# LIFE CYCLE INVENTORY OF THE PRODUCTION OF CRUDE PALM OIL -A GATE TO GATE CASE STUDY OF 12 PALM OIL MILLS

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### ABSTRACT

Life cycle inventory (LCI) is the heart of a life cycle assessment (LCA) study. LCA is a tool to determine the environmental impacts of a product at all stages of its life right from cradle to grave. In order to carry out a LCA, inventory data have to be collected and the raw data have to be extrapolated to produce a LCI. This study has a gate to gate system boundary. The inventory data collection starts at the oil palm fresh fruit bunch hoppers when the fresh fruit bunches are received at the mill up till the production of the crude palm oil in the storage tanks at the mill. For this study, 12 palm oil mills were selected. These palm oil mills were selected based on the type of mill which were either plantation-based mills or private mills and have different processing capacities of oil palm fresh fruit bunches ranging from 20 t  $hr^{-1}$  up till 90 t  $hr^{-1}$ . The mills selected are all located at different zones in east and west Malaysia basically from north, mid south, south Peninsular Malaysia and east Malaysia. Inventory data collection consists of input and output of materials and energy. The input data basically are inputs of raw materials such as oil palm fresh fruit bunches, electricity, diesel, water, fuel for boiler etc. and the output consists of the biomass wastes, palm oil mill effluents, flue gases from stack, kernel etc. All data were collected for duration of three months from each mill. These inventory data were then calculated for the functional unit of every 1 t of crude palm oil produced at the palm oil mill.

Keywords: biomass, crude palm oil, fresh fruit bunch, life cycle assessment, life cycle inventory.

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# INTRODUCTION

Malaysia is one of the world leaders in the production and export of crude palm oil. In Malaysia, the oil palm industry has contributed immensely towards the country's economic well being.

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\*\* Department of Chemical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia. During the economic crisis in 1997/1998, the industry has helped to cushion the impact of the economic downturn through its export-oriented activities, which provided the much needed foreign exchange for the country. In 2006, crude palm oil (CPO) production reached 15.9 million tonnes (Mohd Basri Wahid, 2007).

The oil palm industry is a self-sufficient industry. The concept of recycling of the palm oil mill byproducts is not new but merely resurfaces in the light of recent economic and environmental concerns (Ma, 2002).

Over the years, the oil palm industry has been very responsible and all the by-products have gradually been utilized. Since 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 zerowaste policy (Chan, 1999).

Generally, some of the by-products mainly shell and mesocarp fibre are used as fuel in boiler to generate steam to run a turbine to generate electricity.

# LIFE CYCLE INVENTORY

Life cycle inventory (LCI) is the heart of a life cycle assessment (LCA) study (Narayanaswamy *et al.*, 2002). The Society for Environmental Toxicology and Chemistry (SETAC) Code of Practice defines LCA as:

"... a process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and materials used and released to the environment, and to identify and evaluate opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extraction and processing raw materials, manufacturing, transportation and distribution, use, reuse, maintenance, recycling and final disposal (SETAC, 1993)."

LCI is an inventory of input and output data. Typically inventory data include raw materials and energy consumption and emissions of solid, liquid and gaseous wastes. A LCI consists of data which are extrapolated to quantify the inputs and outputs of a product based on its functional unit (Awang *et al*, 1999; Sanchez, 2003).

#### **OBJECTIVE**

The objective or goal of this study is to identify and quantify the environmental inputs and outputs associated with the production of CPO at the palm oil mill.

#### SCOPE/SYSTEM BOUNDARY

A gate to gate study was carried out whereby the system boundary was set to only include the production process of the CPO as shown in *Appendix 1*. The starting point is at the oil palm fresh fruit bunch (FFB) hoppers where the FFBs are received up till the production of the CPO in the storage tanks. The functional unit for this study is 1 t of CPO produced.

#### METHODOLOGY

Twelve palm oil mills were selected for this study. These palm oil mills were selected based on the type of mill which were either plantation-based mills or private mills. They have different processing capacities of FFBs ranging from 20 t hr<sup>-1</sup> up till 90 t hr<sup>-1</sup> and also these mills are all located at different zones in Peninsular Malaysia basically from north, mid south, southeast and east Malaysia

Inventory data were collected from the selected palm oil mills over a period of three months. They consisted of raw material usage as well as the emissions of solid, liquid and gaseous wastes as shown below:

- raw material usage;
- excess fibre and shell mix from the boiler;
- excess shell;
- quantification of palm oil mill effluent (POME);
- emissions of flue gas from the boiler stack and POME pond;
- quantification of empty fruit bunch (EFB) and boiler ash;
- quantification of fuel flow rate;
- energy consumption; and
- recycling and treatment of wastes.

# QUANTIFICATION OF WASTE



Excess fibre & shell mix

Empty fruit bunch



Quantifying boiler ash

Monitoring stack emission



Quantifying fuel flow rate in boiler

Figure 1. Quantification of biomass and other emissions.

# **RESULTS AND DISCUSSION**

Inventory data collected over a period of three months from each mill were divided into inputs and outputs. The data were then extrapolated to quantify the inputs from the environment and outputs to the environment for every 1 t of CPO produced as shown in *Tables 1* and 2.

Palm oil mills numbered 3, 4 and 12 are private mills. These mills do not own oil palm plantations. They receive their FFBs from other private oil palm plantation owners. The other nine palm oil mills are all plantation-based mills which have their own oil palm plantations.

The environmental inputs to produce 1 t of CPO as shown in *Table 1* are FFB, power consumption from turbine and grid, diesel consumption, boiler fuel, water consumption for boiler as well as process and steam input to turbine, sterilization or cooking of the fruits. The rows which have been highlighted in *Table 1* are basically renewable energy and recycled materials.

Based on the inventory data (*Appendix 2*), approximately 5.09 t of FFB are required to produce

TABLE 1. LIFE CYCLE INVENTORY FOR PALM OIL MILLS NUMBERED 1 TO 12 ENVIRONMENTAL INPUTS FOR EVERY 1 t CRUDE PALM OIL (CPO) PRODUCED

Mill	1	2	3	4	5	6	7	8	9	10	11	12
Туре	PL	PL	PR	PR	PL	PL	PL	PL	PL	PL	PL	PR
Processing capacity (t hr <sup>-1</sup> )	20	30	40	40	45	45	50	50	60	65	70	90
Fuel flow rate (t hr <sup>-1</sup> )	2.50	3.50	5.60	4.50	4.88	5.00	6.00	5.90	7.50	7.50	13.00	11.00
Fuel ratio fibre: shell	80:20	70:30	70:30	80:20	70:30	90:10	80:20	80:20	80:20	80:20	60:40	90:10
Steam output (t hr <sup>-1</sup> )	10.00	14.00	22.50	17.50	19.00	18.00	24.00	23.50	30.00	30.50	52.00	42.50
Environmental Ir	puts											
FFB (t)	4.93	5.07	5.34	5.48	5.27	4.67	5.47	5.10	4.67	4.67	4.87	5.39
Power from turbine (kWhr)	98.59	101.38	106.73	109.57	105.48	93.41	109.34	101.91	93.48	93.46	97.36	107.71
Power from grid (kWhr)	2.00	1.99	0.18	0.25	2.95	0.00	0.00	0.00	0.00	0.00	0.00	0.10
Diesel for mill use (l)	2.17	0.00	1.29	1.98	2.92	2.86	2.45	2.12	4.47	3.37	4.51	0.38
Diesel for vehicles in mill (l)	0.28	0.15	2.60	2.96	0.84	3.54	1.08	1.25	3.40	3.41	0.68	2.10
Boiler fuel												
Mesocarp fibre (t)	0.51	0.63	0.52	0.57	0.47	0.58	0.55	0.52	0.43	0.43	0.55	0.60
Shell (t)	0.13	0.27	0.22	0.14	0.20	0.06	0.14	0.13	0.11	0.11	0.36	0.07
Boiler water consumption (1)	2.50 )	3.64	2.92	2.79	2.66	2.35	2.88	2.54	2.10	2.14	3.64	2.55
Steam for sterilization (t)	2.46	3.29	2.77	2.63	2.64	2.34	2.84	2.55	2.10	2.10	3.16	2.53
Steam to turbine (t)	2.50	3.64	2.92	2.79	2.66	2.35	2.88	2.54	2.10	2.14	3.64	2.55
Water consumption for process (t)	3.42	2.95	3.48	3.79	3.67	3.26	3.68	3.57	3.51	3.47	3.66	3.38

Notes: PL - plantation, PR- private.

Bolded rows indicate renewable energy or recycled materials.

1 t of CPO. The variation in values is because each mill has a different oil extraction rate (OER) and the mills with higher OER, will have a lower value of FFB per tonne of CPO.

The average power consumption from turbine for per tonne of CPO is 101.85 kWhr. This power is a renewable energy source. In the palm oil mills, mesocarp fibre and shell are used as fuel in the boiler and are burnt to produce heat to convert water into steam. This steam is then used to run a turbine which generates electricity for the milling process and the whole mill compound. The mesocarp fibre and shell are actually wastes from the FFB which are then recycled as boiler fuel.

The mesocarp fibre is the waste after oil has been pressed out of the mesocarp of the fruit. The shell is the outer layer of the nut which when cracked produces kernel and shell. Kernel will be shipped to kernel crushing plants to extract palm kernel oil while shell is a waste. However in the palm oil mill these wastes are considered very valuable byproducts which serve as an energy source for the mill. Due to the existence of these by-products, the palm oil mills are very self-sufficient producing their own energy to operate and also to supply energy to the estates in some cases. The load to produce electricity using fossil fuel sources has been taken off from the environment and at the same time the load to treat that amount of mesocarp fibre and shell has been removed from the environment.

The steam that has passed through the turbine is then stored at a back pressure receiver tank. This steam now which is at a lower pressure is used for the sterilization or cooking process. Here this steam is recycled and the load to produce steam again for this process has been taken off from the environment. For every tonne of CPO produced about 2.57 t of steam is recycled for sterilization.

However, there is some electricity consumption from the national grid supply which ranges from as low as 0.10 kWhr to 2.95 kWhr t<sup>-1</sup> CPO. This consumption is mainly for office use and lighting purposes when the mill is not operating. For palm oil mills numbered 6, 7, 8, 9, 10 and 11, the grid consumption is zero because these mills are not connected to the grid. When the mills are not in operation they use diesel generator sets to generate electricity. Palm oil mills numbered 9 and 11 supply power not only for the mill compound but also to the workers quarters and other facilities within the estate. Although the grid consumption is zero but the diesel consumption at these mills are 4.47 and 4.5 litre t<sup>-1</sup> CPO respectively. These values are higher compared to other mills for this reason.

In the case of mill numbered 2, it does not consume any diesel for milling purposes. This is because this mill directly uses the electricity from the grid when the mill is not operating. Even then the power consumption from the grid is not too high. This is because this mill is a 30 t mill and it operates for almost 24 hr a day and so the need to get power from the grid is little. Palm oil mill numbered 12 which is a 90 t mill only consumes about 0.38 litre of diesel per tonne CPO. This is because this mill also operates for almost 24 hr a day. This is also the reason why the grid consumption is also very low about 0.10 kWhr t<sup>-1</sup> CPO as this mill uses the renewable energy generated from the turbine when operating. Since the mill is always running, less electricity is consumed from the grid and less diesel is consumed for the mill.

The vehicles used in the mill for the milling process are mainly, tractors and showlers. The quantity of diesel used in the vehicles within the mill all depend on the size of the mill as well as the operating hours and also how much automation is involved in the process. The diesel consumption for vehicles used for the milling process for mills numbered 6, 9 and 10 t<sup>-1</sup> CPO is 3.54, 3.40 and 3.41 litre respectively. These values are higher than the rest because these mills are rather large mills and use many vehicles as part of their milling process mainly showlers to transport biomass and also to pull in and out the sterilization cages. Palm oil mill 3, 4 and 12 uses 2.60, 2.96 and 2.10 litres of diesel respectively. This is mainly because these three private mills operate for long hours and so the vehicles are running for longer periods. Palm oil mills numbered 1,2,5,7,8 and 11 have low consumptions ranging from 0.15 litre diesel to 1.25 litre of diesel per tonne CPO as these mills use less vehicle support for their milling process and the mill operation hours are less compared to the private mills.

The quantity of fuel used in the boiler all depends on the capacity of the boiler itself and this is calculated based on the quantification of the fuel flow rate at each palm oil mill. The flow rate ranges from 2.1 t hr<sup>-1</sup> to 13 t hr<sup>-1</sup> as shown in *Table 1*. The fuel ratio varies from mill to mill. Palm oil mills numbered 2, 3 and 5 use the ratio of 70: 30, mesocarp fibre: shell. However, mills numbered 1, 4, 7, 8, 9 and 10 uses 80: 20 while mills numbered 6 and 12 have a ratio of 90:10. Palm oil mills 6 and 12 use more of the mesocarp fibre and less shell. This is because they can sell the excess shell at a good price for use in other furnaces elsewhere. Mill 11 uses a ratio of 60: 40. This mill tends to use a larger amount of shell mainly because they have 13 t hr<sup>-1</sup> fuel consumption and also this mill has to meet the high demand for power supply for the whole estate which not only consisted of the workers quarters but also other facilities.

The other input is water which is the source of the steam as well as water for process. This water is normally extracted from rivers, wells or ponds. The amount of steam required to run the turbine to produce electricity mainly depends on the turbine

TABLE	2. LIFE CYCL	E INVEN	TORY F	OR PALM	OIL MI	LLS NUMI	<b>3ERED 1</b>	TO 12 E	NVIRON	AENTAI	OUTPU	<b>TS FOR EVER</b>	Y 1 t OF CRUD	E PALM OIL (	CPO) PRODU	ICED
Mill	1	7	3	4	ŋ	9	7	80	6	10	11	12				
Type	ΡL	PL	PR	PR	ΡL	ΡL	PL	ΡL	ΡL	ΡL	PL	PR				
Environment	al Outputs															
Kernel	0.39	0.41	0.43	0.44	0.42	0.37	0.44	0.41	0.37	0.37	0.39	0.43				
Mesocarp fibre	e (t) 0.08	0.00	0.12	0.09	0.16	0.00	0.10	0.09	0.13	0.13	0.04	0.05				
Shell (t)	0.22	0.09	0.15	0.24	0.17	0.26	0.24	0.23	0.22	0.22	0.00	0.31				
EFB (t)	1.13	1.17	1.23	1.26	1.21	1.07	1.26	1.17	1.08	1.07	1.12 1	.247				
POME (t)	2.96	3.04	3.20	3.29	3.16	2.80	3.28	3.06	2.80	2.80	2.92	3.23				
Methane (m <sup>3</sup>	) 53.83	55.35	58.27	59.82	57.59	51.00	59.70	55.64	51.04 5	1.03	53.16 5	8.81				
CO <sub>2</sub> from POI pond (m <sup>3</sup> )	ME 28.99	29.81	31.38	32.21	31.01	27.46	32.15	29.96	27.48 2	7.48	28.62 3	1.67				
Boiler ash (t)	0.01	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02				
Flue gas from particulate	stack matter															
(kg)	0.07	0.15	0.11	0.13	0.14	0.13	0.15	0.15	0.16	0.17	0.45	0.70				
CO (kg)	0.02	0.05	0.06	0.05	0.06	0.06	0.06	0.06	0.07	0.07	0.14	0.13				
$CO_2$ (kg)	13.74	43.47	56.87	57.39	56.06	60.72	50.70	59.41	67.99 6	8.81 1	51.20 14	2.18				
$SO_{x}$ (kg)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001 0	.001	0.003 0	.003				
NO <sub>x</sub> (kg)	0.04	0.08	0.12	0.10	0.09	0.11	0.10	0.09	0.10	0.10	0.20	0.25				
Mill	1	7	3		4		ß	9		~		8	6	10	11	12
Recycled Waste																
EFB	Mulching	Mulch	uing 5 v	shredded 1sed as fi	l & Mi uel	ulching	Mulcl	ning N	Mulching	[Mu]	lching	Mulching	Mulching	Mulching	Mulching	Mulching
POME	Treated as fertilizer	Treate fertiliz	d as 5 er fi	old as ertilizer	Tre di	eated & scharged	Treate fertili	ed as J zer f	lreated a ertilizer	s Trea ferti	ıted as lizer	Treated as fertilizer	Treated as fertilizer	Treated as fertilizer	Treated as fertilizer	Treated & discharged
Excess mesocarp fibre & shell	Sold as fuel	Sold a fuel	S T	oold as uel	So fu	ld as el	Sold a fuel	si fi	oold as uel	Solc fuel	l as	Sold as fuel	Sold as fuel	Sold as fuel	I	Sold as fuel
Boiler ash	Land application	Land	I tion a	and . Ipplicatio	n ap	nd plication	Land applic	I ation a	and pplicatio	Lan n appl	d ication	Land application	Land application	Land application	Land application	Land application
Note: PL – planta	ttion, PR- priv	vate.														

capacity. The amount of steam required to run the turbine varies from mill to mill. It ranges from 10 t steam per hour to 52 t steam per hour. The higher the requirement the more steam is needed and the more water is required. The water consumption in the mills is for the process itself which include dilution and also for washing. An average of about 6.21 t of water is required both for steam production and process water to produce 1 t of CPO

*Table 2* shows the outputs to the environment when 1t of CPO is produced. The quantity of mesocarp fibre and shell shown in *Table 2* are the final value after subtracting the amount recycled as boiler fuel. The values range from as low as 0.00 t to as high as 0.16 t of mesocarp fibre per tonne CPO. The range of the excess mesocarp fibre is quite high as the amount depends on the fuel flow rate for the boiler and fuel ratio used. Some mills do not have any excess mesocarp fibre as they use up all their mesocarp fibre as boiler fuel. Palm oil mills numbered 2 and 6 use up all their mesocarp fibre. An average of 0.09 t of mesocarp fibre is produced for every tonne of CPO.

Almost all the mills have higher quantity of excess shell compared to mesocarp fibre with the exception to palm oil mill numbered 11 which uses up all the shell. This is because this palm oil mill has to meet the high demand of its 13 t  $hr^{-1}$  boiler and fuel ratio of 60:40 to supply power for the whole estate compound. An average of 0.20 t of shell is produced for every tonne of CPO.

Approximately 1.17 t of empty fruit bunch (EFB) is produced for every tonne of CPO. The plantationbased mills all send their EFB back to the plantation for mulching purposes. Private mill numbered 3 shreds the EFB and uses it as fuel in their second boiler to process part of their palm oil mill effluent into fertilizers for sale. The private mills also send back the EFB to the plantations for mulching in the same lorries that bring the FFBs to the mills. These mills actually pay a small cost to transport back the EFB. This is mainly to dispose of the EFB as these mills do not own their own plantations.

All the mills treat their POME which is actually the sludge from the oil and waste water from the process. An average of 3.05 t of POME is produced for every tonne of CPO. Most plantation mills send the treated effluent (anaerobic liquid) back for land application as substitute for fertilizers at the oil palm plantations. Mills numbered 4 and 12 treat the effluent in accordance to the regulated standards for water discharge into the stream nearby. Mill numbered 3 processes the POME and sells it as fertilizers to the private planters.

Another output emitted from the POME ponds during the anaerobic process is biogas. This biogas mainly consists of methane, carbon dioxide and traces of hydrogen sulphide (Ma *et al.*, 1999). Unfortunately at the current moment less than 5% of mills in Malaysia harvest the biogas and use it as fuel. We may wonder why this biogas is not harvested and we cannot completely blame the industry for not harvesting and stopping this impact. The reason behind this is mainly lack of infrastructure to channel this excess energy. For now most mills have excess energy from their biomass itself. In order to invest in a large sum of money to harvest the biogas will mean that they will need the infrastructure to dispose and sell the harvested biogas. However it is sad to say that such demands for this kind of energy is very minimal in Malaysia and because the mills themselves do not need anymore energy this does not seem to be a logical move to invest large amounts of money on a harvesting system. Approximately 85.55 m<sup>3</sup> of biogas is produced for every tonne of CPO. Out of this 65% is methane and 35% is mainly CO, and traces of other gas. Thanks to the current shift of events and increased environmental awareness, this situation is likely to change in the near future.

The other gaseous emissions are the flue gas emitted from the boiler stack. These emissions are the result of burning biomass as fuel in the boilers. The flue gas comprises particulate matter, carbon monoxide, carbon dioxide, sulphur oxides and nitrogen oxides. All these emissions at the 12 mills are within the regulated limits and some mills achieve far better levels than the regulated limits. The emissions of sulphur oxides are very low and almost negligible. In order to control the particulate matter emissions all the mills have multi cyclone systems in place. The increase in boiler fuel directly relates to the increase in the flue gas emissions from the stack. Palm oil mill numbered 11 shows the highest emission mainly because it has the highest fuel consumption per hour.

Another output from the boiler is the boiler ash. This is the ash formed due to the burning of biomass in the boilers. The ash is normally used for land application in the roads leading to the mills. About 0.02 t of boiler ash is produced for every tonne of CPO.

The other output or rather the by-product from the production of CPO is palm kernel. About 0.41 t of kernel is produced for every 1 t of CPO. The kernel is transported to kernel crushing plants to be crushed to produce palm kernel oil.

#### CONCLUSION

Based on the LCI, the main input for turbine system processing of CPO is electricity and this electricity is self generated in the boiler using the by-products from the milling process. The other input is diesel. This quantity is not much as it is only used when the mill is not operating and for the vehicles. All the outputs from the mills are either recycled within the compound or at the plantation or some even sold and reused as energy or fertilizers elsewhere. Palm oil mills are now slowly upgrading their boilers and this has resulted to lesser gaseous emissions to the environment. The methane emitted from the POME ponds are a potential energy source; however the unharvested biogas is a source of pollution.

In order to overcome this problem, it has to be seen on a wider scale involving not only the palm oil industry on its own but also the whole energy sector of Malaysia which also includes changes in policies to make harvesting such valuable biogas energy worth the while for the palm oil industry. Another option is to actually re-look at this 20 over years old sludge treatment system using the ponding system. Maybe it is time for the industry to also become environmentally savvy and look into other options of sludge treatment instead of sticking to the historical method used. The harvested biogas can be used as energy in the mills for the milling process thereby freeing the biomass and since there is demand for the use of biomass outside the mills even now. The biomass should just be an additional source of fuel to just top up whatever energy is needed for the mills. The palm oil mills which are currently not connected to the grid are using diesel when not operating. Maybe they should look into the option of harvesting the biogas and completely substituting the diesel. However the economics to implement such steps should be examined.

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Appendix 1





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TABLE 3. LIFE C	<b>YCLE INVI</b>	ENTORY O	F THE PRO	DUCTION	OF1 tOF (	CRUDE PA	LM OIL FO	R 12 PALM	I OIL MIL	<b>LS INCLUD</b>	ING MEAN	7	
Mill	1	2	ŝ	4	ŋ	9	Ч	œ	6	10	11	12	Average
Mill type	ΡL	ΡL	PR	PR	ΡL	ΡL	ΡL	ΡL	ΡL	ΡL	ΡL	PR	1
Processing cap (t $hr^1$ )	20	30	40	40	45	45	50	50	60	65	70	90	I
Fuel flow rate (t hr <sup>-1</sup> )	2.50	3.50	5.60	4.50	4.88	5.00	6.00	5.90	7.50	7.50	13.00	11.00	ı
Fuel ratio FB : SH	80:20	70:30	70:30	80:20	70:30	90:10	80:20	80:20	80:20	80, 20	60, 40	90, 10	I
Steam output (t hr <sup>-1</sup> )	10.00	14.00	22.50	17.50	19.00	18.00	24.00	23.50	30.00	30.50	52.00	42.50	ı
Environmetal inputs													
FFB (t)	4.93	5.07	5.34	5.48	5.27	4.67	5.47	5.10	4.67	4.67	4.87	5.39	5.09
Time (hr)	0.25	0.26	0.13	0.16	0.14	0.13	0.12	0.11	0.07	0.07	0.07	0.06	0.11
Power from turbine (kWhr)	98.59	101.38	106.73	109.57	105.48	93.41	109.34	101.91	93.48	93.46	97.36	107.71	101.85
Power from grid (kWhr)	2.00	1.99	0.18	0.25	2.95	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.35
Diesel for mill (litre)	2.17	0	1.29	1.98	2.92	2.86	2.45	2.12	4.47	3.37	4.51	0.38	2.64
Diesel for vehicles in mill (litre)	0.28	0.15	2.60	2.96	0.84	3.54	1.08	1.25	3.40	3.41	0.68	2.10	2.19
Boiler fuel													
Mesocarp fibre (t)	0.51	0.63	0.52	0.57	0.47	0.58	0.55	0.52	0.43	0.43	0.55	09.0	0.52
Shell (t)	0.13	0.27	0.22	0.14	0.20	0.06	0.14	0.13	0.11	0.11	0.36	0.07	0.15
Boiler water consumption (t)	2.50	3.64	2.92	2.79	2.66	2.35	2.88	2.54	2.10	2.14	3.64	2.55	2.66
Steam input for sterilization (t)	2.46	3.29	2.77	2.63	2.64	2.34	2.84	2.55	2.10	2.10	3.16	2.53	2.57
Steam input to turbine (t)	2.50	3.64	2.92	2.79	2.66	2.35	2.88	2.54	2.10	2.14	3.64	2.55	2.66
Water consumption for process (t)	3.42	2.95	3.48	3.79	3.67	3.26	3.68	3.57	3.51	3.47	3.66	3.38	3.55
Environmental outputs													
Kernel	0.39	0.41	0.43	0.44	0.42	0.37	0.44	0.41	0.37	0.37	0.39	0.43	0.41
Mesocarp fibre (t)	0.08	0.00	0.12	0.09	0.16	0.00	0.10	0.09	0.13	0.13	0.04	0.05	0.09
Shell (t)	0.22	0.09	0.15	0.24	0.17	0.26	0.24	0.23	0.22	0.22	0.00	0.31	0.20
Empty fruit bunch (t)	1.13	1.17	1.23	1.26	1.21	1.07	1.26	1.17	1.08	1.07	1.12	1.24	1.17
Palm oil mill effluent (t)	2.96	3.04	3.20	3.29	3.16	2.80	3.28	3.06	2.80	2.80	2.92	3.23	3.05
Methane gas (m³)	53.83	55.35	58.27	59.82	57.59	51.00	59.70	55.64	51.04	51.03	53.16	58.81	55.61
CO <sub>2</sub> from POME pond (m <sup>3</sup> )	28.99	29.81	31.38	32.21	31.01	27.46	32.15	29.96	27.48	27.48	28.62	31.67	29.94

TABLE 3. LIFE CYCL	E INVENTOR	Y OF THE	PRODUCT	ION OF 1 t	OF CRUDI	E PALM OI	L FOR 12 F	ALM OIL ]	MILLS INC	TUDING	MEAN (con	ttinued)	
Mill	1	2	3	4	ß	9	7	80	6	10	11	12	Average
Boiler ash (t) Flue gas from stack	0.01	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02
particulate matter (kg)	0.07	0.15	0.11	0.13	0.14	0.13	0.15	0.15	0.16	0.17	0.45	0.70	0.23
CO (kg)	0.02	0.05	0.06	0.05	0.06	0.06	0.06	0.06	0.07	0.07	0.14	0.13	0.08
CO <sub>2</sub> (kg)	13.74	43.47	56.87	57.39	56.06	60.72	60.70	59.41	62.99	68.81	161.20	142.18	79.13
SOx (kg)	0.0005	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.003	0.001
NOx (kg)	0.04	0.08	0.12	0.10	0.09	0.11	0.10	0.09	0.10	0.10	0.20	0.25	0.13