QUANTIFICATION OF GREENHOUSE GAS EMISSIONS FOR THE PRODUCTION OF CRUDE PALM KERNEL OIL – A CRADLE TO GATE STUDY

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ABSTRACT

The Malaysian oil palm industry is one of the major economic backbones of the country. The industry as a whole brought in an export revenue of RM 63 billion just in the year 2015. In the past, the competiveness of palm products along the supply chain was based on direct economic comparison with other vegetable oil products. However, with increasing attention on sustainable development, the environmental performance of products are now defining issues in trade. This articles presents the greenhouse gas (GHG) emissions for the production of crude palm kernel oil (CPKO). Crude palm oil (CPO) and CPKO both come from the oil palm fresh fruit bunch (FFB). CPO is obtained from the mesocarp of the fruit and the lauric CPKO comes from the kernel at the fruit's core. CPO is produced in the palm oil mill while palm kernels which are the by-product of the production of CPO are transported to kernel crushing plants to be processed into CPKO. The objectives of this study are to quantify the GHG emissions for the production of CPKO and suggest the best solution to reduce the emissions if any. The system boundary starts from the production of oil palm seedlings at the nursery stage right till the production of CPKO at the kernel crushing plant which makes it a cradle to gate study. Inventory data for the production of CPKO was collected from 24 crushing plants which were located near the ports and two kernel crushing plants which were integrated with a palm oil mill. Weight allocation was performed at the kernel crushing plant. The largest GHG contribution came from upstream nursery and plantation with continued land use which amounts to 394.19 kg CO_2 eq/t CPKO followed by emissions from biogas at the palm oil mill which amounts to 87.48 kg CO_2 eq/t CPKO even though the scenario chosen is the biogas capture scenario. The third largest GHG emissions comes from the kernel crushing plant due to the processing of CPKO using the electricity from the grid which emits 74.33 kg CO_2 eq/t CPKO. The GHG emissions from the consumption of electricity from the grid of the kernel crushing plant integrated with a palm oil mill reduced to only 7.59 kg CO_2 eq/t CPKO. A sensitivity analysis on allocation was conducted. With weight allocation, the burden on CPKO was reduced compared to when economic allocation was conducted, where almost the whole burden was on CPKO. The allocation parameter seems to change the outcome of the study drastically because the volume of the palm kernel cake which is the by-product at the kernel crushing plant is high but has low economic value.

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INTRODUCTION

Over the last century, modern industry and life styles have rapidly increased the amounts of greenhouse gas (GHG) in the earth's atmosphere (Agric, 2015). This increase is believed to cause changes to the earth's climate. Changes in climate are expected to lead to more severe weather events such as prolonged droughts and flooding which may reduce the availability of water supplies (Agric, 2015) and suitable land and weather to cultivate food crops. In an attempt to address the problem, virtually all the countries of the world agreed to establish a framework convention known as the UN Framework Convention on Climate Change (UNFCCC) (Theseira, 2013). Under the Convention, all Parties agreed to report their national GHG inventories and mitigation measures in their respective National Communication (Theseira, 2013).

The Malaysian oil palm industry is one of the major economic backbones of the country. The industry as a whole brought in an export revenue of RM 63 billion just in the year 2015 (Choo, 2015). In the past, the competiveness of palm products was based on direct economic comparison with other vegetable oil products. However, with increasing attention on sustainable development, the environmental performance of products is now defining issues in trade.

In Europe, the European Union Renewable Energy Directive (EURED) has imposed a non-tariff barrier on the imports of palm biodiesel based on GHG emissions calculations. The Notice of Data Availability (NODA) published by the Environmental Protection Agency (EPA) of USA in 2012 for the Renewable Fuels Standard 2 (RFS2) programme ruled that oil palm biofuel does not meet the GHG emissions threshold requirements when compared to fossil fuel.

These market demands show the global trend that demands producers like the oil palm industry to measure and also reduce the GHG emissions of their products. One such study was published in Choo *et al*. (2011) where the GHG emissions for the various products for the system boundary of oil palm seedling - oil palm fresh fruit bunch (FFB) – crude palm oil (CPO) - refined palm oil (RPO) - palm biodiesel was reported. Another study by Rodrigues *et al*. (2014) also calculated the GHG of the supply chain for the production of palm biodiesel. Hassan *et al*. (2011) also charted the GHG of CPO for bioenergy perspective. However, all these publications did not include another important product which is the production of crude palm kernel oil (CPKO). There was a study of the GHG emissions of CPKO by the same authors (Subramaniam *et al*., 2012) but that study was only a gate to gate assessment. This article presents the GHG emissions for the production of CPKO.

CPO and CPKO both originate from FFB from the oil palm but the similarity of both oils ends there. CPO comes from the mesocarp or flesh of the fruit and the lauric CPKO comes from the kernel at the fruit's core as shown in *Figure 1*. The two oils are separated in the oil palm fruitlets by a thick shell surrounding the palm kernels. The kernel is surrounded by the fruit wall made up of hard shell

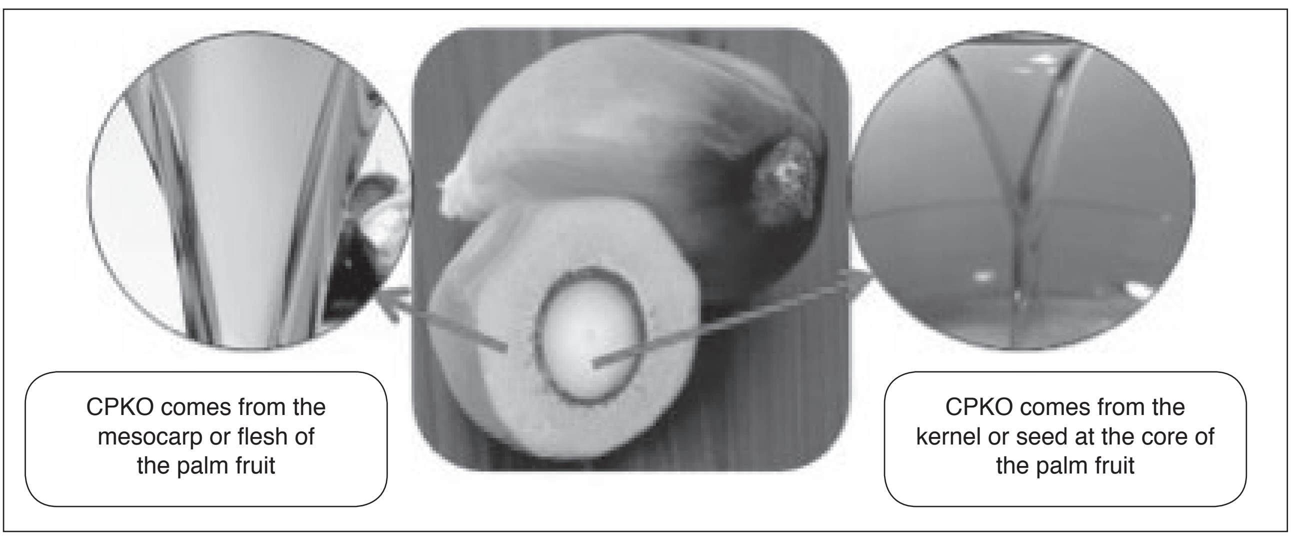


Figure 1. Oil palm fruitlet cross-section.

(endocarp), fibrous fruit pulp or oil bearing tissue (mesocarp) and the skin. The kernel is within the nut itself which is obtained by cracking the nut of the fruit.

CPKO is produced by a simple mechanical pressing method using a continuous screw press, commonly known as an expeller (Vijaya *et al*., 2010a) as shown in *Figure 2*.

As described in Vijaya *et al*. (2010a), the expeller consists basically of a perforated cylindrical cage in which runs a worm or screw where the discharge end of the cage is fitted with an adjustable cone which restricts the discharge opening of the cage. The rotation of the worm transports the meal towards the outlet end of the perforated cage and the outlet is restricted by the cone (Vijaya *et al*., 2010a). This causes pressure to build up in the cage causing the oil to be squeezed out of the meal which seeps out through the perforations in the cage while the pressed cake is discharged. The same process is repeated and the cake is squeezed again to obtain more oil (Vijaya *et al*., 2010a).

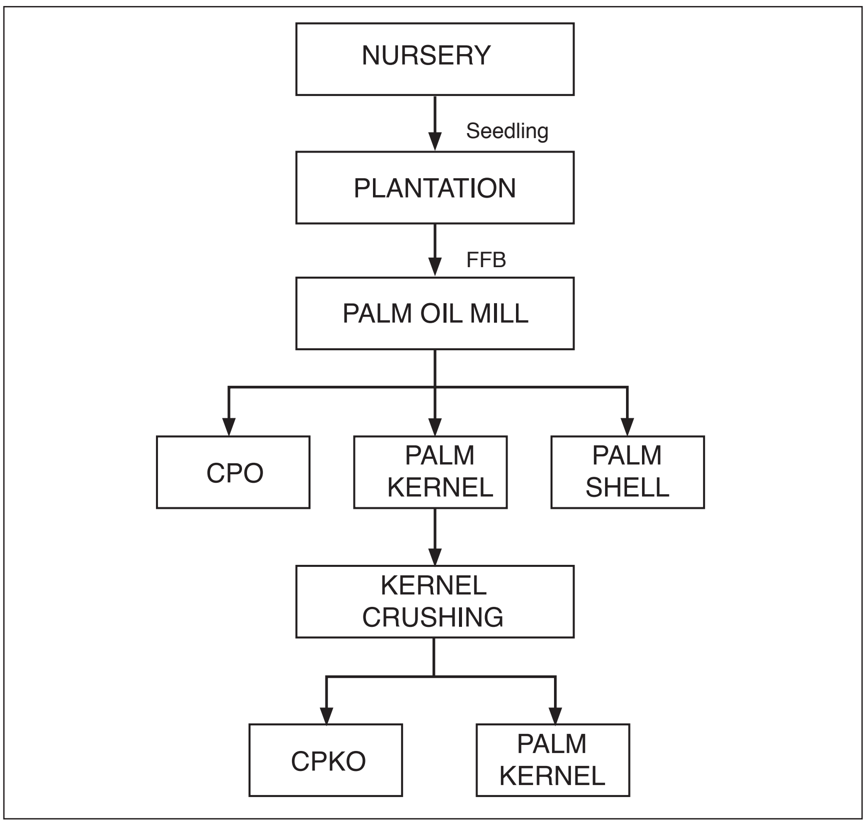
Figure 2. A series of screw presses to crush the palm kernels.

The objective of this study is to quantify the GHG emissions for the production of CPKO and to suggest the best solution to reduce the emissions if any.

METHODOLOGY

System Boundary

The system boundary starts from the production of oil palm seedlings at the nursery stage right till the production of CPKO at the kernel crushing plant which makes it a cradle to gate study. The various stages included in the system boundary are shown in *Figure 3*. The functional unit is the unit where all the inputs and outputs are calculated for the system boundary. The functional unit of this study was 1 t CPKO produced at the kernel crushing plant.



Note: CPO - crude palm oil.
CPKO - crude palm kernel oil.
FFB – fresh fruit bunch.

Figure 3. System boundary.

Inventory Data Collection

In order to enable easy access to the ports to export the CPKO and palm kernel cake, kernel crushing plants are usually located near the ports. However, there are a few kernel crushing plants which are located far from the ports but are integrated with a palm oil mill. Inventory data for the production of CPKO was collected from 26 kernel crushing plants, out of which two were integrated with a palm oil mill while the rest were located near the ports.

Inventory data were collected directly from the kernel crushing plants 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. The data validation procedure was carried out by on-site visits, on-site measurements, communication and discussions via e-mail and telephone, and interviews to verify the reliability of collected data.

Apart from the data within the kernel crushing plant boundary itself, this study also used data from the upstream and midstream activities of the oil palm industry as listed in *Table 1*. The continued land use change scenario was used in the plantation stage which means that the previous land use was oil palm plantation. The scenario chosen for the palm oil mill was the biogas capture scenario because as stated in Choo *et al*. (2011), the highest GHG contribution for the production supply chain comes from biogas which originates from the anaerobic treatment of the palm oil mill effluent or waste water at the palm oil mill. In order to avoid the domination of this upstream impact at the kernel crushing plant, the biogas capture scenario was adopted. At the kernel crushing plant, two scenarios were chosen:

- kernel crushing plants located near the ports; and
- kernel crushing plant integrated with a palm oil mill.

TABLE 1. INVENTORY DATA SOURCES

Life cycle stage	Data source
Oil palm nursery	Halimah *et al*. (2010)
Oil palm plantation	Zulkifli *et al*. (2010)
Palm oil mill	Vijaya *et al*. (2010b)

Allocation of By-products

At the kernel crushing plants, the by-product of CPKO production is palm kernel cake or palm kernel expeller. Weight allocation was carried out between CPKO and palm kernel cake at a ratio of 47:53.

RESULTS AND DISCUSSION

Life cycle inventory (LCI) data are inventory data that have been calculated to quantify the environmental inputs and outputs of the functional unit within the system boundary. *Table 2* shows the LCI for the production of seedlings at the nursery for every tonne of CPO while *Table 3* shows the characteristics of the plantation used for the study by Zulkifli *et al*. (2010). *Table 4* shows the LCI for the production of oil palm FFB at the plantation for every tonne CPO and *Table 5* shows the LCI for the production of 1 t CPO with no allocation and 1 t palm kernel with weight allocation at the palm oil mill. These data were extrapolated from the LCI from Halimah *et al*. (2010), Zulkifli *et al*. (2010) and Vijaya *et al*. (2010b) and calculated back for 1 t CPO.

TABLE 2. LIFE CYCLE INVENTORY (LCI) FOR THE PRODUCTION OF OIL PALM SEEDLING PER TONNE CRUDE PALM OIL (CPO)

Input	per tonne CPO
Electricity (kWh)	0.0099
Diesel (litre)	0.0066
Polybag (kg)	0.003465
Water (litre)	2.457
Fertiliser	
N (kg)	0.0008415
P_2O_5 (kg)	0.000429
K_2O (kg)	3.47E-04
Thiocarbamate (kg)	0.00001848
Pyrethroid (kg)	0.000005841
Organophosphate (kg)	0.000033
Dithiocarbamate (kg)	0.000158565
Unspecified pesticide (kg)	2.2275E-06
Urea/sulfonylurea (kg)	0.000035805
Glyphosate (kg)	0.000014685
Transportation (tkm)	
Van (<3.5 t) B250	1.06755E-08

Source: Halimah *et al*. (2010).

TABLE 3. THE CHARACTERISTICS OF THE PLANTATIONS USED IN THE STUDY

Plantation characteristics	
FFB yield (t ha^{-1} yr^{-1})	20.7
Planting density (palm ha^{-1})	142
Soil char acteristics	Mineral soils
Plantation lifetime	25 years
Number of plantations	102
Total area	1.1 million hectares (93.7% mature and 6.3% immature)

Note: FFB - fresh fruit bunch.
Source: Zulkifli *et al*. (2009).

TABLE 4. LIFE CYCLE INVENTORY (LCI) FOR THE PRODUCTION OF FRESH FRUIT BUNCH (FFB) PER TONNE CRUDE PALM OIL (CPO)

Input	per tonne CPO
Energy use	
Diesel; agriculture machinery (litre)	11.85
Material use	
Oil palm seedling (transplant)	1.65
Ammonium sulphate (kg)	40.25
Urea (kg)	2.05
Ammonium nitrate (kg)	3.80
Ammonium chloride (kg)	3.60
N from compound, mixture (kg)	5.80
N fertiliser application (kg)	17.45
Muriate of potash (kg)	58.00
Fertiliser K_2O from compound, mixture (kg)	22.50
Total K_2O applied (kg)	57.50
Phosphate rock (kg)	32.75
Fertiliser P_2O_5 from compound, mixture (kg)	3.20
Total P_2O_5 applied (kg)	14.00
Glyphosate (kg a.i)	1.69
[Sulfonyl]urea compounds (kg a.i)	0.74
Bypyridylium compounds (kg a.i)	0.52
Pyretroid compounds (kg a.i)	0.11
Organophosphorus compounds (kg a.i)	0.32
Carbofuran (kg a.i)	0.18
2,4-D,dimethylamine salt (kg a.i)	0.16
Pesticide unspecified (kg a.i)	10.44
Transport	
FFB to mill; lorry (tkm)	250.00
Fertiliser from port to plantation; lorry (tkm)	25.50
Pesticides from port to plantation; lorry (tkm)	0.75

Source: Zulkifli *et al*. (2009).

TABLE 5. AVERAGE LIFE CYCLE INVENTORY (LCI) DATA FOR 1 t CRUDE PALM OIL (CPO) AND 1 t PALM KERNEL

Parameter	1 t CPO	1 t Palm kernel (weight allocation)
Fresh fruit bunches (t)	5.08	3.10
Power consumption from turbine (MJ)	367.34	223.99
Power consumption from grid (MJ)	2.89	1.76
Diesel consumption for mill (MJ)	164.48	100.29
Transportation of diesel to mill (tkm)	0.89	0.54
Fuel used in boiler		
Mesocarp fibre (t)	0.59	0.36
Shells (t)	0.15	0.09
Boiler water consumption (t)	2.57	1.57
Water for processing (t)	3.56	2.17
Kernels (t)	0.41	1.00
Mesocarp fibre (t)	0.00	0.00
Shells (t)	0.38	0.23
Empty fruit bunches (EFB; t)	1.16	0.71
Palm oil mill effluent (POME; t)	3.05	1.86
Methane gas (kg)	36.41	22.20
CO_2 from POME pond (kg)	59.08	36.03
Boiler ash (t)	0.02	0.01
Steam input to turbine (t)	2.66	1.62
Steam input for sterilisation (t)	2.56	1.56
Flue gas from stack		
Particulate matter (kg)	0.20	0.12
CO (kg)	0.07	0.04
CO_2 (kg)	67.67	41.26
SO_x (kg)	0.00	0.00
NO_x(kg)	0.11	0.07

Source: Vijaya *et al*. (2010b).

Table 6 shows the average LCI data for 1 t CPKO produced at 24 kernel crushing plants located near to the ports and two kernel crushing plants integrated with a palm oil mill.

GHG EMISSIONS

The GHG emissions for the production of 1 t CPKO for kernel crushing plants located near the ports and integrated is shown in *Table 7*. The GHG values are a total from nursery, plantation with oil palm to oil palm land use change, palm oil mill with biogas capture and kernel crushing plant with weight allocation.

The largest GHG contribution comes from the nursery and plantation with continued land use which amounts to 394.19 kg CO_2 eq/t CPKO. This emission from the plantation is largely contributed by the use of fertilisers and pesticides. The second largest GHG emissions come from the palm oil mill mainly from the biogas emissions. This is due to the methane emissions from the palm oil mill effluent (POME) during the anaerobic treatment at the palm oil mill. Even though the scenario chosen is the biogas capture scenario the capture efficiency assumed in the study by Vijaya *et al*. (2010b) was only 85% capture efficiency resulting to a residual biogas emission of 87.48 kg CO_2 eq/t CPKO. Finally the third largest GHG emissions comes from the kernel crushing plant due to the consumption of electricity from the grid for processing the CPKO which emits 74.33 kg CO_2 eq/t CPKO. However, when the kernel crushing plant is integrated with a palm oil mill, the GHG emissions for the consumption of electricity from the grid reduces to only 7.59 kg CO_2 eq/t CPKO. The GHG for the transportation of palm kernel from the mill also reduces from 6.53 kg CO_2 eq/t CPKO to only 0.24 kg CO_2 eq/t CPKO.

The kernel crushing plant which is located beside the palm oil mill is identical in the processing methods with the other crushing plants that are

TABLE 6. AVERAGE LIFE CYCLE INVENTORY (LCI) DATA FOR 1 t CRUDE PALM KERNEL OIL (CPKO) PRODUCED AT 24 KERNEL CRUSHING PLANTS LOCATED NEAR TO THE PORTS AND TWO KERNEL CRUSHING PLANTS INTEGRATED WITH A PALM OIL MILL

No.	Parameter	Located near ports	Integrated with palm oil mill
1.	Palm kernel (t)	2.27	2.30
2.	Electricity form grid (MJ)	954.50	93.60
3.	Electricity generated at palm oil mill (MJ)	-	896.00
4.	Transportation of kernel (km)	149.00	2.00
5.	Palm kernel cake (t)	2.56	2.60

TABLE 7. THE GREENHOUSE GAS (GHG) EMISSIONS FOR 1 t CRUDE PALM KERNEL OIL (CPKO) (nursery to kernel crushing plant system boundary)

Parameters	Kernel crushing plant located near the ports (kg CO_2 eq)	Kernel crushing plant integrated with palm oil mill (kg CO_2 eq)
Plantation and nursery	394.19	394.19
Palm oil mill (biogas captured)	102.15	102.15
Kernel crushing plant		
Electricity from grid	74.33	7.59
Boiler emissions	-	46.16
Transportation of palm kernel	6.53	0.24
Total	577.20	550.33

located near the ports but it has one big difference which is the source of the energy. The kernel crushing plants located near the ports only use the electricity from the national grid supply for processing. However, the kernel crushing plant located beside the palm oil mill uses the electricity supply from the neighbouring palm oil mill. The palm oil mill generates renewable energy by burning the pressed mesocarp fibre and palm shell in a biomass boiler which generates steam. This steam is used to run a turbine which produces electricity that is used by the palm oil mill as well as for the kernel crushing plant nearby.

SENSITIVITY ANALYSIS

A sensitivity analysis on allocation was conducted. Weight allocation between CPKO and palm kernel cake gives a ratio of 47:53. When economic allocation was carried out the ratio between CPKO and palm kernel cake was 92:8. The comparison of GHG emissions for CPKO with weight allocation and economic allocation is as shown in *Figure 4*.

With weight allocation, the burden on CPKO is reduced to almost half as compared to when economic allocation is conducted. When economic allocation is conducted almost the whole burden is on CPKO. This goes to show that the decision on which allocation method should be used can alter the findings drastically in this context because the volume of the palm kernel cake which is the by-product at the kernel crushing plant is high but has low economic value. So when weight allocation is carried out it takes off much of the burden from the CPKO. However, when economic allocation is carried out the burden shifts back to CPKO as the economic value of palm kernel cake is very low.

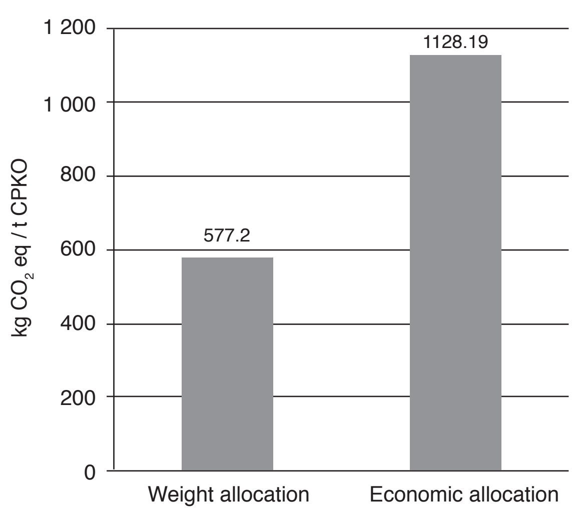


Figure 4. Greenhouse gas (GHG) emissions for the production of crude palm kernel oil (CPKO) with weight allocation vs. *economic allocation (nursery to kernel crushing plant located near ports).*

CONCLUSION

For this system boundary which starts at the nursery right till the kernel crushing plant; the results show that the main impacts from upstream are from the fertiliser production and application at the plantation and nursery, and the residual biogas emissions at the palm oil mill. The impacts directly associated with the production of CPKO are mainly the transportation of palm kernel from the palm oil mills to the kernel crushing plants and the electricity consumption from the grid for the processing of CPKO. In view of this, a kernel crushing plant integrated with a palm oil mill is the better way to reduce the GHG emissions. However, integrating the kernel crushing plant with the palm oil mill will increase the distance to the ports for export. In order to truly gauge if integrating the kernel crushing plant with a palm oil mill is more beneficial than locating near the ports the transportation of CPKO and palm kernel cake to the ports have to be examined which is out of the scope of this study. Since weight and economic allocation gives such different findings the best method is to carry out system boundary expansion and avoid allocation all together. As it goes to show that decisions on allocation procedures can drastically alter the findings of a study.

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