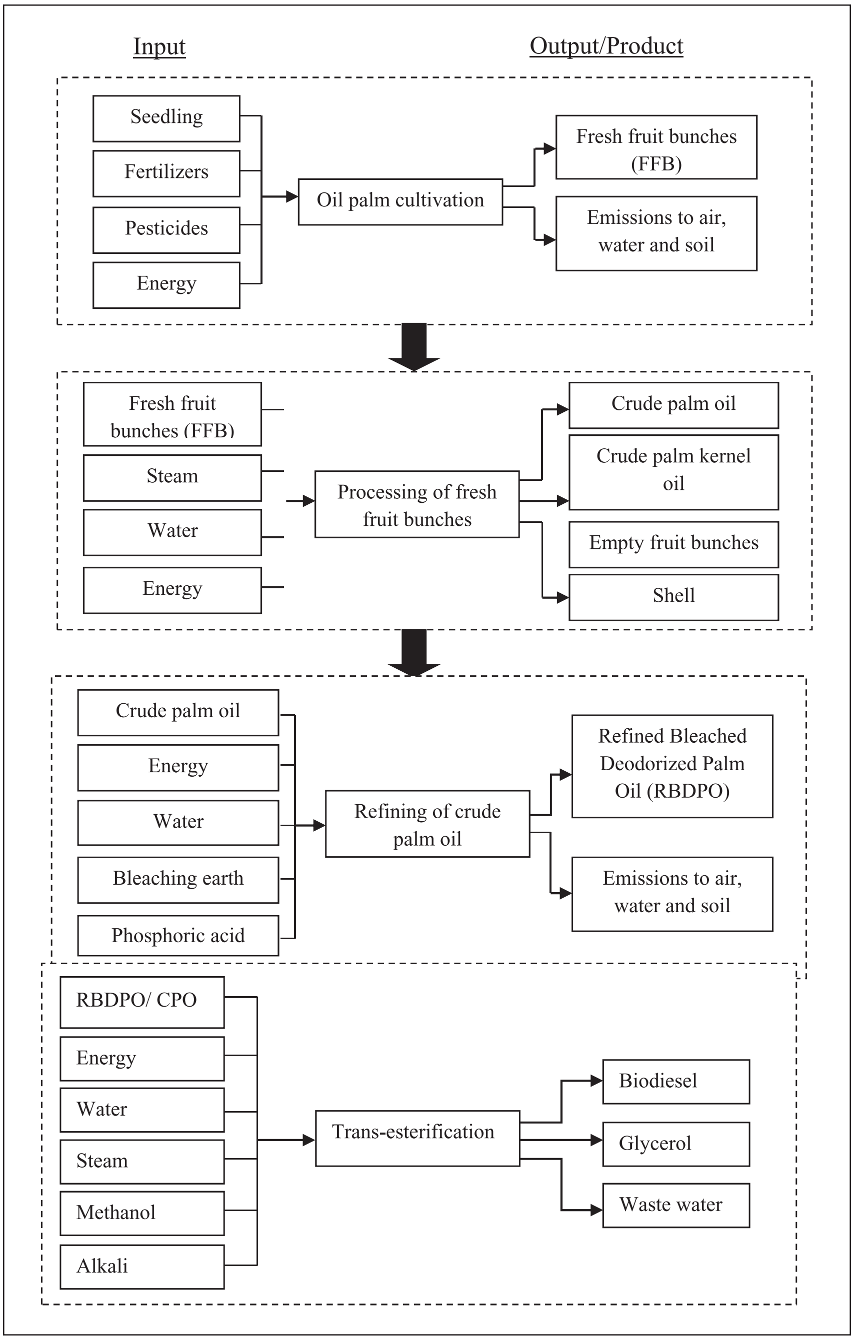

Fig. 1. System boundaries for palm biodiesel production.

Based on the observed data (Table 1), the oil palm cultivation process involved the use of fertilizer inputs, pesticides, minerals (calcium carbonate) and diesel for transportation (within the farm), where the quantity of inputs used in Thailand was higher than that in Malaysia. However, the type and quantity of inputs used were different in the two countries. The main product from each process becomes the input for the next process. Each process was interdependent and related to the others. In general, the inputs of electricity, water and steam were the main inputs used for each process (in two phases) in the production of palm biodiesel in Malaysia and Thailand. The electricity used was quantified in units of watts per hour.

Life Cycle Impact Assessment

Life Cycle Impact Assessment (LCIA) is the third stage of the LCA process that involves identifying and classifying the potential impact on the environment by the system used in the study (ISO, 2006). The 'Eco-Indicator 99' from the SimaPro software was used to analyze the impact. In the Eco-Indicator 99 method, impacts were classified into 11 categories and divided into three areas of protection

Table 1. Inventory for the production of 1 metric tonne of palm biodiesel in Malaysia and Thailand

Input item	Unit	Amount	
		Malaysia	Thailand
Oil Palm Cultivation			
Ammonium sulphate (N)	Kg	6.30	44
Diammonium phosphate (P)	Kg	1.28	12
Potassium chloride (K)	Kg	9.46	31
Magnesium carbonate (Mg)	Kg	3.24	–
Magnesium sulphate (Mg)	Kg	–	8
Boron trifluoride (B)	Kg	–	0.50
Organophosphorus compound	Kg	$4.05\ 10^{-2}$	–
Thio-carbamate compound	Kg	$2.04\ 10^{-2}$	–
Phenoxy compound	Kg	$5.83\ 10^{-3}$	–
Pyrethroid compound	Kg	$2.88\ 10^{-3}$	–
Benzimidazole compound	Kg	$3.72\ 10^{-5}$	–
Glyphosate	Kg	$1.14\ 10^{-4}$	0.40
Paraquat	Kg	–	0.20
Calcium carbonate	Kg	1.72	5.50
Diesel	Kg	3.90	3
Fresh Fruit Bunch (FFB) Processing			
Fresh fruit bunches	Kg	5270	5260
Diesel	Kg	3.76	3
Electricity	kWh	108.43	100
Steam	Kg	2660	2500
Water	Kg	3422.50	3500
Crude Palm Oil Refining			
Crude palm oil	Kg	1000	–
Electricity	kWh	6	–
Water	Kg	180.19	–
Phosphoric acid	Kg	0.50	–
Bleaching earth	Kg	10	–
Transesterification Process			
Crude palm oil/Refined palm oil	Kg	1036.27	1140.04
Electricity	kWh	215	256.50
Water	Kg	315	200
Steam	Kg	270	270
Methanol	Kg	114	150.11
Sodium metoxide	Kg	5	–
Sodium hydroxide	Kg	1	8
Hydrochloric acid	Kg	13.20	–

Table 2. Classification of impacts based on damage category

Damage Category	Unit	Impact Category
Human Health	DALY	Carcinogens, respiratory organic, inorganic respiratory, climate change, radiation, ozone depletion
Ecosystem Quality	PDF m^2 yr	Eco-toxicity, acidification/ eutrophication, land use
Resource Depletion	MJ surplus	Mineral and fossil fuel

i.e human health, ecosystem quality and resource depletion (Table 2).

RESULTS AND DISCUSSION

Oil palm cultivation: Figures 2 and 3 show the weighted results for oil palm cultivation with relative contribution from the inputs in Malaysia and Thailand. The characterized results were weighted using the weighting factors in the Eco-Indicator 99 method.

The input of ammonium sulphate as the N fertilizer was found to be the major contributor to the resulting impacts in both countries, followed by diammonium phosphate (P fertilizer). However, the

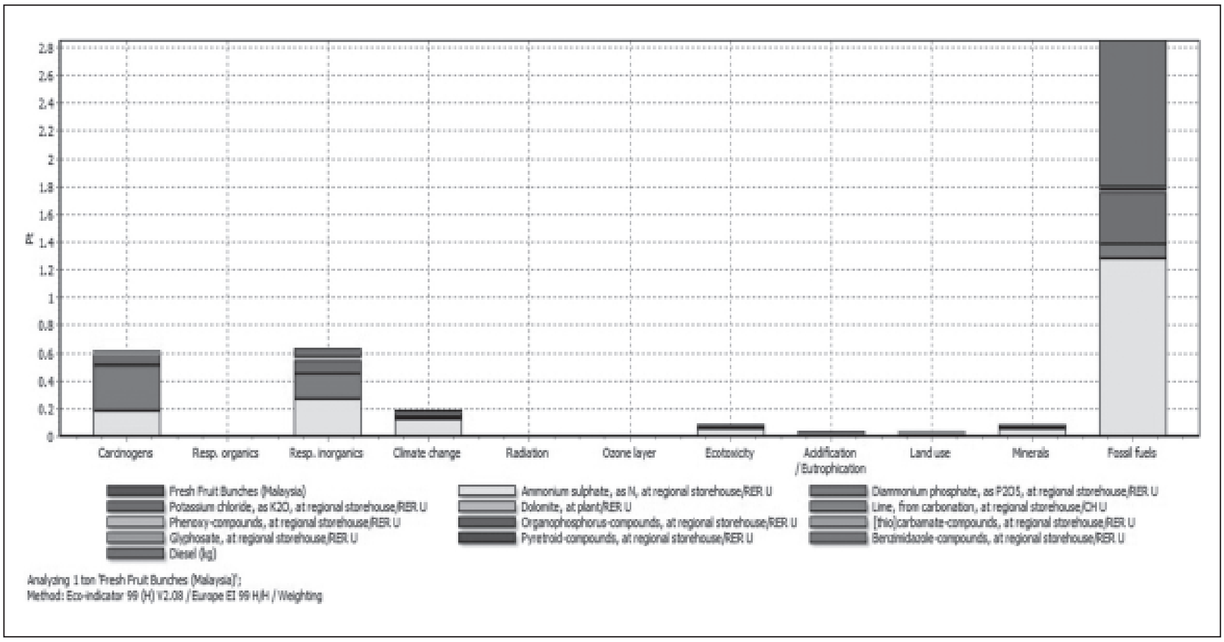

Fig. 2. Weighted results for the production of 1 tonne fresh fruit bunches in Malaysia.

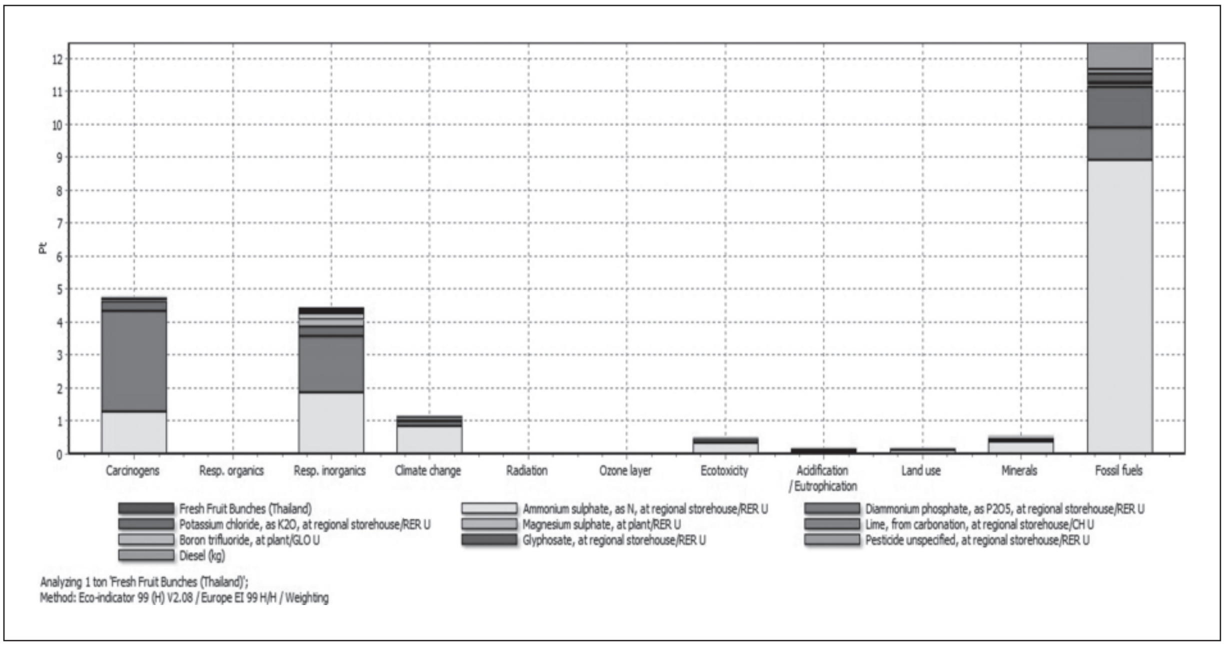

Fig. 3. Weighted results for the production of 1 tonne of fresh fruit bunches in Thailand.

weighted values recorded in Malaysia and Thailand was different, as Thailand recorded higher values for all impact categories (compared to Malaysia).

The weighted results showed that the categories with significant impact were from fossil fuels, respiratory, inorganics and carcinogens in both Malaysia and Thailand. These impact categories were related to air emissions while the acidification/ eutrophication impact category was related mainly to water emission. The impact from the 'fossil fuels' category came from the production of the various fertilizers as well as diesel usage for transportation within the plantation areas. From the data obtained through questionnaires, fertilizers are essential in the production of healthy oil palm fruits where they are manually applied. The total amount of fertilizers needed to produce 1 metric tonne of fresh fruit bunches in Malaysia was 6.30 kg (N), 1.28 kg (P) and 9.46 kg (K), while in Thailand, the amount of fertilizers needed was much higher being 44 kg (N), 12 kg (P) and 31 kg (K).

The difference in the type and quantity of fertilizer used in Malaysia and Thailand were determined by the quality of the planting area in both countries. In Thailand, most of the oil palm cultivation areas are of poor quality due to meteorological factors such as low annual rainfall of around 1500 to 2000 mm per year and that influenced the soil moisture content (Mhanmad *et al*., 2011).

Generally, the use of ammonium sulphate (N) fertilizer releases nitrous oxide gas that can affect the human lung function and cause respiratory diseases such as asthma and bronchitis (Bhat and Ramaswamy, 1993). In addition, nitrous oxide gas has the potential to cause global warming 296 times higher than that of carbon dioxide thus contributing to the climate change impact category (Prather and Enhalt, 2001).

Pesticide usage in palm cultivation in Malaysia and Thailand, had insignificant impact values due to low usage quantities. Pesticide inputs contributed mostly to the eco-toxicity impact category while acidification was caused by the release of ammonia into the air and leakage of nitrate into groundwater.

Processing of fresh fruit bunches: The weighted results for the processing of fresh fruit bunches in Malaysia and Thailand mirror the impacts seen in the production of crude palm oil (Fig. 4 and 5). In both Malaysia and Thailand, fossil fuel was found to be the major impact category, followed by respiratory (inorganics) and carcinogens.

The impact categories of respiratory (inorganic) and fossil fuels originate from activities associated with plantation procedures such as the production and application of fertilizers and fuel used for transportation of materials within the plantation area. Regarding the activities in the processing of fresh fruit bunches, the environmental impact was insignificant. A minor contribution to the production of crude palm oil can be attributed to the use of electricity and water.

In the case of climate change, the impact was contributed from the emission of biogas by the palm oil mill effluent (POME). Usually, the fresh fruit bunch processing plant uses aerobic and anaerobic ponds to treat waste water generated during the process of producing crude palm oil. In Thailand and Malaysia, the quantity of waste water produced is 2.6 m^3 per tonne of crude palm oil produced.

The treatment process of waste water will result in the release of greenhouse gases into the atmosphere. POME in the anaerobic treatment ponds produces biogas containing methane, carbon dioxide and hydrogen sulfide (Ma *et al*., 1999). According to Chavalparit *et al*. (2006), 1 m^3 of waste water in the anaerobic ponds produces 20 m^3 of biogas containing 70% methane and 29% carbon dioxide. However, the POME obtained can be used to replace fertilizer in oil palm plantations. The biogas produced from POME is suitable for use as fuel. The application of biogas as fuel is still low due to the lack of infrastructure and demand for the fuel. Malaysia is currently moving towards either harnessing biogas from POME, or producing value added products such as fertilizer from POME which will eliminate the generation of methane gas (Basri *et al*., 2008). The impact category of climate change in Thailand registered the weighted value of 4.03 Pt, whereas in Malaysia the value was 0.66 Pt.

In Malaysia, electricity was also produced from steam using the mesocarp fiber as fuel for heating water in the boiler which in turn produced steam to generate electricity for the milling process. The use of biomass as fuel to produce electricity causes the release of gases such as carbon monoxide, nitrogen oxides and particulate matter where the level of pollution by these substances sometimes exceeds the emission level of burning coal or natural gas (Zhang and Smith, 2007). These gasses contribute to the climate change impact category.

For the fresh fruit bunch processing, the amount of fresh fruit bunches used in Thailand was 5260 kg, lower by 10 kg compared to that in Malaysia with the amount of 5270 kg. The quantity of fresh fruit bunches used to produce crude palm oil depended on the oil extraction rate (OER) and capacity of the plant. A palm oil processing plant with high OER requires lower amounts of fresh fruit bunches. This means that the FFB processing plant in Thailand has a higher OER, but the impact generated for the processing of fresh fruit bunches was still higher than that in Malaysia.

Refining of crude palm oil: Based on the weighted results for producing 1 tonne RBDPO (Fig. 6), the significant impact categories are fossil fuels, respiratory (inorganic) and carcinogens. For the impact category of fossil fuels, the weighted value recorded was 9.99 Pt, for respiratory inorganic it was 2.44 Pt and for carcinogens, 2:03 Pt.

In the production of RBDPO, the impacts were mainly associated with upstream activities at the oil palm plantation and the palm oil mill. The upstream impacts resulting from fresh fruit bunches and crude palm oil production were channeled down to the production of RBDPO, while the activities that were confined to the production of RBDPO were found to have a minor impact on the environment in comparison.

The main contributor to the fossil fuel category was the production and use of fertilizers in the cultivation of the oil palm, with minor inputs from

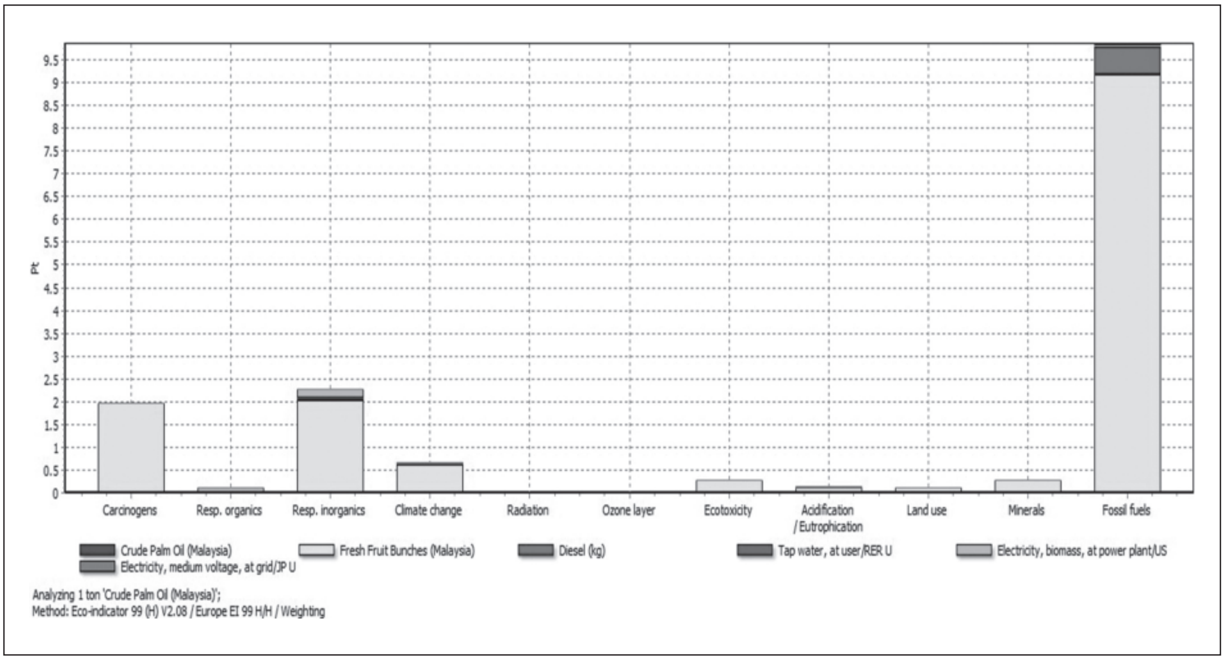

Fig. 4. Weighted results for the processing of fresh fruit bunches in Malaysia.

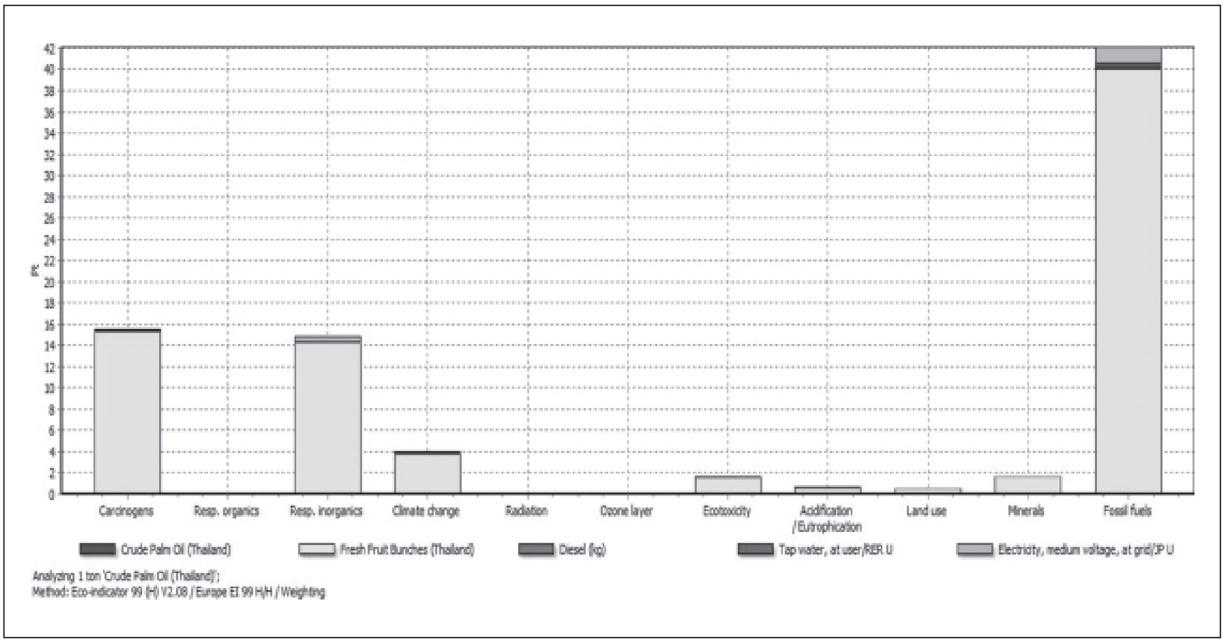

Fig. 5. Weighted results for the processing of fresh fruit bunches in Thailand.

the refining process. In addition, the use of electricity from grid, and the bentonite that was used as the bleaching agent also contributed to the impact. The hotspots in relation to respiratory inorganics were mainly from upstream activities, namely the application of nitrogen as fertilizers in the cultivation of the palms, and the emission of carbon dioxide, methane and hydrogen sulphide from the POME ponds at the mill.

The transesterification process: Transesterification is the final process in the production of palm biodiesel. For the production of biodiesel from the transesterification process, the weighted results using the Eco-Indicator 99 showed that the significance of the impacts were in the following order i.e fossil fuels, respiratory inorganics and carcinogens.

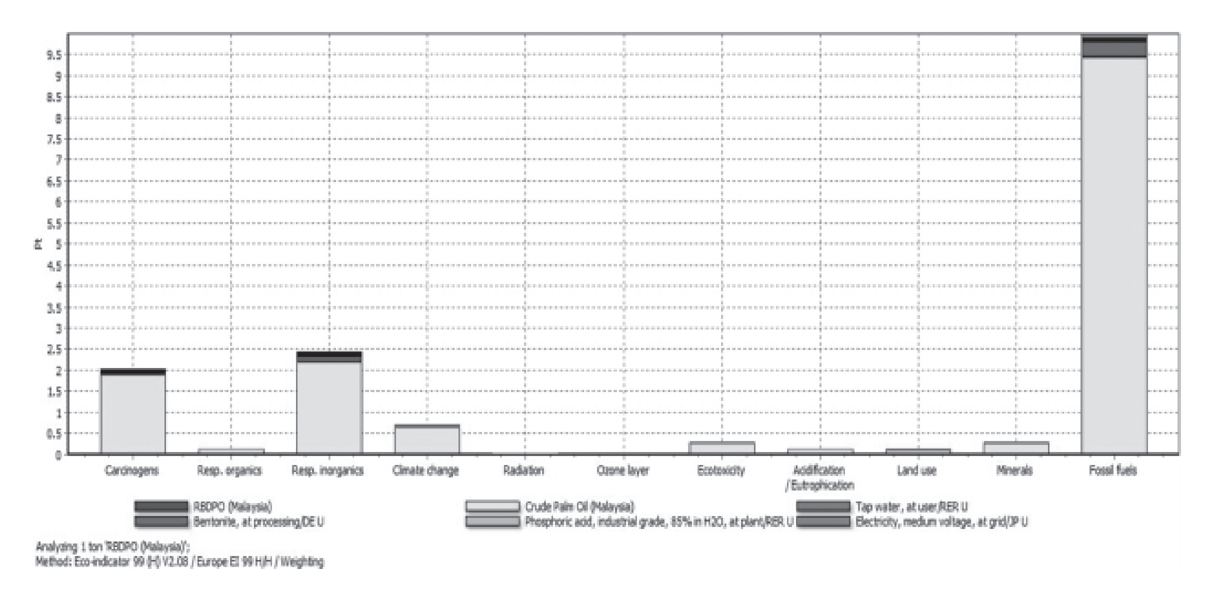

Fig. 6. Weighted results for crude palm oil refining in Malaysia.

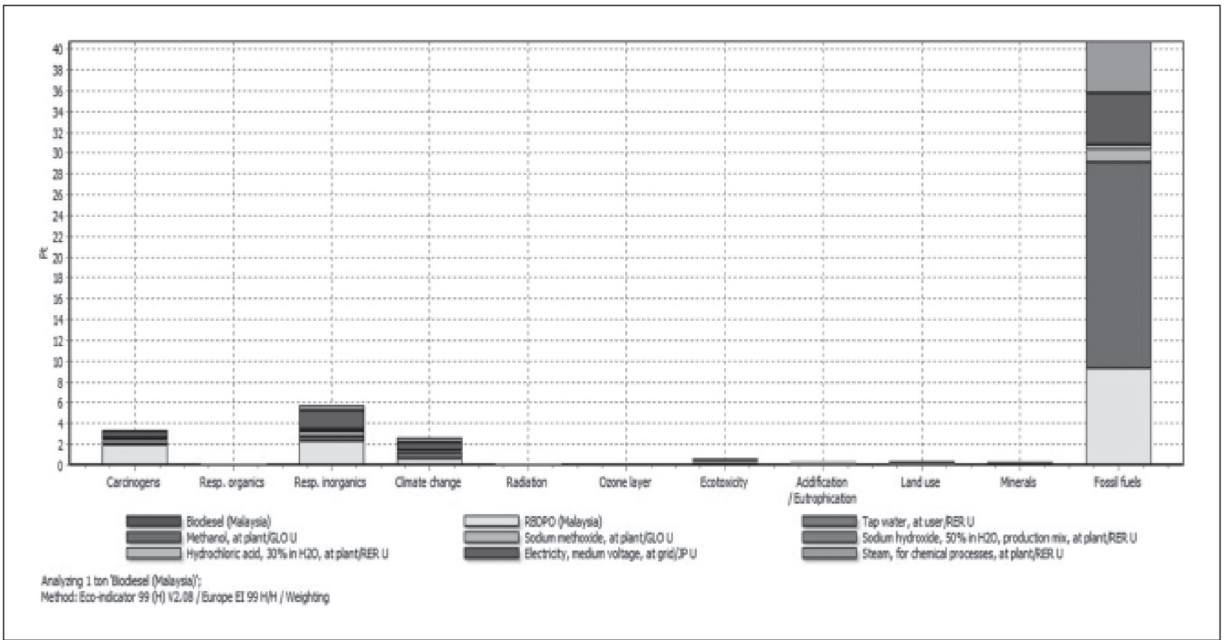

Fig. 7. Weighted results for the transesterification process in Malaysia.

The impact on fossil fuels was due to the use of non-renewable sources of materials, such as methanol which is produced from natural gas and fuel oil for the boiler to generate steam. The use of fossil fuels to generate steam during the transesterification process also effected the release of gasses such as carbon dioxide, sulfur dioxide and nitrogen dioxide, which can affect human health (Dermibas, 2007). The impact on respiratory inorganics is associated with emissions to the atmosphere, and therefore caused by emission from the boiler.

Compared to Malaysia, in the transesterification process in Thailand sodium methoxide was not used as an input. Sodium methoxide is toxic and volatile and contributed to the respiratory inorganic impact category. According to Vicente *et al*. (2004), sodium metoxide has major effects on the respiratory and nervous systems.

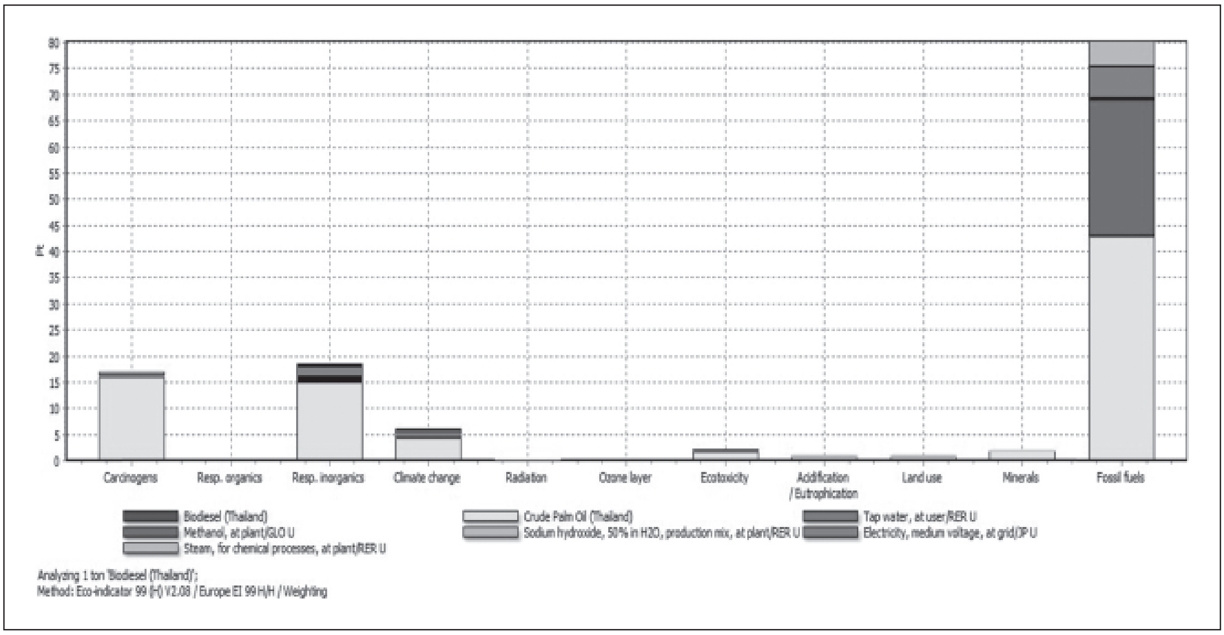

Fig. 8. Weighted results for the transesterification process in Thailand.

Table 3. Total impacts for palm biodiesel production in Malaysia and Thailand

Damage Category	Unit	Impact value	
		Malaysia	Thailand
Human health	DALY	$6.89\ 10^{-4}$	$2.53\ 10^{-3}$
Ecosystem quality	PDF m^2 yr	34.87	109.20
Resource depletion	MJ surplus	1628.00	3497.00

The use of water in the transesterification process in Malaysia and Thailand is to wash the methyl ester before the drying process in the production of biodiesel. The input of water recorded insignificant impact values for all the impact categories. However, waste water discharged from this process was one of the outputs released into the environment.

Generally, the waste water discharged during the transesterification process was less polluted. The content of chemical oxygen demand (COD) in this waste water was between 15,000 to 30,000 mg liter^{-1} and for the biochemical oxygen demand (BOD), the range was between 10,000 to 20,000 mg liter^{-1}. The waste water also contained substances such as sodium hydroxide and methanol. Water treatment and waste water recycling methods were used to reduce the amount of waste water discharged into the environment (Tongurai *et al*., 2001).

The main difference between the transesterification process in Malaysia and Thailand was the raw materials used. Malaysia used RBDPO as the raw material while Thailand used CPO. This meant that in Thailand, the process of crude palm oil refining was not involved in the palm biodiesel production. The type and quantity of inputs used were also different between in the two countries, as sodium methoxide and hydrochloric acid were not used as inputs in Thailand.

Comparison of palm biodiesel production in Malaysia and Thailand: Table 3 summarizes the total impacts of palm biodiesel production in Malaysia and Thailand, which include the raw material extraction phase (oil palm cultivation, fresh fruit bunch processing and crude palm oil refining) and the biodiesel processing phase (transesterification process). The total impacts were analyzed using the Eco-Indicator 99 method from the SimaPro 7.2 software. Inventory of each process was characterized into 3 damage categories, and the total impact values of palm biodiesel production in Malaysia and Thailand were compared.

Comparing the overall impact of the production of palm biodiesel in Malaysia and Thailand, it can be seen that in Thailand higher impact values were recorded for all damage categories: 2.53 10^{-3} DALY (human health), PDF 109.20 m^2 yr (ecosystem quality) and 3497 MJ Surplus (resource depletion category). The impact values for biodiesel production in Malaysia were 6.89 10^{-4} DALY for human health damage category, PDF 34.87m^2 yr for ecosystem quality and 1628 MJ surplus for resource depletion.

The difference in impact values for Malaysia and Thailand was influenced by various factors especially the type and quantity of inputs, as well as the techniques used. The application rate of fertilizers for oil palm cultivation has affected the resulting impacts of the process itself and the entire processes involved in palm biodiesel production for both countries.

CONCLUSION AND RECOMMENDATIONS

The results obtained from the study reflect the relationship between the type and quantity of inputs used and their influence on the environmental impacts generated in the production of palm biodiesel in Malaysia and Thailand. Thailand recorded higher impact values for all the damage categories compared to those in Malaysia. The major hotspots identified in the palm biodiesel production in Malaysia and Thailand were the fossil fuels, respiratory inorganic and carcinogen impact categories from the use of N fertilizer in oil palm cultivation and energy for electricity.

The emissions from the production and application of fertilizers are unavoidable as fertilizers have to be used in oil palm cultivation. Improvement options exist to mitigate the environmental burden, which among others are, the application of more sources of organic fertilizers and increasing the yield of FFB. Increasing the yield of FFB can be achieved by planting the latest high yielding and improved oil palm planting materials which have the potential for higher fruit production. Much improvement can also be obtained by disseminating information and to educate the growers on the best management practices. Returning the nutrient-rich slurry from the POME treatment ponds to the field will help reduce nitrous oxide emission from inorganic fertilizer application.

As the LCA procedure is an interactive process, the different stages in the palm oil supply chain have to be re-evaluated more efficient data collection to increase the reliability of the LCA results for each interaction. Data collected for the LCI in the present study represents only a snapshot for the period of the study, and is therefore in need of regular updating. A better alternative to achieve the best environmental performance in the production of CPO is to capture the biogas at the POME anaerobic ponds and to use to generate renewable energy.

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