LIFE CYCLE ASSESSMENT FOR THE PRODUCTION AND USE OF PALM BIODIESEL (Part 5)

PUAH CHIEW WEI*; CHOO YUEN MAY* and MA AH NGAN**

ABSTRACT

In Malaysia, the major consumers of energy are the industrial and transport sectors. The demand is expected to increase steadily in tandem with the growth of the economy. As such, alternative sources of energy need to be developed, in particular energy from renewable sources, to meet the energy requirements. Fatty acid methyl esters, commonly known as biodiesel, derived from oils and fats have long been known as a potential diesel substitute. Biodiesel is suitable to be used neat or blended with petroleum diesel in any proportion in an unmodified diesel engine. However, the many concerns related to the emissions from the production and use of biodiesel have been discussed globally. Thus, this life cycle assessment study was conducted to investigate the environmental impacts from the production and use of palm biodiesel produced using MPOB's production technology. The results show that the environmental impact from the production of palm biodiesel is related to the use of methanol, while the use of palm biodiesel contributes to the impact categories of respiratory inorganics and acidification/eutrophication. In spite of these, the production and use of palm biodiesel is more environmental-friendly as compared to petroleum diesel.

Keywords: biodiesel, environment, palm oil, sustainability.

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INTRODUCTION

The increase in energy demand worldwide and diminishing fossil fuel reserves have driven the development of sustainable alternative energy sources to progress at a faster pace to ensure energy security in every part of the world. To date, the most widely used renewable energy for transport is the first generation biofuel, namely biodiesel. Biodiesel is alkyl esters derived from vegetable oils and animal fats. Many pathways are available to produce biodiesel. However, commercially available biodiesel is mainly produced through the transesterification process using methanol in the presence of sodium hydroxide. In addition, this is the most economical approach as it requires only a low operating temperature and pressure, yields are high (>98% direct conversion to methyl ester) and achieved in a short reaction time. According to Freedman *et al.* (1984), the main advantage of an alkaline catalyst over an acid catalyst is the high conversion under mild conditions in a short reaction time. However, acid catalysts are suitable for esterification, especially for feedstocks with high fatty acids content.

The alternative approach is esterification of fatty acids and alcohols in the presence of a solid acid catalyst (Choo and Goh, 1987; Choo and Ong, 1989). Esterification can also be carried out continuously in a counter-current reaction column using superheated methanol (Kreutzer, 1984).

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Biodiesel can also be produced using supercritical methanol without any catalyst (Saka *et al.*, 1986). In addition, methanol is not the only alcohol that can be used to produce biodiesel. Thus, methyl ester is not the only ester that can be considered as biodiesel. Other alcohols, such as ethanol, butanol and propanol, can also be used. For the transesterification process, sodium hydroxide is also not the only catalyst that can be used. Other usable base catalysts include sodium methoxide and potassium hydroxide. Lipases are also potential substitutes as the catalyst.

Research and development of palm biodiesel in Malaysia has been carried out since the early 1980s. The key purpose in the development of palm biodiesel then was to provide a safety net to enhance and stabilize palm oil price in the country in times of over-supply of the commodity. The Malaysian Palm Oil Board (MPOB) has developed a patented technology for the production of palm biodiesel (Choo *et al.*, 1992). The process involves mild reaction conditions of transesterification to convert palm oil into palm biodiesel by methanol in the presence of a base catalyst. The palm biodiesel produced has been extensively evaluated through engine testing and exhaustive field trials with positive results, showing that palm biodiesel is a suitable diesel substitute (Choo *et al.*, 1995). MPOB's biodiesel production technology has been commercialized with plants operating in Malaysia, South Korea and Thailand. The biodiesel produced also meets the international specifications for biodiesel, such as the EN 14214 and ASTM D6751.

Today, the drivers for biodiesel development, besides enhancing commodity prices, are the provision of energy security, the mitigation of global warming and climate change. However, the many concerns related to emissions from the production and use of biodiesel have been debated by environmentalists worldwide. In some reports, biodiesel is described as creating more problems instead of solving the existing environment problems. In view of this development, this article discusses a life cycle assessment (LCA) study conducted by MPOB to provide a quantifiable measure to evaluate the environmental impacts from the production and use of palm biodiesel in Malaysia.

METHODOLOGY

System Boundary

Figure 1 shows the system boundary of LCA for the production and use of palm biodiesel. The production energy, raw materials and auxiliary materials were included as the inputs while the outputs included the products, by-product and wastewater. Subsequently, palm biodiesel is transported and used for combustion in diesel engine vehicles. The exhaust emissions due to the use of palm biodiesel in diesel engine vehicles were also taken into consideration for this study.

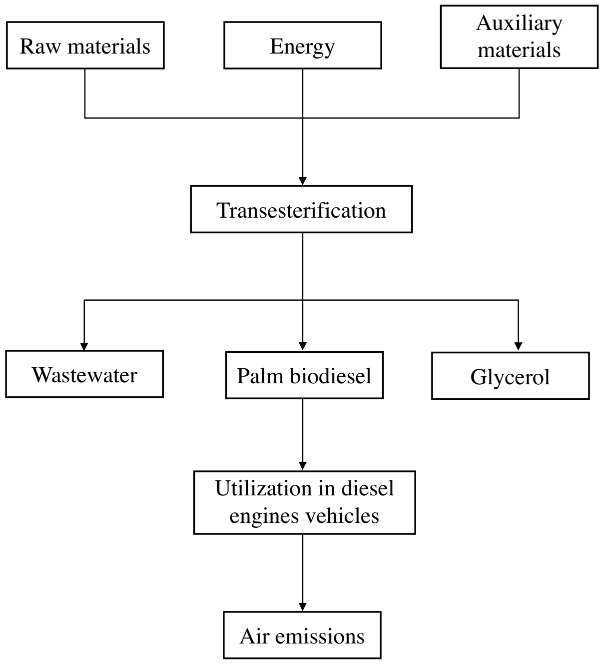

Figure 1. System boundary for the production and use of palm biodiesel.

Functional Unit

The functional unit for this study was the production and use of 1 MJ palm biodiesel in diesel engine vehicles.

RESULTS AND DISCUSSION

Life Cycle Inventory

Commercially, the most commonly used feedstock for the biodiesel production is refined, bleached and deodorized (RBD) palm oil. The results of the cradle-to-gate study of LCA, *i.e.* from the nursery to the production of RBD palm oil have been discussed in the Parts 1 to 4 articles. *Figure 2* shows the detailed process flow chart for the production of palm biodiesel. The inventory data for the production of palm biodiesel were obtained from two biodiesel plants using MPOB's biodiesel production technology through questionnaires. Subsequently, validation and verification were carried out involving stakeholders from the biodiesel industry, and in consultation with representatives from the Malaysian Biodiesel Association. However, the processing technology is being continuously optimized and improved.

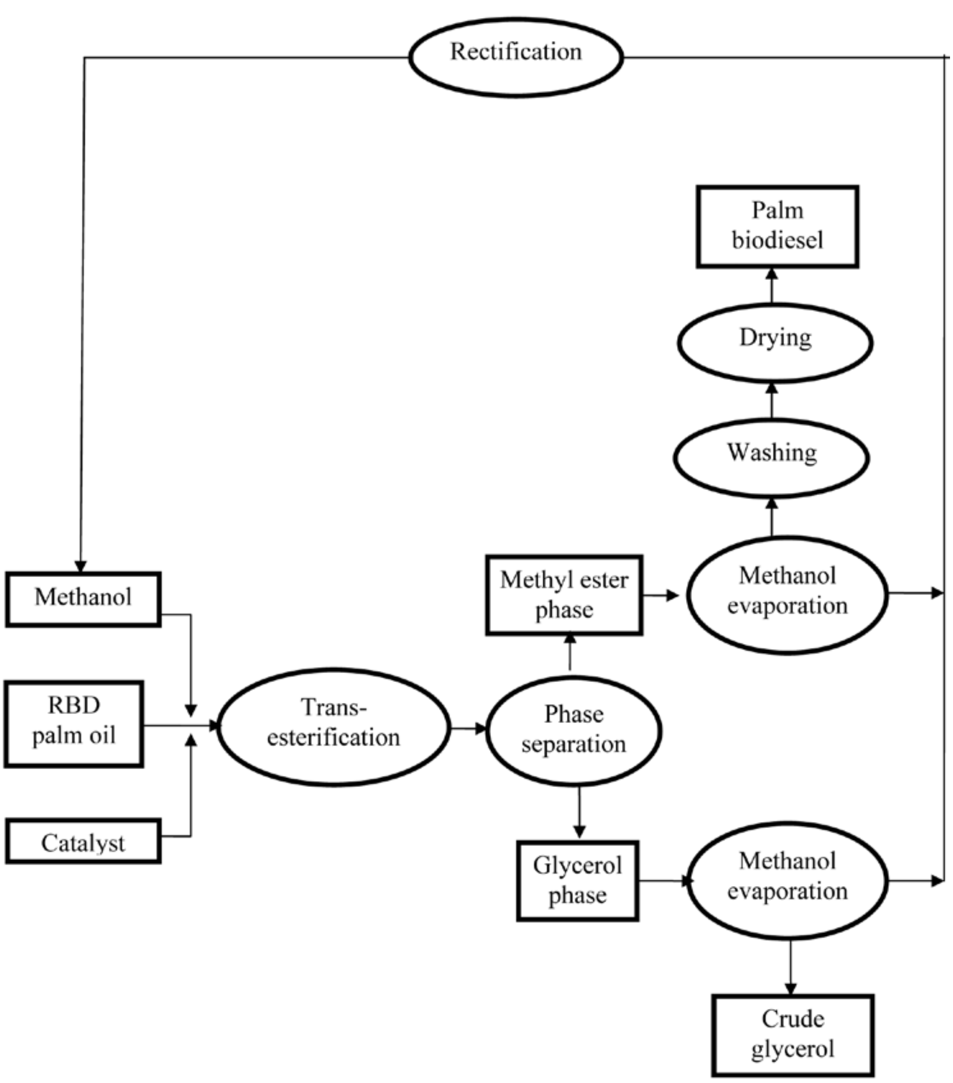

Figure 2. Process flow chart for the production of palm biodiesel.

In addition, LCA is a site-specific assessment. As such, inputs and waste materials may vary from plant to plant, even if they were using the same production technology. In order to calculate the inventory data based on the functional unit, the energy values used are shown in *Table 1*. Thus, life cycle inventory (LCI) for this study was based on the functional unit as shown in *Table 2*. LCI obtained has been carefully evaluated to ensure the reliability of LCA of the present study.

TABLE 1. ENERGY VALUE (MJ kg^{-1}) FOR SELECTED INVENTORY

Material	Energy value (MJ kg^{-1})
Palm oil	39.0
Methanol	19.7
Palm biodiesel	40.3

TABLE 2. LIFE CYCLE INVENTORY BASED ON FUNCTIONAL UNIT OF USE OF 1 MJ PALM BIODIESEL

Inputs and outputs	Unit	Amount
Raw materials		
RBD palm oil	MJ $MJ_{biodiesel}^{-1}$	1.006
Methanol	MJ $MJ_{biodiesel}^{-1}$	0.055
Sodium hydroxide	kg $MJ_{biodiesel}^{-1}$	0.0001
Hydrochloric acid	kg $MJ_{biodiesel}^{-1}$	0.0004
Utilities		
Electricity	MJ $MJ_{biodiesel}^{-1}$	0.0022
Water	kg $MJ_{biodiesel}^{-1}$	0.009
Steam	MJ $MJ_{biodiesel}^{-1}$	0.0144
Instrument air	kg $MJ_{biodiesel}^{-1}$	0.00008
Products		
Biodiesel	$MJ_{biodiesel}^{-1}$	1.00
Glycerol	kg $MJ_{biodiesel}^{-1}$	0.0030
Wastewater	kg $MJ_{biodiesel}^{-1}$	0.009

Assumptions

There are limitations and assumptions used in the present study because palm biodiesel has yet to be used commercially as a diesel substitute in this country; thus, some data on infrastructure and facilities are not available for the use of biodiesel.

Co-product allocation. The transesterification process produces biodiesel and glycerol as the co-product (*Figure 2*). Thus, glycerol which is produced in its crude form is not treated to higher purity. In addition, glycerol with different degrees of purity has different applications, especially in the oleochemicals industry. As such, mass allocation was carried out to distribute the environmental impact due to glycerol as it is not a waste material. Biodiesel and glycerol were allocated based on mass at a ratio of 89.3: 10.7.

Wastewater. In the biodiesel production process, water is mainly used for washing purposes. The wastewater generated is treated and recycled to be reused in the process. In general, the chemical oxygen demand (COD) is in the range of 15 000 to 30 000 mg litre^{-1} while the biochemical oxygen demand (BOD) is in the range of 10 000 to 20 000 mg litre^{-1}. The discharged BOD and COD are 50 mg litre^{-1} and 100 mg litre^{-1}, respectively. In addition, the wastewater generated in the production of 1 MJ of palm biodiesel is 0.009 kg (*Table 2*). The amount is relatively small as compared to other stages of biodiesel production.

Transportation. Currently, palm biodiesel is not used in the domestic market but is mainly for export purposes. As such, there is no inventory data available on the transportation of palm biodiesel from the factory to the distribution terminal, and subsequently to the diesel kiosk to be used in diesel engine vehicles. In the present study, the transportation of RBD palm oil to the biodiesel factory was assumed to be negligible.

Energy for the transportation of methanol and the catalyst was also considered to be low and was not taken into consideration in the present study. Excess methanol is recycled and reused in the process, and therefore methanol recovery and intermediate tanks are more important to be taken into account. In addition, the catalyst used is in the range of 2 to 5 kg for every tonne of palm biodiesel produced; thus, transportation of the catalyst was also not taken into consideration.

TABLE 3. MATERIALS BREAKDOWN OF BIODIESEL PLANT

Item	Unit	Replacement factor	Amount
Vessels and tanks	tonne	10%	56.5
Pumps and agitators	tonne	5%	12.3
Pipes	tonne	5%	16.7

Capital goods. The determination of capital goods was conducted by taking into account the total materials used to construct a 60 000 t biodiesel plant using MPOB's biodiesel production technology. These comprise mainly stainless steel for vessels and tanks, pumps and agitators as well as pipes. Replacement factors based on annual replacement requirements were used to indicate the need to replace the equipment based on their shelf-lives. *Table 3* shows a breakdown of the materials with their corresponding replacement factor. All vessels and tanks for the production of palm biodiesel at the processing plant were taken into consideration. A replacement factor of 10% was assigned to these, taking into consideration major vessels and tanks which are constructed with stainless steel are expected to last for more than 10 years.

A replacement factor of 5% was allocated to all pumps and agitators, taking into account the higher wear and tear that is expected to occur with these equipment. The assumption was made that the main material to assemble these pumps and agitators is stainless steel. In addition, the total amount of stainless steel used in pumps and agitators is relatively low as compared to vessels and tanks. It was estimated that pumps and agitators made up 20% of the total amount of steel required for vessels and tanks. However, the construction materials are for a plant producing 60 000 t of biodiesel per year, and the contribution due to capital goods was expected to be insignificant when it was translated into the functional unit of the present study. Thus, the materials for the construction of the factory building were not included. They were expected to be insignificant, taking into account that the structure will last for at least 20 years.

Exhaust emission. The first exhaustive field trial on the use of palm biodiesel in diesel engine vehicles was conducted by MPOB from 1986 to 1989. A wide range of diesel engines such as stationary engines, passenger cars, lorries, tractors, taxis and vans in Malaysia was included in the study. Subsequently, palm biodiesel was evaluated in bench endurance tests by Mercedes Benz AG, Germany. This exhaustive and comprehensive field trial involved 30 buses covering more than 10 million kilometres in total (each travelling more than 300 000 km, the life time of the engine as recommended by the engine manufacturer). Results have shown that the exhaust emissions of

TABLE 4. TAILPIPE EMISSIONS (per km) FOR ULTRA LOW SULPHUR DIESEL (ULSD) BIODIESEL BLENDS USING PALM OIL

Impact category	Tailpipe emission (g km^{-1})					
	ULSD	BD2	BD5	BD10	BD20	BD100
Carbon dioxide	692	679	659	626	560	0
Methane	0.01	0.01	0.01	0.01	0.01	0.01
Nitrous oxide	0.016	0.016	0.016	0.016	0.016	0.015
Carbon monoxide	2.81	2.78	2.75	2.69	2.57	1.79
Nitrogen oxides	8.68	8.71	8.76	8.84	8.99	10.33
Non-methanic hydrocarbon	0.72	0.71	0.71	0.71	0.71	0.71
Particulate matters (PM 10)	283	278	271	260	238	119

the engines were cleaner with less hydrocarbons, nitrogen oxides (NO_x), carbon dioxide and sulphur dioxide (Choo *et al.*, 2005).

Table 4 shows the tailpipe emissions (per km) for the use of ultra low sulphur diesel (ULSD) as compared to palm biodiesel blends (Beer *et al.*, 2007). It is shown that the use of palm biodiesel contributes to lower emissions of carbon dioxide, carbon monoxide and particulate matter. However, the use of biodiesel increases the emissions of NO_x, while there are similar emissions of methane, nitrous oxide and non-methanic hydrocarbon as from ULSD.

Life Cycle Impact Assessment

The life cycle impact assessment (LCIA) was carried out using the SimaPro software, version 7.1 with the methodology Eco-indicator 99. The foreground biodiesel production data based on MPOB's production technology were obtained directly from the commercial biodiesel plants while the foreground capital goods data were obtained directly from the biodiesel technology provider. However, the background data were obtained from the Ecoinvent database under SimaPro. These included the production of capital equipment and various chemicals used in the transesterification process. LCIA for the use of 1 MJ of palm biodiesel in diesel engine vehicles was presented in this study based on two case studies: continued land use for oil palm plantations with biogas emission at palm oil mills, and continued land use for oil palm plantations with biogas capture at palm oil mills. LCIA that was conducted incorporated results from the nursery to the refinery as are presented in the Parts 1 to 4 articles.

Figure 3 shows the weighted LCIA results for continued land use for oil palm plantations with biogas emission at palm oil mills. The processing step for the conversion of RBD palm oil to palm biodiesel contributed to two impact categories, namely fossil fuels and respiratory inorganics. Impact on fossil fuels was due to the use of non-renewable sources of materials, including methanol which is produced from natural gas and fuel oil for the boiler to generate steam. Impact on respiratory inorganics is associated with emissions to the atmosphere, and therefore was due to emission from the boiler.

The use of palm biodiesel contributed to respiratory inorganics and acidification/eutrophication as both impact categories are related to emissions to atmosphere. Based on the latest findings reported by Beer *et al.* (2007), the use of 100% palm biodiesel contributes to greater reductions in emissions of total carbon dioxide, particulate matter and carbon monoxide (100%, 58% and 36%, respectively) (*Table 4*).

The effects of acidification/eutrophication were due to a higher emission of NO_x from the use of biodiesel. The presence of the oxygen component in biodiesel increases the formation of NO_x. Currently, the use of B5 which is a blend of 5% biodiesel with 95% petroleum diesel is being implemented in the country. Thus, the emission from NO_x is similar to that of petroleum diesel (*Table 4*). In this context, the adverse effects of acidification/eutrophication were not significant due to the use of 5% blends of palm biodiesel. More importantly, the results show that the production and use of palm biodiesel did not contribute significantly towards the impact category on climate change (*Figure 3*).

The impact on climate change as contributed by RBD palm oil has been discussed in the Parts 1 to 4 articles. The impact category on climate change was also reduced with palm oil mills installed with biogas capture facilities. *Figure 4* shows the weighted LCIA results for continued land use for oil palm plantations with biogas capture at palm oil mills.

For biodiesel production, the environmental impacts associated with the production of capital equipment had been included and found to be

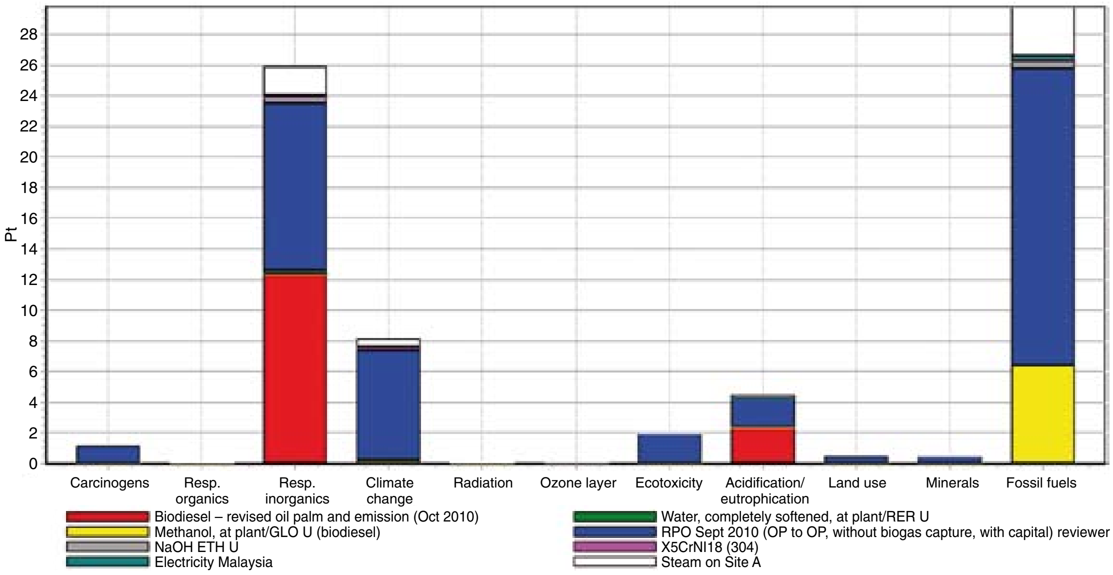

Figure 3. Weighted life cycle impact assessment of cradle to grave for production and use of palm biodiesel based on continued land use for oil palm plantations with biogas emission at palm oil mills.

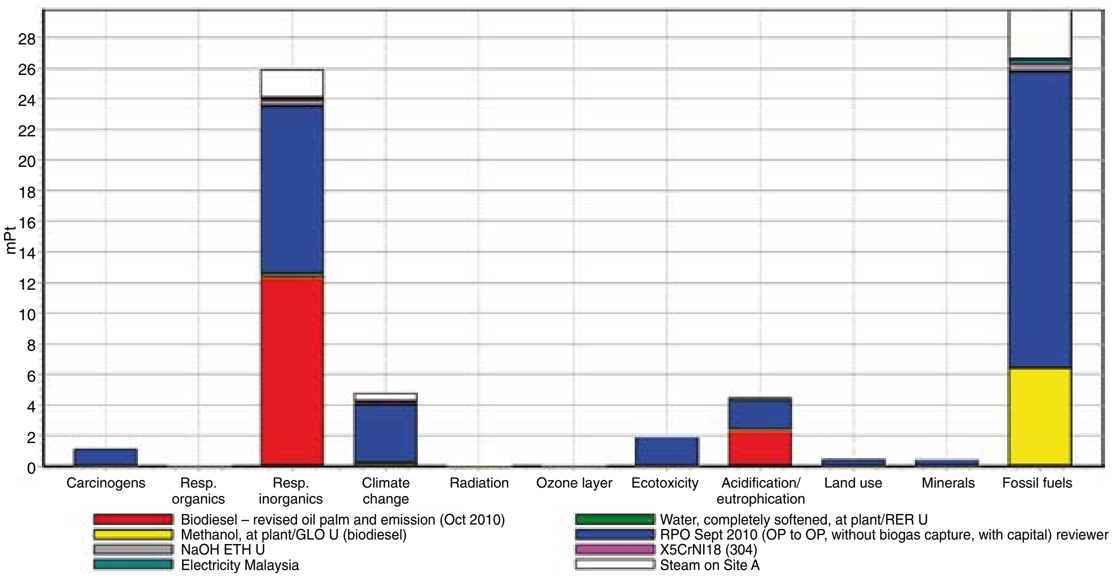

Figure 4. Weighted life cycle impact assessment of cradle to grave for production and use of palm biodiesel based on continued land use for oil palm plantations with biogas capture at palm oil mills.

insignificant. However, the impact due to the construction of the factory building was excluded based on results from earlier studies which indicate that their contribution is small. In addition, land occupation by the biodiesel factory have been excluded in this study.

The use phase of biodiesel was the major contributor towards the impact on respiratory inorganics and acidification/eutrophication. The exhaust emissions based on published data show that the use of palm biodiesel contributes towards lower emissions as compared to petroleum diesel. The greater reductions in emissions shown in a more recent study are mainly due to the advancement in technological development in diesel engine manufacture. Based on the LCIA results, it was found that the production of palm biodiesel using MPOB's technology does not contribute significantly towards to overall life cycle while the use of palm biodiesel is more environmental-friendly as compared to petroleum diesel in terms of emissions.

CONCLUSION

LCIA of this study shows that the environmental impact from the production of palm biodiesel is related to the use of methanol, while the use of palm biodiesel contributes to the impact categories of respiratory inorganics and acidification/eutrophication. In spite of these, the production and use of palm biodiesel is more environmental-friendly as compared to petroleum diesel.

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