# LIFE CYCLE ASSESSMENT OF THE PRODUCTION OF CRUDE PALM OIL (Part 3)

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#### **ABSTRACT**

The oil palm industry is a very important industry which contributes immensely towards the economy of the country. In 2009 alone, the total exports of oil palm products, constituting palm oil, palm kernel oil, palm kernel cake, oleochemicals and finished products, amounted to 22.40 million tonnes, resulting in total export earnings of RM 49.59 billion. The oil palm industry is an export-orientated industry which relies heavily on the world market. Therefore, it is vital for the oil palm industry to be sustainable and competitive to increase its long-term profitability. The objective of this study is to identify the potential environmental impacts associated with the production of crude palm oil (CPO), and to evaluate opportunities to overcome the potential impacts. This study has a cradle-to-gate system boundary. This article is part of the life cycle assessment (LCA) of the whole supply chain for palm oil, and is linked to the upstream LCA for nursery and plantation which can be found in Parts 1 and 2. This article examines the life cycle impact assessment (LCIA) of the production of 1 t of CPO at the palm oil mill.

For this study, 12 palm oil mills were selected. These mills were selected based on the type of mill, i.e. whether they were plantation-based mills or private mills, and having different processing capacities for fresh fruit bunches (FFB). The mills selected were all located in different zones in West Malaysia. Inventory data collection consisted of inputs and outputs of materials and energy. LCIA was carried out using the Simapro software version 7.1 and the Eco-indicator 99 methodology. Results show that the impact categories with significant impacts were from fossil fuels, respiratory inorganics and climate change. The impact under the fossil fuels category came from the production of the fertilizers used as well as diesel usage for transportation and harvesting in the nursery and plantation phases. The impact categories of climate change and respiratory inorganics came from upstream activities and the palm oil mill effluent (POME) in the mill. Both these impact categories are related to air emissions. The main air emission from the POME ponds during the anaerobic digestion was biogas which consisted of methane, carbon dioxide and traces of hydrogen sulphide. The unharvested biogas is a greenhouse gas. The impact under respiratory inorganics and climate change from upstream was caused by the application of nitrogen fertilizers in the plantation as well as the nursery. When biogas was captured, the impact under climate change was reduced. What was left were the impacts from upstream activities. The Malaysian oil palm industry should seriously look into the old sludge treatment system which is emitting biogas. They should capture the biogas and use it as renewable energy source, or produce value-added products such as fertilizer from POME which will eliminate methane generation.

Keywords: life cycle assessment, life cycle impact assessment, palm oil mill, crude palm oil, biomass, Malaysian oil palm industry.

Date received: 4 October 2010; Sent for revision: 6 October 2010; Received in final form: 18 October 2010; Accepted: 25 October 2010.

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#### INTRODUCTION

The world is demanding for economic growth, yet this growth must be achieved through environmental conservation while enhancing the quality of human life. Sustainability is about preserving the health of the biosphere, and the efficient use of natural resources like air, water, land, flora and fauna (Chan, 2004). Sustainable development has been popularly defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (UNCED, 2002). This clarion call has resulted in the recognition of environmental issues increasing enormously from the last decade onwards as well as gaining momentum each year. The consumers or public have become more aware that the consumption of manufactured products and services offered may contribute to adverse effects on resources and the quality of the environment, and that these effects can occur at all stages of the life cycle of the product and service, and not just during its manufacture.

Life cycle assessment (LCA) is a tool to evaluate the environmental impacts of a product or process throughout its entire life cycle (SETAC, 1993). LCA has become a common environmental management tool, and is a good analytical method for assessing and optimizing the environmental quality of a system over its whole life cycle (Stalmans *et al.*, 1995).

The oil palm industry is a very important industry which contributes immensely towards the economy of the country. In 2009 alone, the total exports of oil palm products, constituting palm oil, palm kernel oil, palm kernel cake, oleochemicals and finished products, amounted to 22.40 million tonnes, resulting in total export earnings of RM 49.59 billion (Basri, 2010). The oil palm industry is an export-orientated industry which relies heavily on the world market. Therefore, it is vital for the oil palm industry to be sustainable and competitive to increase its long-term profitability and sustainability.

The flow chart of the milling process is shown in Figure 1. Fresh fruit bunches (FFB) which are delivered to the palm oil mills are received at the FFB hoppers, and are transferred into the sterilization cages. These cages are rolled into the sterilization chambers. Live steam passes through these chambers for a duration of 90 min, and this process called sterilization helps to loosen the individual fruits from the stalk or bunch. The steam also deactivates the enzymes which cause the breakdown of the oil into free fatty acids (FFA). FFA are undesirable in palm oil. The industry tries to limit the development of FFA to less than 4% (Pathak, 2005). Next, the sterilized FFB are sent to a stripper where the fruitlets are separated from the stalks or bunches which are now called empty fruit bunches (EFB). EFB are normally sent back to the

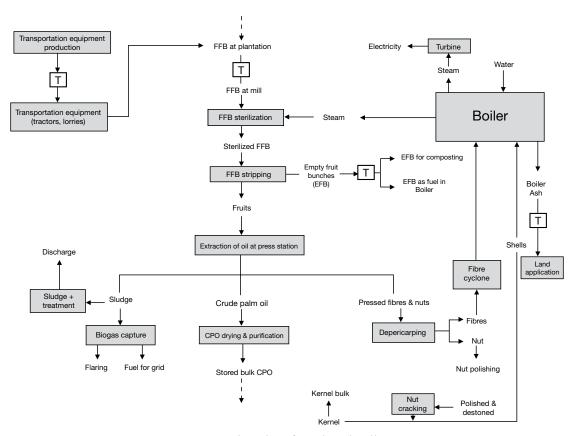


Figure 1. Flow chart for palm oil milling.

plantations for use in mulching and as a fertilizer substitute.

The fruitlets from the stripper are then sent to a digester where they are converted into a homogeneous oily mash by means of a mechanical stirring process. The digested mash is then pressed using a screw press to remove most of the crude palm oil (CPO). At this point, CPO comprises of a mixture of oil, water and fruit solids which is screened on a vibrating screen to remove as much solids as possible. Then, CPO is clarified in a continuous settling tank operation. The decanted CPO passes through a centrifugal purifier and desander to remove any remaining solids, and is then transferred to the vacuum dryer to remove the moisture. Finally, CPO is pumped into storage tanks before it is sent off for export or refining at the refineries. The nuts with the pressed mesocarp fibre are separated at the fibre cyclone. The nuts are then cracked to produce kernels and shells. The kernels are shipped to kernel-crushing plants to be processed into crude palm kernel oil (CPKO) while the shells and pressed mesocarp fibre are used as boiler fuel. The main solid wastes from the milling process are EFB, pressed mesocarp fibre, shells and boiler ash, while the liquid waste is palm oil mill effluent (POME). The gaseous emissions are from the boiler stack while biogas is emitted from the effluent treatment ponds.

The concept of recycling the palm oil mill by-products is not new but has merely resurfaced in the light of recent economic and environmental concerns. Over the years, the oil palm industry has been very responsible and all the by-products have gradually been utilized. By the 1980s, the judicious utilization of the various by-products through nutrient recycling in the fields has reduced the environmental impact, paving the way towards achieving a zero waste policy. Currently, there is a further move to improve the use of these by-products through the development of value-added products (Chan, 1999).

# **OBJECTIVES**

The objectives or goals of this study are to:

- identify the potential environmental impacts associated with the production of CPO; and
- to use this assessment for evaluating opportunities to overcome the potential impacts.

# SCOPE/SYSTEM BOUNDARY

The life cycle inventory (LCI) data presented in this article (*Table 1*) has a gate-to-gate system boundary.

TABLE 1. LIFE CYCLE INVENTORY FOR 1 t CRUDE PALM OIL (with weight allocation)

OIL (with weight allocation)					
Parameter	Amount				
Fresh fruit bunches (t)	3.10				
Power consumption from turbine (MJ)	224.08				
Power consumption from grid	1.76				
(MJ)	100.00				
Diesel consumption for mill (MJ)	100.33				
Transportation of diesel to mill (tkm)	0.54				
Fuel used in boiler:					
Mesocarp fibre (t)	0.36				
Shells (t)	0.09				
Boiler water consumption (t)	1.57				
Water for processing (t)	2.17				
Kernels (t)	0.41				
Mesocarp fibre (t)	0.00				
Shells (t)	0.23				
Empty fruit bunches (EFB) (t)	0.71				
Palm oil mill effluent (POME)(t)	1.86				
Methane gas (kg)	22.21				
CO <sub>2</sub> from POME pond (kg)	36.04				
Boiler ash (t)	0.01				
Steam input to turbine (t)	1.62				
Steam input for sterilization (t)	1.56				
Flue gas from stack:					
Particulate matter (kg)	0.12				
CO (kg)	0.04				
$CO_2$ (kg)	41.28				
$SO_{x}(kg)$	0.0006				
$NO_x$ (kg)	0.07				
Wastes	Medalahin a				
EFB POME	Mulching Treated as				
TOWLE	fertilizer				
Excess mesocarp fibre and shells	Sold as fuel				
Boiler ash	Land application				
Capital goods					
Buildings, steel (kg)	1.00				
Buildings, concrete (kg)	3.14				
Oil mill machinery (kg)	2.83				
Tractors (kg)	0.02				

The starting point is at the oil palm FFB hoppers where the FFB are received, with the ending point at the production of CPO in the storage tanks. The life cycle impact assessment (LCIA), on the other hand, is carried out for a cradle-to-gate system boundary

as shown in *Figure 2* which includes LCI from the Part 1 and Part 2 articles. This article is linked to LCA of oil palm seedling production (Part 1) and LCA of FFB production (Part 2). The functional unit for this study is 1 t of CPO produced.

In this study, all processes are considered relevant unless excluded based on the exclusion criteria shown in *Table 2*. In general, processes are excluded if they are judged to have an insignificant contribution (<3%) to the overall environmental load; if representative data for the processes are extremely difficult or impractical to gather; or if the processes are clearly part of a separate product system.

#### **METHODOLOGY**

# **Inventory Data**

Inventory data were collected directly from the palm oil mills and millers through questionnaires which were developed specifically for data collection, and also through actual on-site measurements and quantification. Compliance with geographical coverage for data collection was adhered to by collecting data from different regions in Malaysia. For each data set, the period during which the data were collected and how the data were collected were documented. The data

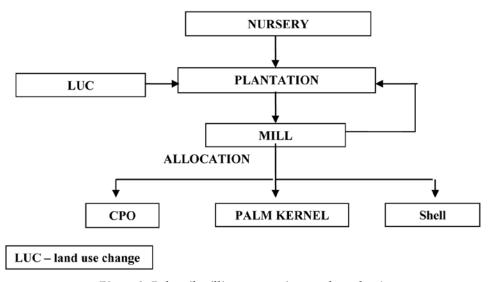


Figure 2. Palm oil milling process (system boundary).

TABLE 2. SYSTEM BOUNDARY DEFINITION CRITERIA

	Included	Excluded		
Processing category		Insignificant environmental impact	Difficult to obtain representative data	Part of a different system
Production, maintenance and replacement of capital equipment	✓	-	-	-
Transportation of capital goods	-	$\checkmark$	$\checkmark$	$\checkmark$
Water treatment and supply	$\checkmark$	-	-	-
Extraction of crude palm oil from FFB	✓	-	-	-
Transportation of diesel to mill	$\checkmark$	-	-	-
Management of solid waste in mill	$\checkmark$	-	-	-
Electricity generation	$\checkmark$	-	-	-
Production of fuel for boilers	$\checkmark$	-	-	-
Processing of co-products <i>e.g.</i> palm kernels, palm shells	-	-	-	✓
Capital goods	$\checkmark$	-	-	-
Wastewater treatment	✓	-	-	-

validation procedure was carried out by on-site visits, on-site measurements, communication and discussions via e-mail and telephone, and through interviews to obtain evidence and to verify the reliability of the collected data.

For this study, 12 palm oil mills were chosen from the main clusters which contain a high density of palm oil mills within them. The palm oil mills were chosen from these clusters to ensure that they were representative of and cover the main areas that have palm oil mills in Malaysia. Within a cluster itself, the palm oil mills were chosen based on the age, type of mill (either plantation-based or private mills), FFB processing capacity, location and also other variables such as grid connection and oil extraction rate. The reason for using these selection criteria is to ensure that the chosen mills had all the different variations existing in the palm oil mills in Malaysia.

Data on all capital goods were collected from the mills through actual visits or information supplied by the palm oil mills except where stated. The use of capital goods is obtained by estimating the total stocks of capital goods divided by the amount of CPO produced in the year 2007, followed by multiplying the estimates with a replacement factor expressing the fraction of the goods replaced each year. Based on the data collected from the 12 palm oil mills with CPO processing capacities ranging from small to large volumes, the average total FFB processed was estimated at 270 000 t yr<sup>-1</sup>.

# Allocation of Co-products

More often than not, a system will yield more than one product. In such cases, allocation must be made for input and output flows for each product. The main by-product from the milling process is palm kernel. Besides the main products comprising CPO and palm kernel, other outflows include the production of sludge or POME during the clarification step, EFB during the stripping of FFB, pressed mesocarp fibre from the mechanical pressing of palm fruits, nuts from the depericarping stage and, lastly, shells after nut cracking to release the palm kernels.

The kernels are subsequently sent to kernel-crushing plants for extraction of CPKO which will be discussed in LCA of CPKO (Part 3a). This crushing process is not accounted for in this study because CPKO extraction is considered as part of a different system which is excluded from the boundary of the system under study. POME is an important semisolid stream. The biological treatment of POME to reduce biological oxygen demand (BOD) to 5000 ppm for land application, and below 50 ppm for discharge into waterways, results in the emission of biogas which can be captured. This can be done by diverting the POME to digester tanks where biogas

is trapped for use as fuel. The pressed mesocarp fibre and shells would have been solid waste emissions from the milling process but they serve as alternative fuel sources to fire the boilers in the palm oil mills to produce steam used for electricity generation and sterilization of FFB. EFB is used as mulch or compost to substitute fertilizer. The treated POME is also used as a fertilizer substitute. The recycling of solid wastes such as mesocarp fibre and shells for use within the milling process establishes closed-loops for these outputs from the palm oil mill, while EFB and POME which are recycled for use in the plantation are considered to be open-loop processes.

In this study, the method selected for partitioning co-products was allocation based on weight. Palm kernels and palm shells are considered as co-products. System boundary expansion was conducted for EFB and POME which are recycled in the plantation as part of fertilizer substitution. The savings from using both EFB and POME as fertilizer substitute are given in LCA of FFB production (Part 2). The pressed mesocarp fibre and shells are burnt as fuel in the palm oil mill boiler while the excess shells are sold to other biomass boilers. However, the credits from the use of shells elsewhere are not included in this study as it is out of the system boundary, and so allocation is carried out for the shells.

The value for biogas emission was sourced from literature (Ma *et al.*, 1999) and not calculated or quantified according to the COD in the respective palm oil mills. The typical chemical oxygen demand (COD) range in the palm oil mills is from 47 500 to 70 000 mg litre<sup>-1</sup> (Tong, 2008). The statistics on just what percentage of the mills falls closer to a particular value are not available as most mills do not capture their biogas. The higher biogas value will be 41 m³ t¹ POME which is equivalent to COD of 70 000 mg litre<sup>-1</sup>. For this study, the lower value of 28 m³ t¹ POME was adopted.

# Life Cycle Impact Assessment

LCIA was conducted using the SimaPro software version 7.1 and the Eco-indicator 99 methodology. LCIA was conducted for two scenarios. Scenario 1 was for a palm oil mill with biogas emissions while Scenario 2 was for a palm oil mill that captured the biogas.

# **RESULTS AND DISCUSSION**

# Life Cycle Inventory (LCI)

LCI data is inventory data that have been calculated to quantify the environmental inputs and outputs of the functional unit within the

system boundary. *Table 1* shows the LCI data for 1 t CPO produced at the palm oil mill. The LCI data shown in *Table 1* are data which had been allocated. As discussed earlier, CPO is not the only product produced in the palm oil mills. The by-products of the milling process are palm kernels and palm shells. In view of this, weight allocation has been conducted to allocate part of the inputs and outputs to palm kernels and palm shells. The allocation between CPO, palm kernels and palm shells was 61%, 25% and 14%, respectively.

# Life Cycle Impact Assessment (LCIA)

LCIA was also conducted using the SimaPro software version 7.1 and the Eco-indicator 99 methodology. The characterization and weighted

results for both scenarios were for the system boundary which started from the nursery right up to the production of CPO at the palm oil mill. Land occupation by the mill was not included in LCIA for both scenarios.

# Scenario 1

LCIA was conducted for 1 t CPO produced at the palm oil mill. The system boundary included:

- nursery;
- plantation (continued land use); and
- palm oil mill (allocation with palm kernels and shells and with biogas emissions).

The characterization and weighted results are shown in *Figures 3* and 4, respectively.

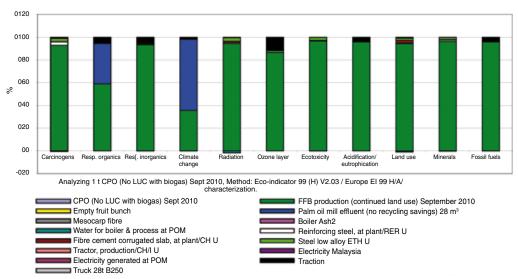


Figure 3. Characterization in life cycle impact assessment (LCIA) for 1 t crude palm oil (CPO) – continued land use, biogas emission.

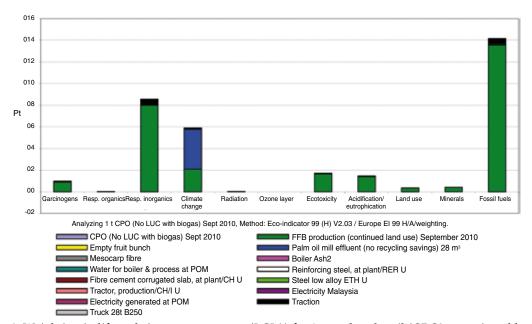


Figure 4. Weighting in life cycle impact assessment (LCIA) for 1 t crude palm oil (CPO) – continued land use, biogas emission.

The weighted results show that the impact categories with significant impacts were from fossil fuels, respiratory inorganics and climate change. The impact from the fossil fuels category came from the production of the various fertilizers as well as diesel usage for transportation and harvesting which were used in the nursery and plantation phases. The parameters that contributed towards the impact categories of climate change and respiratory inorganics were from upstream activities and POME at the mill. Both these impact categories are related to air emissions. The main air emission from the POME ponds during anaerobic digestion was the biogas which consisted of methane, carbon dioxide and traces of hydrogen sulphide. The unharvested biogas is a greenhouse gas which harms the quality of the air. The impact from the biogas falls under the climate change impact category.

The impact under respiratory inorganics and climate change from upstream activities was caused by the application of nitrogen fertilizers in the plantation as well as the nursery.

# Scenario 2

LCIA was conducted for 1 t CPO produced at the palm oil mill. The system boundary included:

- nursery;
- plantation (continued land use); and
- palm oil mill (allocation with palm kernels and shells, with biogas captured).

The characterization and weighted results are shown in *Figures 5* and *6*.

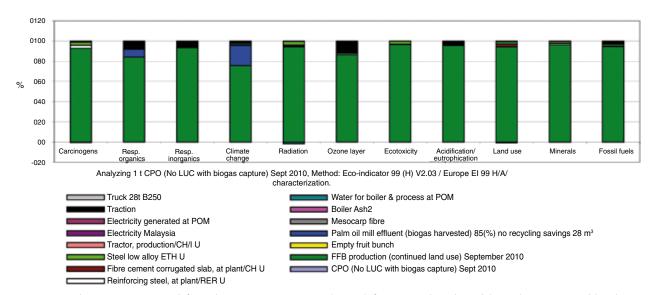


Figure 5. Characterization in life cycle impact assessment (LCIA) for 1 t crude palm oil (CPO) – continued land use, biogas capture.

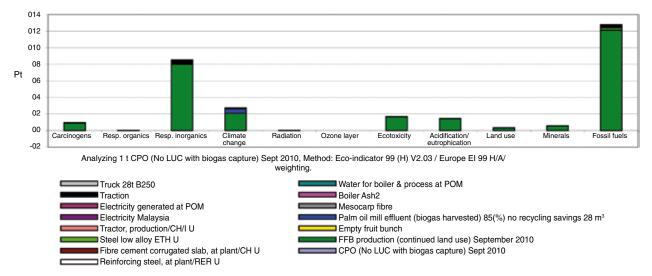


Figure 6. Weighting in life cycle impact assessment (LCIA) for 1 t crude palm oil (CPO) – continued land use, biogas capture.

The weighted results show that when biogas was captured, the impact from the climate change impact category due to POME was reduced significantly. The only remaining impacts were from upstream (in green) under the fossil fuels impact category due to the production of fertilizers, and for the climate change and respiratory inorganics impact categories from the application of those fertilizers.

Although biogas from POME has great potential to be used as a renewable energy source, the capture of biogas is not actively adopted by the industry due to several issues related to costs, benefits and risks, poor logistics associated with national grid connection, feed-in tariffs, stage of technology maturity, and a general lack of interest from mills which are operating in a 'comfort zone'. However, the 'business as usual' attitude in the industry is beginning to change (Basri *et al.*, 2008). Currently, the industry is moving towards either harnessing biogas from POME, or producing value-added products such as fertilizer from POME which will eliminate methane generation.

# CONCLUSION AND RECOMMENDATIONS

All this while, environmental management has been more for image purposes. However, in recent developments, with a shift towards wanting a 'greener' earth, environmental demands are becoming marketing tools. Consideration for the environment is becoming a determining factor for the use of products. In view of the current shift towards higher environmental demands from customers as well as the emergence of eco labels, the need for the oil palm industry to also shift in parallel with the current trend is unavoidable. The findings of this study are based on the Eco-indicator 99 methodology and on a system boundary from nursery to the palm oil mill. Based on the results from the two scenarios, the parameters causing impact were the biogas emission, fertilizer production and application. The emissions from the production and application of fertilizers are unavoidable as fertilizers have to be used to grow oil palm. A better alternative to achieve the best environmental performance in the production of CPO is to process FFB from plantations that have been replanted with oil palm practicing continued land use, to capture the biogas at the POME anaerobic ponds and to use it to generate renewable energy. It should be noted that the impact from capital goods is negligible in both scenarios. It is strongly recommended for palm oil mills either to capture their biogas and use it as renewable energy, or to move into measures that avoid methane generation.

#### **ACKNOWLEDGEMENT**

The authors would like to thank the palm oil millers for allowing them to conduct the study at the mills.

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