LIFE CYCLE ASSESSMENT OF REFINED PALM OIL PRODUCTION AND FRACTIONATION (Part 4)

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ABSTRACT

With the increasing global attention to sustainable development, the environmental and social relevance of palm oil production are now defining issues in responsible trade. The life cycle assessment (LCA) study on refined palm oil (RPO) and its fractionated products is part of the sustainable solution provided by the Malaysian palm oil industry. The study was conducted according to established ISO (International Standards Organization standards) for LCA. The system model for this LCA study was developed and analyzed using SimaPro software, and the Eco-indicator 99 methodology was used for the life cycle impact assessment (LCIA).

An average of 1.05 t of crude palm oil (CPO) is required for the production of 1 t of RPO. The greatest environmental burden arising from refining is from CPO, and consequently from RPO for fractionation to produce refined palm olein (RPOo) and palm stearin (RPOs). This is followed by boiler fuel combustion and the transport of materials, suggesting that a potential mitigation measure for the reduction of greenhouse gases (GHG) and consequently the impact on climate change would be to address these three inflows into the system. It was found that sourcing CPO from mills with systems in place for capturing biogas reduced the impact on climate change by about 40%.

Keywords: refining, refined palm oil, fractionation, refined palm olein, refined palm stearin.

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INTRODUCTION

Palm oil is the most widely traded oil in the vegetable oils market. It can be found in one in 10 products sold in supermarkets. In 2009, palm oil accounted for 59% of the world's vegetable oils exports, and Malaysia alone accounts for 45% of palm oil exports (MPOB, 2009). World consumption of oils and fats for all purposes is forecast at 169.5 million tonnes in 2009/2010, and palm oil makes up an estimated 47.1 million tonnes of total usage (Oil World Annual, 2010). Palm oil is internationally known for its price competitiveness and ready supply to meet the growing world demand for vegetable oils. In recent years, pro-conservation groups have pressured buyers of palm oil to identify and exclude from their supply chain producers linked to companies which clear forest or peatland to grow oil palm. It now appears that the purchase of sustainable palm oil is a common policy adopted by environment-conscious manufacturers.

Before the mid- 1970s in Malaysia, crude palm oil (CPO) was the oil traded in international markets. With the establishment of refineries in the 1980s, the palm oil trade deals mostly in refined palm oil (RPO). CPO, the main feed material for the production of RPO, refined palm olein (RPOo) and refined palm stearin (RPOs), is obtained from upstream activities in the palm oil supply chain which include the cultivation of oil palm from

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seeds, the production of fresh fruit bunches (FFB) from which CPO is extracted, and culminate in the refining and fractionation processes.

Refining is a process to purify edible oils. Vegetable oils contain a number of undesirable non-(glyceride) oil impurities which are removed from the oil to make the oil suitable for human consumption or for use in technical applications. The objectionable impurities removed during refining include free fatty acids (FFA), phosphatides, metal ions, pigments or colour bodies, oxidation by-products, hydrocarbons, moisture and extraneous particulates.

The basic steps in refining CPO are degumming, earth bleaching, and deacidification and deodorization. Degumming ensures that the phosphatides and gums are aggregated for easier removal by the bleaching earth, while bleaching removes impurities such as pigments, hydroperoxides and trace metals, *e.g.* copper and iron, which are picked up from the oil-processing equipment at the mill or along the upstream supply chain. There are two methods for refining CPO to produce RPO – physical and chemical refining. Both methods are basically the same except that the latter involves neutralization of FFA in CPO with caustic soda while the former uses steam to strip the acid from the oil. The resulting soapstock from chemical refining is then treated with dilute sulphuric acid; producing palm acid oil as the by-product. The by-product in the physical refining of CPO is the palm fatty acid distillate (PFAD) which is obtained as a condensate of the volatile compounds carried over from the deodorizer by the stripping steam. A valuable component in PFAD is vitamin E in the form of tocopherols. PFAD has often been used as a raw material for soap making, feed compounding, and as an oleochemical feedstock. Physically refined oils normally require a higher bleaching earth dosage than oils that are alkali-refined. Besides a higher oil yield, the main environmental advantage of the physical process vis-à-vis chemical refining is the use of less chemicals and water, thereby resulting in less effluent.

Fractionation is the crystallization of RPO under controlled conditions followed by separation of the low melting liquid phase (olein) and the high melting solid phase (stearin).

This article presents results of an life cycle assessment (LCA) study on the production of RPO, RPOo and RPOs; using the system model developed by MPOB, and analyzed using SimaPro version 7.1 (Pré Consultants, 2007) software. Weight allocation was used to distribute the environmental burden between RPO and PFAD, and CPO refining was modelled using the physical refining process.

As of 2009, there are 54 palm oil refineries in Malaysia consisting of 38 refineries in West Malaysia (Peninsular Malaysia) and 16 in East Malaysia (Sabah and Sarawak). In this LCA exercise, inventory data were obtained from 11 refineries, representing 20% of the refineries located in Peninsular and East Malaysia.

OBJECTIVES

The main objective of this LCA study is to make available the gate-to-gate life cycle inventory (LCI) data for the refining and fractionation process so that the data can be calculated for a life cycle impact assessment (LCIA). Environmental consequences from the production of RPO and its fractionated products can then be estimated using a weight attributional LCA approach (Schmidt, 2008a).

Another objective is to determine the changes, if any, on the environmental loads resulting from CPO sourced from mills with and without a process in place for capturing 85% of the biogas from the palm oil mill effluent (POME). In addition, the study only covers the scenario where FFB are sourced from a plantation which was established on old oil palm land, *i.e.* no land use change was involved in the cultivation of the palms. *Table 1* shows the two scenarios from which CPO could be procured from refineries. It is to be noted that only 5% of the palm oil mills in Malaysia have implemented a system for the capture of biogas from POME.

TABLE 1. OIL PALM CULTIVATION AND PALM OIL MILLING AND THE DIFFERENT LAND USE CHANGE (LUC) AND BIOGAS TREATMENT SCENARIOS

Scenario No.	Land use	Treatment of biogas from palm oil mill effluent (POME)	Scenario
1	Cultivation of palms on previous oil palm stands *i.e.* no land use change (OP to OP)	No capture of biogas	OP to OP, without biogas capture
2	Cultivation of palms on previous oil palm stands *i.e.* OP to OP	85% capture of biogas	OP to OP, with biogas capture

GOAL AND SCOPE

This study determines the environmental impacts from RPO, RPOo and RPOs production. The methodology used is aimed at identifying and quantifying energy and materials used and wastes released to the environment in the processes for refining and fractionating palm oil. These data obtained through a detailed LCI were then calculated to determine the environmental impacts. The impact categories considered include: climate change, respiratory inorganics and organics, carcinogenic substances, radiation, ozone depletion, ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuels. Subsequently, the results were analyzed and interpreted to identify improvement opportunities and mitigation options.

The LCA study was conducted according to ISO 14040/14044. The assessment was also used to test the environmental benefits of alternative scenarios for sourcing of CPO so as to identify, prevent and/or reduce adverse environmental impacts arising from refining and fractionation to produce RPO and RPOo and RPOs, respectively. The inputs and outputs for this LCA study were based on production practices both in West (Peninsular) and East Malaysia.

LIFE CYCLE INVENTORY FOR REFINING AND FRACTIONATION

Material inputs for the refining of CPO are phosphoric acid for degumming and bleaching earth for adsorptive cleansing. Spent bleaching earth containing an average of 20% retained oil is obtained when the degummed, bleached oil is filtered before the subsequent step of refining, *i.e.* the deacidification and deodorization stage.

Energy for oil processing is met by electricity from the grid and fossil fuel to fire boilers which produce steam from municipal water. Steam is used to heat the oil during degumming and earth bleaching, while live steam is injected into the deodorizers during the stripping of FFA and other undesirable volatiles from the oil in the deacidification and deodorization step.

Generally, about 90% of the oil produced in refineries is fractionated. This process involves cooling RPO in crystallizers to partition the liquid olein from the solid stearin, followed by separation of the olein from the stearin by passing the mixture through a high pressure membrane press. As most fractionation plants are located in the same premises as refineries, both facilities share energy and water input, and data for their respective allocations to refineries and fractionation plants are provided by a survey questionnaire as well as through on-site verification visits to refineries. Liquid waste from the refinery include wastewater which is discharged after treatment, while PFAD is the co-product resulting from the stripping of the more volatile fatty acids from the oil during the deacidification and deodorization step to produce low FFA oil. The refining and fractionation processes relative to upstream and downstream production activities in the palm oil supply chain are shown in *Figure 1*.

Functional Unit

The relevant function of the system under study is to provide RPO, RPOo and RPOs for use in further downstream processing as food or non-food products. In this study, the functional unit is RPO/RPOo/RPOs as feed material for food and non-food preparations. Thus, an appropriate functional unit for this study is 1 t of RPO, RPOo or RPOs.

SYSTEM BOUNDARY

The LCI data gathered for this study are from gate-to-gate where selected life cycle stages are included in the system boundary. These stages are those within the dotted boundary shown in *Figure 1*. Thus, the study gate begins with the transportation of CPO to the refinery gate, and ends with the bulk storage of RPO, RPOo and RPOs, also within the refinery gate. The supply chain of RPO and its fractions starts with the processes shown in the flow chart in *Figure 2*. Each of the processes is linked to a following process by a flow of intermediate products. All the processes are linked to the environment by elementary inflow of materials or energy entering, and outflow of waste or emissions leaving the system under investigation.

Allocation of Co-products

In the refinery, PFAD is a co-product of CPO refining to produce RPO. Further processing or treatment of PFAD for incorporation into animal feed or as a feed material for soap manufacture is regarded as parts of different systems and are therefore excluded from the boundary of this study. System boundary expansion (Schmidt, 2008a; 2010) was not used for the treatment of PFAD, mainly because it is difficult to determine the substituted marginal source which could be (i) barley when PFAD is used in animal feed, (ii) tallow/vegetable oil when used for soap production, (iii) other vegetable oils for production of oleochemicals, or (iv) fatty acid distillate derived from other vegetable oils for the extraction of vitamin E.

The method selected for partitioning of the co-products in this study was allocation based on weight. Data collected showed that an average of

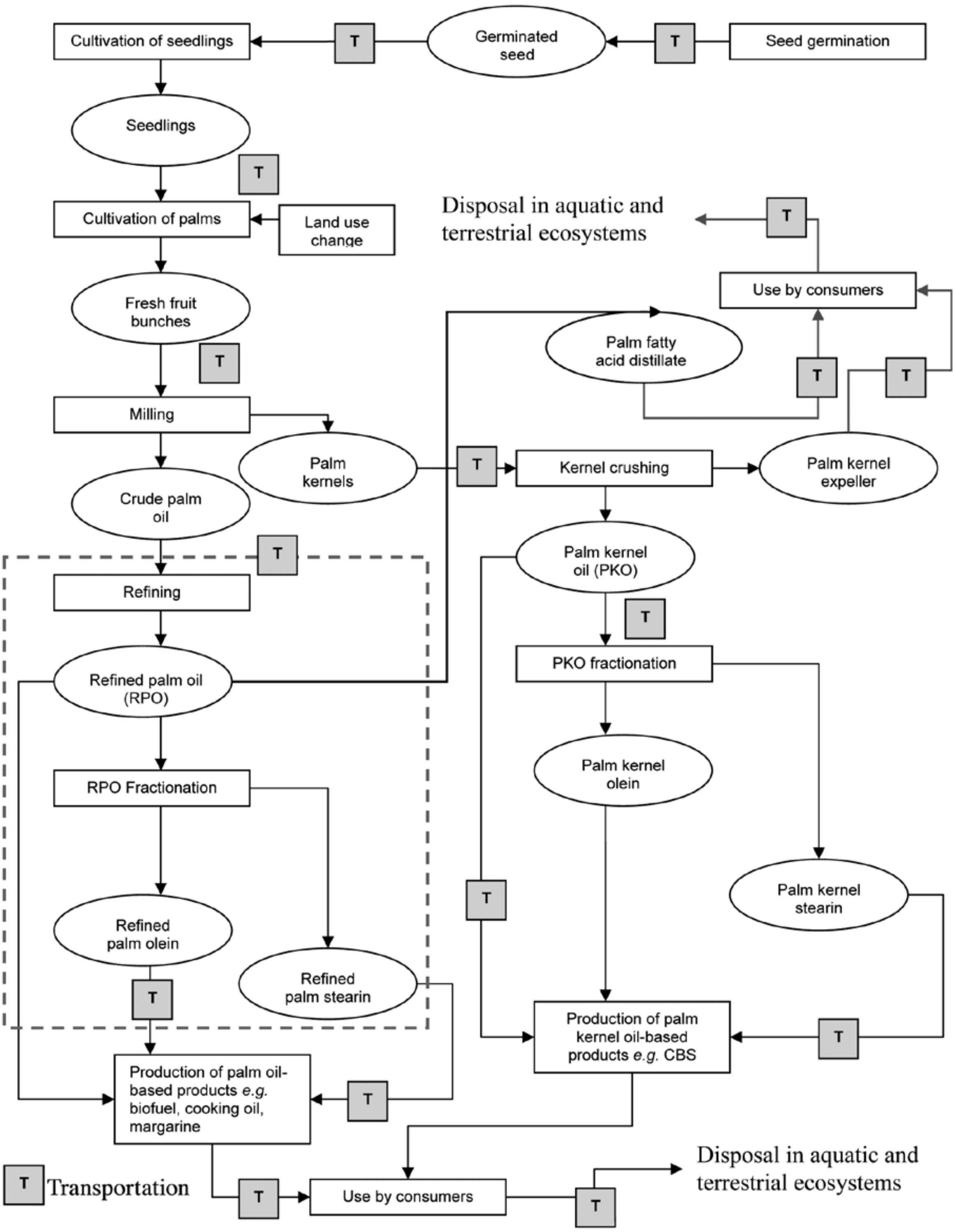

Figure 1. System boundary (dotted boundary) of the life cycle assessment (LCA) of the production of refined palm oil (RPO), refined palm olein (RPOo) and refined palm stearin (RPOs).

45 kg PFAD is produced for every tonne of CPO processed. In the case of RPO fractionation, data from the 11 refineries showed the average yield of RPOo and RPOs to be 75% and 25%, respectively. Thus, weight allocations of 95.5:4.5 (RPO:PFAD) and 75: 25 (RPOo: RPOs) were used in this study. To determine the reliability of the results obtained from weight allocation, allocations based on economic values were calculated. The data for determining the allocation percentage based on economic value for RPO:PFAD and RPOo:RPOs were derived from calculations of the prices for the two products in the years 2002 to 2009. These were found to be 96:4 and 77:23, respectively, indicating that there was no significance difference in allocation based on weight or on economic value.

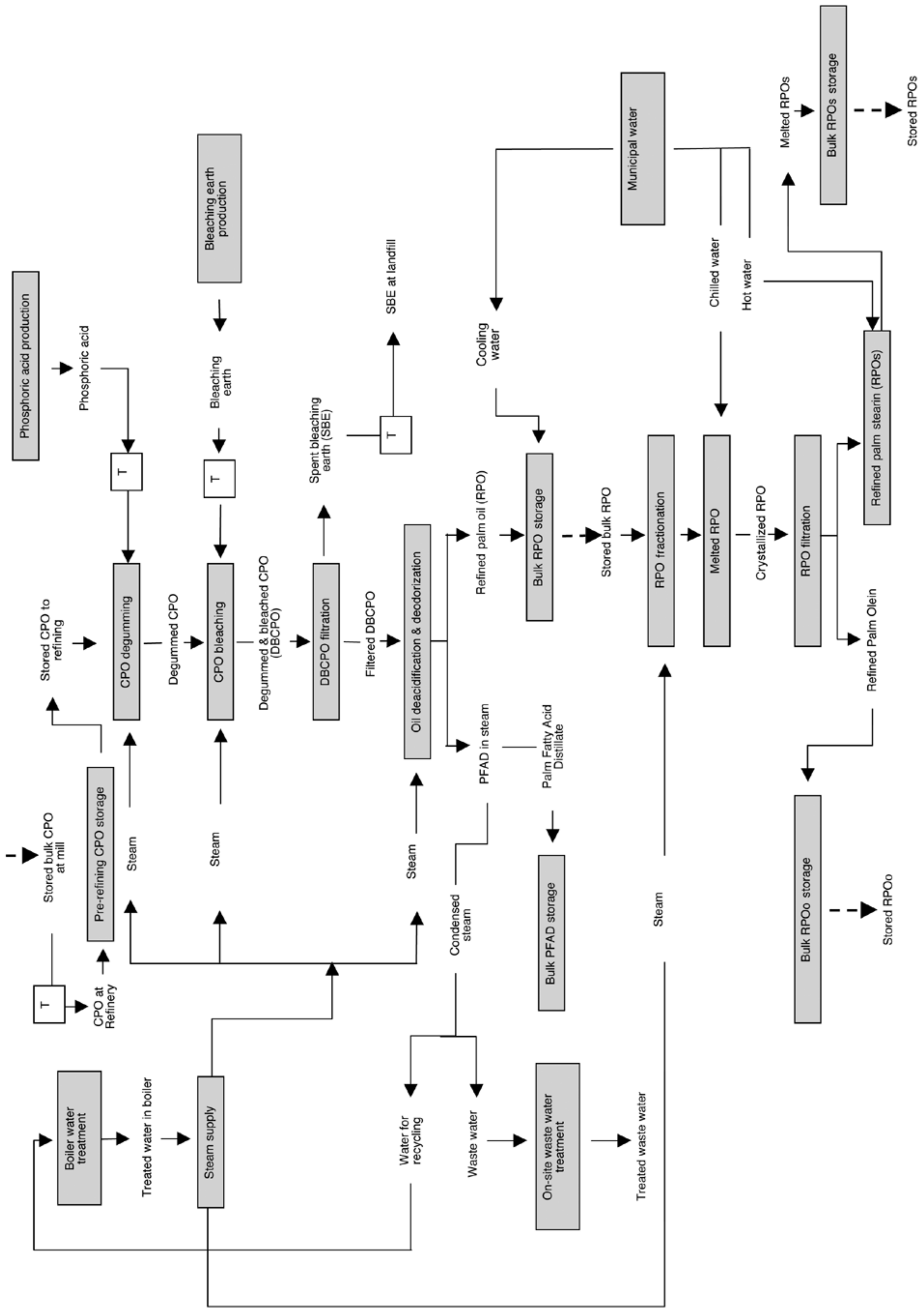

Figure 2. Flow chart for physical refining and fractionation.

Items Excluded from the Study

In the environmental assessment, processes are excluded if they are judged to have an insignificant contribution (<1%) to the overall environmental load; if representative data for the processes are extremely difficult or impractical to gather; if the processes are clearly part of a separate product system; and if the processes are not relevant to the goal of the study.

Inputs to ancillary operations in all unit processes such as lubricants for the operation of the pumps and screw presses, membranes used for filtration of the degummed and bleached oil, and separation of olein from stearin, anti-scaling agents for boilers, and chemicals for water treatment were not included as these were not significant due to their low consumption in comparison with the other inputs.

Also excluded was the production of transportation vehicles such as trucks because many studies have shown that the environmental load from production of these vehicles is insignificant compared to their operation. Land occupation by the refinery and fractionation plant was also omitted.

METHODOLOGY

Life Cycle Inventory

The LCI data for the RPO, RPOo and refined RPOs supply chains were collected through questionnaires disseminated to stakeholders and palm-related agencies. On-site visits were then carried out to verify the information from the questionnaires. Background data for resource exploitation and production of supporting feed materials were obtained through public database searches, literature and the Malaysian LCA database project under SIRIM Berhad. Foreground data for CPO refining and RPO fractionation were site-specific data from refineries in Peninsular and East Malaysia. Data gaps were filled by information obtained from literature and public databases, or calculated using published models.

Co-products

PFAD, the co-product of physical refining of CPO, can be utilized in animal feed to provide the energy component, used for the production of soap and oleochemicals as well as for extraction of phytochemicals such as vitamin E and sterols. These processes are not accounted for in this study as system expansion was not used for the treatment of PFAD.

Capital Goods

In this study, data for capital goods such as refinery structures, equipment and machinery used for processing of the oil were computed based on data from literature (Schmidt, 2008b), mainly because of the difficulty in obtaining reliable capital goods LCI data. The inventory for fractionation equipment was based on the estimate that about a third of the total steel used for the refinery would be required in the fractionation plant. In addition, capital goods for the fractionation plant have been included into the production of RPO because of the complexity involved in allocation of capital goods between RPOo and RPOs. As refining and fractionation plants share the same premises, steel and concrete for the refining plant buildings would include those for the fractionation plant as well.

Data Sources and Data Quality

The period of data collection from 11 refineries was for the year 2007/2008. The data validation procedure was carried out by on-site visits, actual measurements, communication and discussions via e-mail and telephone, and interviews to verify the reliability of the collected data. Technology coverage was not an issue as both refining and fractionation technologies used in Malaysia are standard. Compliance with geographical coverage for data collection was adhered to by collecting data from 11 refineries and plants sited in different regions in Peninsular Malaysia and East Malaysia (Sabah and Sarawak). For each data set, the period during which the data were collected and how the data were collected were documented (*Table 2*).

As the fractionation plant is located in the same premises as the refinery, both facilities share energy and water input; thus, the data for their respective allocation to refineries and fractionation plants were provided by the questionnaire survey as well as on-site verification visits to the refineries.

LCIA of RPO Production and Fractionation

The system boundary for LCIA for RPO includes the nursery, plantation, palm oil mill and the refinery. Thus, background data for the production of CPO beginning from the nursery to the mill were obtained from parallel LCA studies (MPOB, 2010), the results of which are reported in articles in the same issue of this journal. In the case of RPOo and RPOs, the boundary is extended to the fractionation plant. Results presented are based on the production of 1 t of each of the palm oil products. As shown in *Table 1*, CPO for the production of RPO could have been obtained from FFB produced by palms cultivated on previous oil palm (OP) land (OP to

TABLE 2. REFINED PALM OIL PRODUCT SYSTEM AND THE ASSOCIATED DATA TYPE/SOURCE (data collected in the period 2007/2008)

Process gate	Unit process	Process starts	Nature of transmission	Process ends	Data type (B/F*)/ data source
Refining process	Transportation of CPO from mill to refinery	Collection of CPO from the milling unit gate	Physical	Delivery of CPO to refining unit gate	F/site specific data
Refining process	Electricity production	Mining and extraction of fossil fuels	Physical	Distribution to grid at the points of use	B/Ecoinvent database
Refining process	Electricity usage	Refining gate	Energy conversion	Points of use at the refining and fractionation unit gate	F/site specific data
Refining process	Fuel oil production	Mining and extraction of fossil fuels	Physical	Fuel at supplier gate	B/Ecoinvent database
Refining process	Transportation of fuel oil from supplier to refinery	Collection of fuel from supplier gate	Physical	Delivery of fuel oil to refining gate	F/site specific data
Refining process	Fuel usage	Boiler in refinery	Energy conversion	Fuel use for boiler	F/site specific data
Refining process	Water treatment	Extraction of water from aquifers or surface water (river)	Physical, chemical and biological processing	Potable water at water works gate	B/Ecoinvent database
Refining process	Water supply (for steam and chilled water supply)	Potable water at water works gate	Physical	Potable water at refining and fractionation unit gate	B/Ecoinvent database
Refining process	Phosphoric acid production	Acquisition of raw materials	Physical and chemical processing	Phosphoric acid at the production unit gate	B/Ecoinvent database
Refining process	Transportation of phosphoric acid to refinery (includes intermediate storage and retailing)	Collection of phosphoric acid from production unit gate	Physical	Delivery of phosphoric acid to refining unit gate	F/site specific data
Refining process	Phosphoric acid usage	Phosphoric acid store at refinery	Physical	Phosphoric acid for degumming CPO	F/site specific data
Refining process	Bleaching earth production	Acquisition of raw materials	Physical and chemical processing	Bleaching earth at the production unit gate	B/Ecoinvent database
Refining process	Transportation of bleaching earth to refinery (includes intermediate storage and retailing)	Collection of bleaching earth from production unit gate	Physical	Delivery of bleaching earth to refining unit gate	F/site specific data

TABLE 2. REFINED PALM OIL PRODUCT SYSTEM AND THE ASSOCIATED DATA TYPE/SOURCE (data collected in the period 2007/2008) (continued)

Process gate	Unit process	Process starts	Nature of transmission	Process ends	Data type (B/F*)/ data source
Refining process	Phosphoric acid usage	Phosphoric acid store at refinery	Physical	Bleaching earth for adsorptive cleansing of CPO	F/site specific data
Refining process	CPO degumming and earth bleaching	CPO as delivered and stored at refinery	Physical and Chemical processing	Degummed, bleached palm oil Solid waster - spent bleaching earth (SBE)	F/site specific data
Refining process	Solid waste handling (includes transportation)	SBE with retained oil and moisture	Physical	SBE at landfill	F/site specific data
Refining process	Solid waste recycling (includes transportation)	SBE with retained oil and moisture	Physical	SBE and spent earth oil at SBE processing unit gate	F/site specific data
Refining process	Palm oil deacidification and deodorization	Degummed, bleached palm oil	Physical processing	Refined palm oil (RPO)	F/site specific data
Refining process	Recovery of palm fatty acid distillate (PFAD) from waste water	Waste water from processing of CPO	Physical	Waste water and PFAD	F/site specific data
Refining process	On-site waste water treatment	Waste water after recovery of PFAD	Chemical/chemical processing	Treated waste water (to be discharged)	F/site specific data
Refining process	Storage of PFAD	PFAD ready	Physical	PFAD at refining unit gate	F/site specific data
Refining process	Storage of RPO (on tank farm)	RPO ready	Physical	RPO at the refining unit gate	F/site specific data
Refining and fractionation process	Capital goods use including steel and concrete in buildings and processing plant equipment	CPO at RPO gate	Physical/chemical processing	RPO at refining and fractionation gate	B and F/Ecoinvent data base, reference to other site specific data
Fractionation process	RPO fractionation	Refined palm oil at refining gate	Physical processing	Refined palm olein and palm stearin	F/site specific data
Fractionation process	Storage of refined palm olein and refined palm stearin	Refined palm olein and refined palm stearin ready	Physical	Refined palm olein and refined palm stearin at fractionation unit gate	F/site specific data

Note: *B/F – background/foreground.
CPO – crude palm oil.

OP) and extracted in mills with or without a system for capturing biogas. Hence, the outcome of LCIA would depend on the upstream data/activities in the plantation and subsequently the mill. These two scenarios for the production of RPO were evaluated.

In LCIA of RPOo and RPOs, only one scenario, *i.e.* Scenario 1 (*Table 1*) where no land use change (LUC) is involved for the cultivation of palms, and CPO is from a mill without a system for capturing biogas, is investigated. This is because most mills (95%) have not implemented a process for capturing biogas from POME.

RESULTS

Table 3 summarizes material and energy inputs and outputs associated with the refining of CPO to produce 1 t of RPO, while *Table 4* shows the

TABLE 3. INVENTORY FOR PRODUCTION OF 1 t OF REFINED PALM OIL (RPO) BEGINNING AND ENDING AT REFINERY GATE

Input item	**Unit**	**Amount**
Electricity	kWhr	11.94
Boiler fuel	MJ	476.91
Boiler fuel	kg	11.09
Water	litre	113.39
Crude palm oil (CPO)	t	1.05
Phosphoric acid	kg	0.59
Bleaching earth	kg	9.11
Road Transport	Unit	Amount
CPO transport (distance) from mill to refinery (28-t truck)	km	120
Transport of CPO to refinery	tkm	126
Fuel oil transport (distance) from supplier to refinery (28-t truck)	km	500
Transport of fuel oil to refinery	tkm	5.545
Phosphoric acid transport (distance) from chemical plant to refinery (28-t truck)	km	500
Transport of phosphoric acid to refinery	tkm	0.30
Bleaching earth transport (distance) from chemical plant to refinery (16-t truck)	km	100
Transport of bleaching earth to refinery	tkm	0.91
Spent bleaching earth transport (distance) from refinery to landfill (16-t truck)	km	15
Transport of spent bleaching earth to landfill	tkm	0.17
Sea Transport	Unit	Amount
Phosphoric acid sea transport (distance) from Europe to Malaysia	km	15 000
Transport of phosphoric acid Malaysia	tkm	8.85
Bleaching earth sea transport (distance) from Asia to Malaysia	km	3 000
Transport of bleaching earth Malaysia	tkm	27.33
Output item	Unit	Amount
Waste water	litre	42.16
Palm fatty acid distillate	kg	45.62
Spent bleaching earth	kg	11.09
Waste water biochemical oxygen demand (BOD)	kg	1.12
Waste water chemical oxygen demand (COD)	kg	3.26

TABLE 4. INPUT FOR FRACTIONATION OF 1 t OF REFINED PALM OIL (RPO) TO PRODUCE REFINED PALM OLEIN (RPOo) AND REFINED PALM STEARIN (RPOS), BEGINNING AND ENDING AT THE FRACTIONATION PLANT

Input	Amount
Electricity (kWhr)	9.84
Water (litre)	76.27
Refined palm oil (t)	1.00

consumption for the fractionation of 1 t of RPO. LCIA results presented in this article are based on the production of 1 t of each of the palm oil products.

Characterized Results for RPO

Figures 3 and *4* show the characterized results with the relative contribution from the inputs for RPO produced using CPO sourced under the two scenarios listed in *Table 1*.

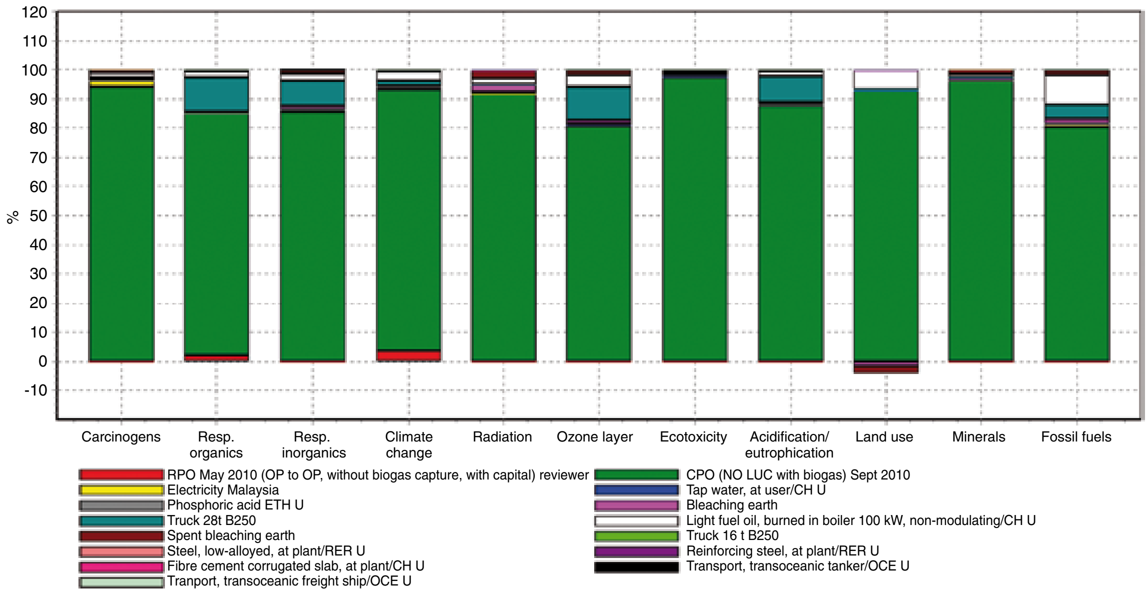

Figure 3. Characterized results for production of 1 t refined palm oil (RPO) (oil palm to oil palm, without biogas capture) – Scenario 1.

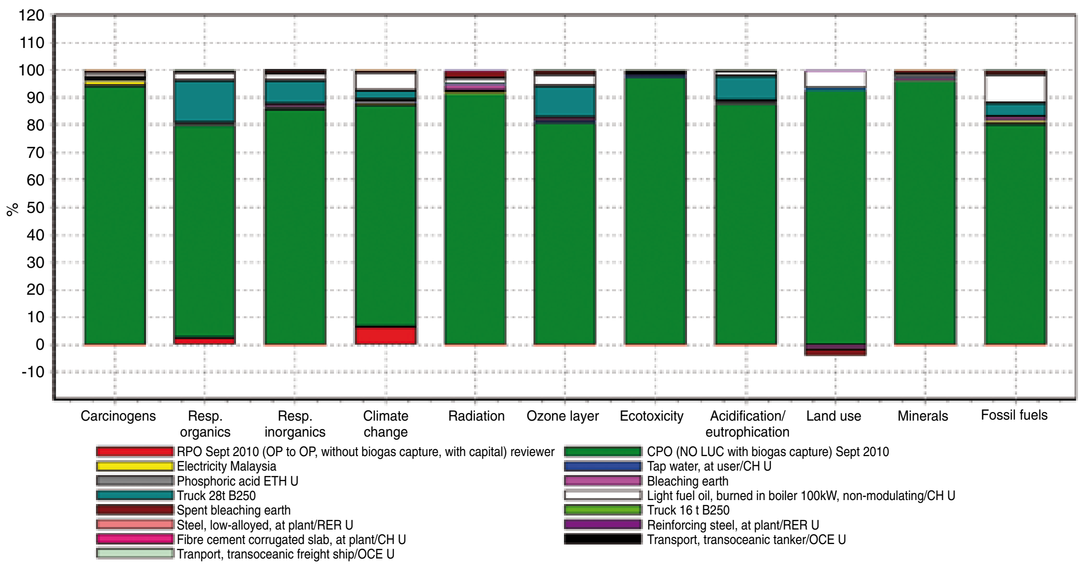

Figure 4. Characterized results for production of 1 t refined palm oil (RPO) (oil palm to oil palm, with biogas capture) – Scenario 2.

The characterization results indicate that the most significant life cycle stage is the production of CPO in the mill which in turn is affected by the production of FFB (MPOB, 2010). The significance is observed in all 11 impact categories and in both the scenarios studied. The contributions from the other inputs are insignificant in comparison with that from CPO. Comparison of the less significant group of contributors show that the combustion of fuel in the boiler and for transporting CPO to the refinery also has an impact, albeit minor in comparison to CPO, on all the categories, especially on fossil fuel depletion.

Weighted Results for RPO

Weighting was used to compare the impact categories among themselves. The characterized results were weighted using the weighting factors in the Eco-indicator method. The weighted results for the production of RPO under the two scenarios are shown in *Figures 5* and *6*. A comparison of the two figures shows a notable reduction in climate change impact when biogas is captured.

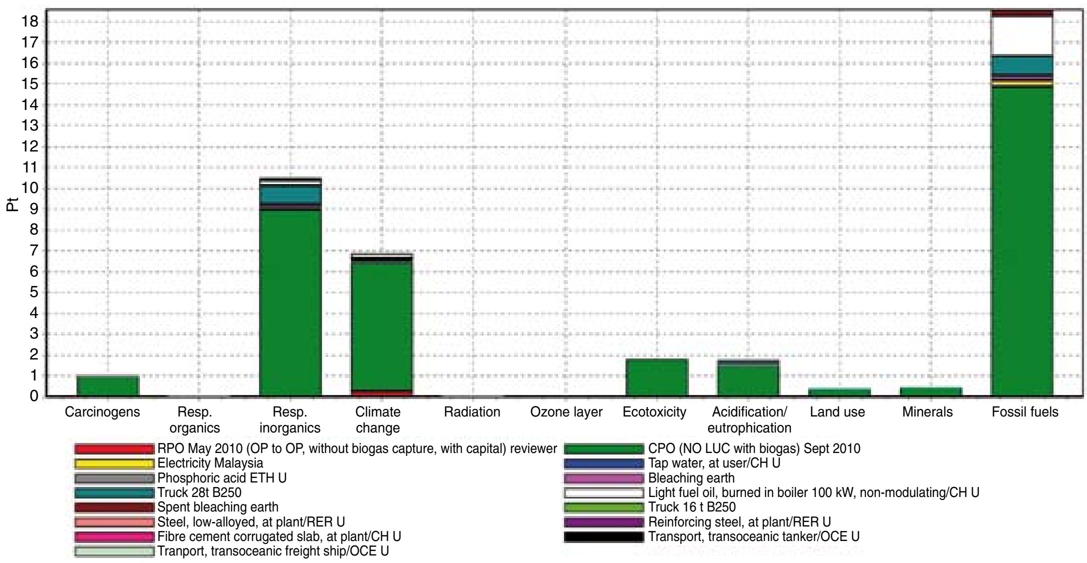

Figure 5. Weighted results for production of 1 t refined palm oil (RPO) (oil palm to oil palm, without biogas capture) – Scenario 1.

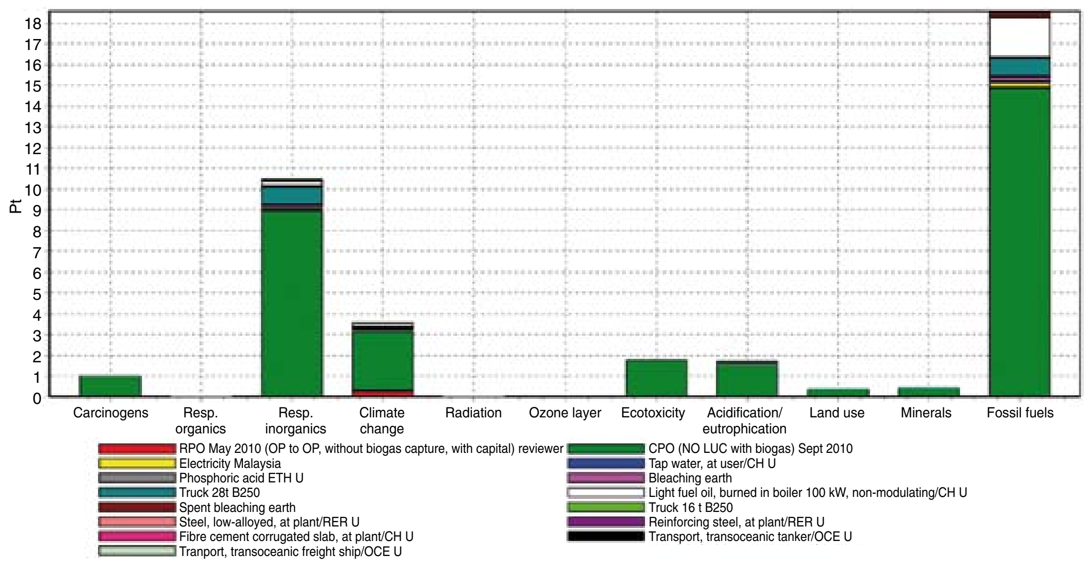

Figure 6. Weighted results for production of 1 t refined palm oil (RPO) (oil palm to oil palm, with biogas capture) – Scenario 2.

Characterized Results for RPOo and RPOs

Figures 7 and *8* show the characterized results of RPOo and RPOs with and without the capture of biogas, respectively. As the production of RPOo and RPOs is largely determined by the feed, RPO, the environmental loads resulting from the production of these RPO fractions are similar to those for RPO.

The characterized results for the production of RPOo and RPOs are similar to that for RPO, *i.e.* the production of the feed material has the most significant impact, and this is seen in all the impact categories (*Figures 7* and *8*). As expected, the other contribution, though insignificant in comparison with RPO, is from electricity.

Weighted Results for RPOo and RPOs

The weighted results for the production of the fractionated products of RPOo and RPOs (*Figures 9* and *10*) mirror the impacts seen in the production of RPO. The main impacts, and in the same order of significance, are again in the categories of fossil fuels, respiratory inorganics, followed by climate change.

Environmental Hotspots

For the production of RPO, RPOo and RPOs, the weighted results using the Eco-indicator 99 show the following impacts as being the most significant

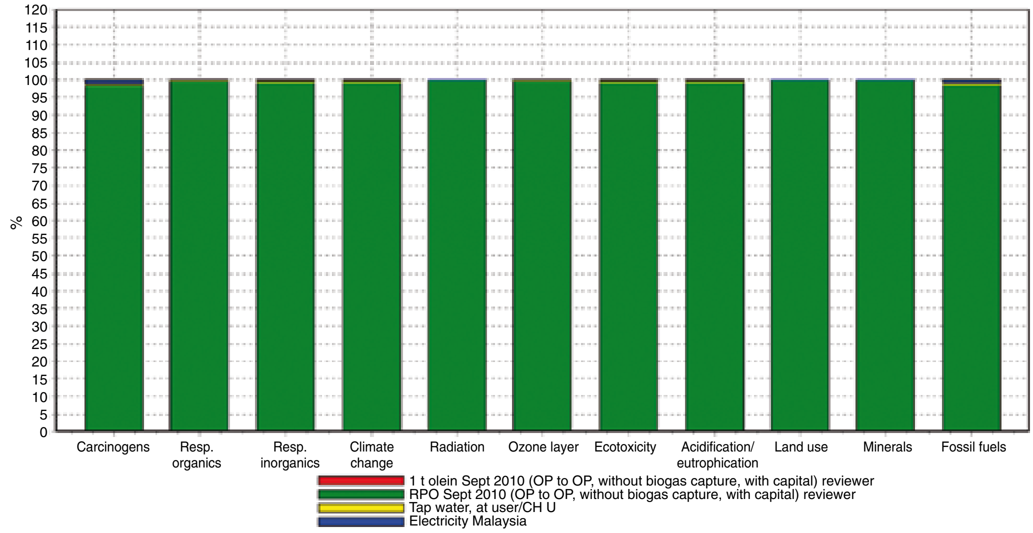

Figure 7. Characterized results for production of 1 t refined palm olein (RPOo) – Scenario 1.

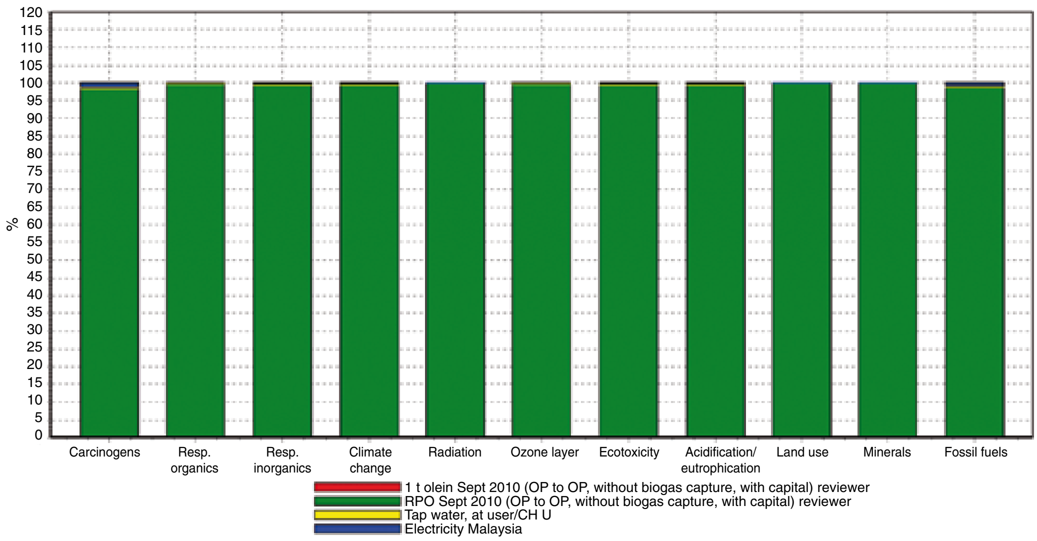

Figure 8. Characterized results for production of 1 t refined palm stearin (RPOs) – Scenario 1.

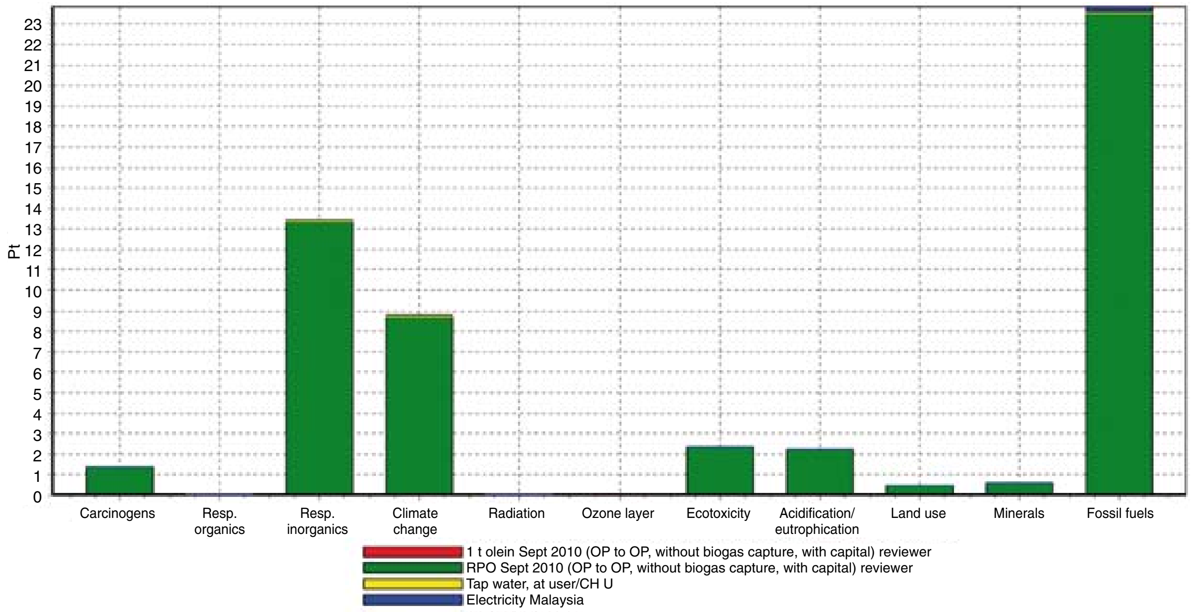

Figure 9. Weighted results for production of 1 t refined palm olein (RPOo) – Scenario 1.

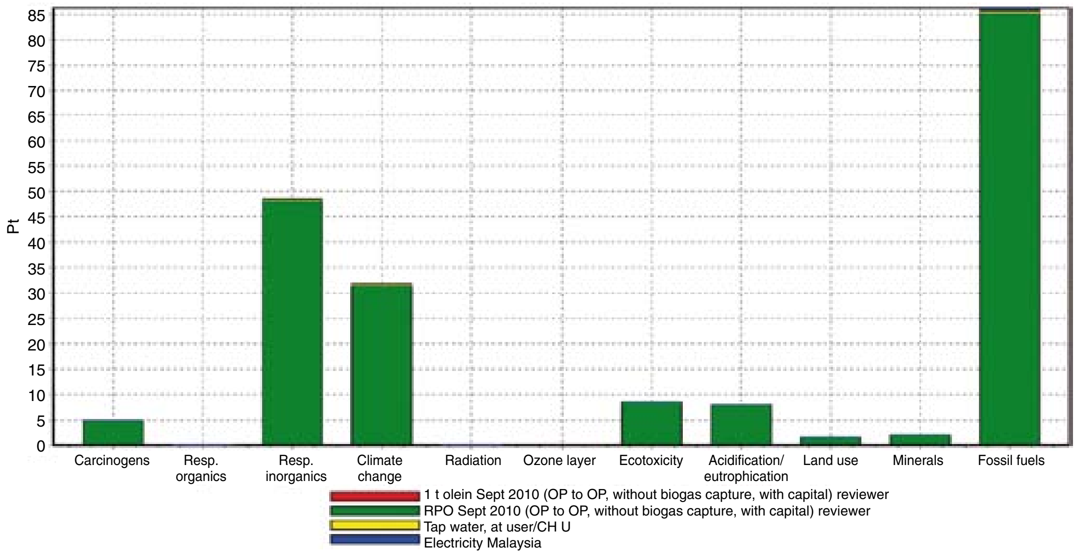

Figure 10. Weighted results for production of 1 t refined palm stearin (RPOs) – Scenario 1.

(in descending order): fossil fuels, respiratory inorganics and climate change.

The impact categories of respiratory inorganics and fossil fuels originate from activities associated with the plantation such as the production and application of fertilizer, and fuel used for machinery and for transport of materials into and out of the plantation. In the case of climate change, the impact results from the emission of biogas by POME. Activities in the refinery itself contribute insignificant environmental impacts. Minor contributions attributed to the process for the production of RPO and its fractions include the use of electricity for fractionation, boiler fuel, emissions from transport during the delivery of CPO to the refinery and of both bleaching earth and spent bleaching earth.

CONCLUSION AND RECOMMENDATIONS

In the production of RPO, the impacts are mainly associated with upstream activities at the oil palm plantation and the palm oil mill. The upstream impacts resulting from FFB and CPO production are propagated down to the production of RPO/ RPOo/RPOs, while the activities confined to the production of RPO, RPOo and RPOs are found to have minor impacts on the environment in comparison.

Weighted results show that the most dominant impact categories for RPO and its fractionated products are fossil fuels, respiratory inorganics and climate change. The main contributor to the fossil fuels category is the production and use of fertilizers for the cultivation of oil palm, with minor inputs from the refining and fractionation processes through the transport of raw and waste material and the use of boiler fuel. The hotspots in relation to respiratory inorganics and climate change are mainly from upstream activities, namely the application of nitrogen fertilizers for cultivation of the palms, and the emissions of methane, carbon dioxide and hydrogen sulphide from POME ponds at the mill. The role of capital goods in the refinery and fractionation plant was found to be insignificant. In the case of fractionation, electricity is an item for mitigation.

The results and conclusions presented in this study reflect the current technology in the systems for refining CPO and for the fractionation of RPO. Therefore, the results are only valid under the circumstances outlined in this article. Gate-to-gate mitigation measures proposed for CPO refining could include the following:

- the sourcing of sustainably produced CPO, *i.e.* oil produced in mills which have a system for biogas capture from POME;
- the combustion of renewable energy as boiler fuel, *e.g.* second generation biofuel; and
- improvement in transport logistics for delivery of materials such as CPO, phosphoric acid and bleaching earth to the refinery, *e.g.* by routing delivery for the shortest distance from supplier to refinery, or integration of mill and refinery.

As the LCA procedure is an iterative process, the different stages in the palm oil supply chain will be re-evaluated with a higher level of data collection details to increase the reliability of the LCA results with each iteration. Data collected for LCI in this study represent only a snapshot for the period of the study, and are therefore in need of regular updating. This is in line with the continued efforts by the refineries and fractionation plants in improving their efficiency in energy consumption as well the development of new technology for processing CPO and fractionating RPO. Focus will be on energy savings and the introduction of innovative technology.

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REFERENCES

DOORN, M R J; STRAIT, R; BERNARD, W and EKLUND, B (1997). *Estimate of Global Greenhouse Gas Emissions from Industrial and Domestic Wastewater Treatment*. Final report, EPA-600/R-97-091. Prepared for United States Environmental Protection Agency, Research Triangle Park, NC, USA.

IPCC (2006). *Guidelines for National Green House Gas Inventories*. Intergovernmental Panel on Climate Change (IPCC), IPCC/OECD/IEA, Paris, France.

MOHD NAZRI, A (2008). LCI of electricity for Malaysia. Paper presented at the Seminar on Life Cycle Assessment for Industry and Business Sustainability, 20 Jan 2008, Sheraton Hotel, Subang Jaya, Selangor, Malaysia.

MPOB (2009). *Malaysian Palm Oil 2008 Statistics*. MPOB, Bangi.

MPOB (2010). *Malaysian Palm Oil 2009 Statistics*. MPOB, Bangi.

MPOB (2010). *LCA of Malaysian Oil Palm Products on Mineral Soil Including Palm Biodiesel.* Third party reviewed LCA report by MPOB.

OIL WORLD ANNUAL (2010). Chapter 2: 17 oils and fats. Vol. 1. ISTA Mielke GmbH, Langenberg 25, 21077 Hamburg, Germany.

PRÉ CONSULTANT (2007). SimaPro version 7.1. Amersfoort, Netherlands.

SCHMIDT, J (2008a). System delimitation in agricultural consequential LCA: outline of methodology and illustrative case study of wheat in Denmark. *Int J Life Cycle Assess, 13 (4)*: 350-364.

SCHMIDT, J (2008b). *Life Cycle Assessment of Palm Oil at United Plantations Berhad*. Published by United Plantations Berhad, Teluk Intan, Malaysia.

SCHMIDT, J (2010). Comparative life cycle assessment of rapeseed oil and palm oil. *Int J Life Cycle Assess, 15 (2)*: 183-197.