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WATER FOOTPRINT: PART 3 - THE PRODUCTION OF CRUDE PALM OIL IN MALAYSIAN PALM OIL MILLS

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ABSTRACT

The Malaysian oil palm industry contributes immensely to the nation's economy. In 2013 alone the export revenue of palm products reached RM 61.36 billion. The industry is constantly asked to prove the sustainability of its products. Currently, carbon footprint is such a catchphrase in the world that it has become a must for responsible producers to quantify their carbon footprint. The next catchphrase in the environmental front is water footprint. In view of this, there is an imminent need for the oil palm industry to be accountable for its water consumption. This study has a cradle-to-gate system boundary which starts at the oil palm nursery and ends in the palm oil mill. It covers the water footprint of the production of oil palm seedlings; oil palm fresh fruit bunches and the production of crude palm oil. The water footprint network, Hoekstra 2011 methodology is used to determine the water footprint. The functional unit for this study is 1 t crude palm oil (CPO) produced at the palm oil mill. At the palm oil mill, comparison was made for mills that practise dilution versus no dilution and allocation was carried out at the palm oil mill with palm kernel and palm shell which are considered as co-products of the production of CPO. Within the system boundary of the palm oil mill, the highest footprint comes from the blue water for the process. The grey water footprint for 1 t CPO increases when the biological oxygen demand of the final discharge standard decreases to 20 ppm as compared to 100 ppm. There was a reduction in the water footprint if the mills did not practise dilution. For the cradle-to-gate system boundary, the highest water footprint came from the green water footprint in the plantation for the production of fresh fruit bunch (FFB). This is natural as the oil palm is a perennial crop with an economic life cycle of 25 years and so it is quite natural to have high green water. However, this green water comes from the rain as the oil palm are rain fed and not irrigated. The contribution from nursery is very small. The best option for mills is to avoid dilution during process to obtain the best water footprint.

Keywords: water footprint, crude palm oil, palm oil mill, water use.

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INTRODUCTION

Processing of oil palm fresh fruit bunch (FFB) into crude palm oil (CPO) was carried out in Malaysia as early as the 1920s. This is based on records which show that some palm oil mills were built even before the World War I. At that time, there were only five mills, and since then they have been upgraded and refurbished. It was only in the 1970s that the World Bank identified oil palm as a suitable alternative crop for Malaysia and since then the growth of this industry has been rapid (Chow and Ma, 2001).

The flow chart of the milling process is shown in *Figure 1*. FFB which are delivered to the palm oil mills

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are received at the FFB hoppers and are transferred into the sterilisation cages. These cages are then put into the sterilisation chambers. Live steam passes through these chambers for a duration of 90 min and this process, called sterilisation, 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 is undesirable in palm oil. The industry tries to limit the development of FFA to less than 4% (Pathak, 2005). Next, the sterilised FFB are sent to a stripper where the fruitlets are separated from the stalks or bunches. The FFB, devoid of fruitlets, are now referred to as the empty fruit bunches (EFB). The EFB are normally sent back to the plantations for use in mulching and as a fertiliser substitute (Vijaya *et al.*, 2010) and nowadays there are mills which convert their EFB to organic fertilisers to be used as fertilisers in the plantation.

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 extract most of the 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 (Vijaya *et al.*, 2010). Then, the CPO is clarified in a continuous settling tank operation. This is where the mills add water to dilute the mixture to obtain a better oil separation. However, some mills still are able to obtain good oil separation without having to dilute the mixture with water at the clarification stage.

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 refining at the refineries, or export. The nuts with the pressed mesocarp fibres are separated at the fibre cyclone. The nuts are then cracked to produce kernels and shells (Vijaya *et al.*, 2010). 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 and the excess shell is sold for use in other biomass boilers.

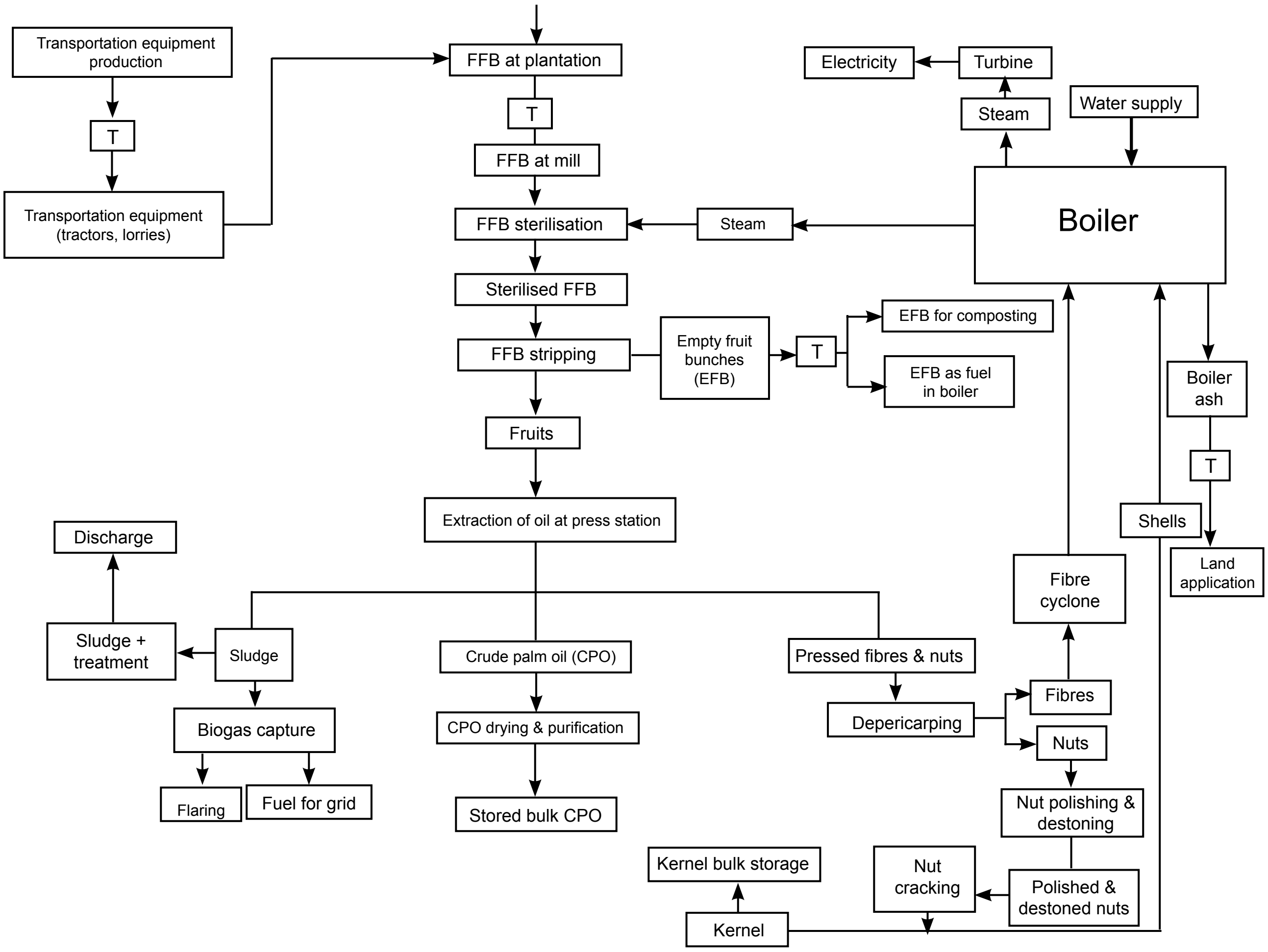


Figure 1. Flow chart of the milling process.

Water Footprint for the Oil Palm Industry

The Malaysian oil palm industry is a very important industry which contributes immensely to the nation's economy. In 2013 alone, the export revenue of palm products reached RM 61.36 billion (Choo, 2014). The industry is faced with the question on sustainability of its products. Sustainability is no longer an option but has now become the primary driver of long-term economic development. The oil palm industry must include sustainability as part of its business strategy.

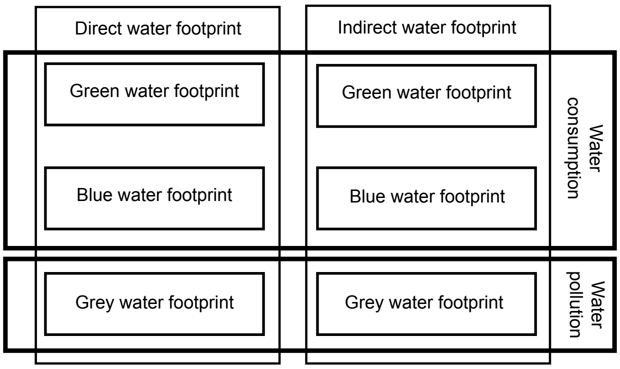
Currently, carbon footprint is such a catchphrase in the world that it has become a must for responsible producers to quantify their carbon footprint or also known as greenhouse gas (GHG) emissions (Vijaya *et al.*, 2011). The European Union (EU) Renewable Energy Directive has imposed a non-tariff barrier on the imports of palm biodiesel based on GHG emissions calculations. In 2012, the Environmental Protection Agency (EPA) of USA, under the Renewable Fuels Standard 2 (RFS2), published the Notice of Data Availability (NODA) ruling that oil palm biofuel does not meet the GHG threshold requirements when compared to fossil fuel. Now EPA is evaluating if palm biodiesel will meet the GHG requirements set based on comments received from the public on the NODA. These non-tariff barriers which are solely based on environmental performance of the product have a big impact on the oil palm industry and on the market access of palm biodiesel. These barriers too have an impact on the image of palm oil in general. Just as how carbon footprint is creating such an impact to the oil palm industry, the next catchphrase in the environmental front is water footprint. For example, the study by Gerbens *et al.* (2009) came to a conclusion that jatropha is not a suitable feedstock for biodiesel production due to its high water footprint. This study compared the water footprint between soya, rapeseed and jatropha and the recommendation was that soya is the best crop for biodiesel just based on the water footprint. This kind of studies show the trend of how water footprint is slowly being used as an indication for choosing a feedstock, just as how carbon footprint is being used now. In view of this development, there is an imminent need for the oil palm industry to be accountable for its water consumption and pollution.

OBJECTIVES

1. To quantify the water footprint of the production of 1 t CPO produced at the palm oil mill.
2. To identify the hotspots where the most amount of water is consumed in the supply chain of the production of 1 t CPO.
3. To evaluate opportunities to reduce the water footprint of the production of 1 t CPO, if any.

METHODOLOGY

The methodology used to conduct this study was the water footprint network methodology (Hoekstra *et al.*, 2011). According to this methodology, the water footprint means the amount of water that is needed to produce goods and services (Chapagain and Hoekstra, 2004). It consists of water withdrawn from surface water and groundwater and the use of soil water. Water consumption will be determined into three categories as shown in *Figure 2*.



Source: Hoekstra *et al.* (2011).

Figure 2. Water footprint categories.

A water footprint consists of three components: the blue, green and grey water footprints. The blue water footprint is the volume of fresh water that evaporates from the global blue water resources (surface water and ground water) to produce the goods. The green water footprint is the volume of water evaporated from the global green water resources (rain water stored in the soil as soil moisture). The grey water footprint is the volume of polluted water that is associated with the production (Hoekstra *et al.*, 2011).

Blue Water Footprint

Direct water. The water footprint (WF) of the CPO processing (WF_{proc}) is calculated by adding the direct water footprint of the process and its indirect water footprint as shown in the formula below:

$$WF_{proc} = WF_{proc,\,dir} + WF_{proc,\,indir}\ [\text{volume/time}]$$

The direct blue water footprint refers to the water consumption that is related to water use at the palm oil mill.

The indirect water footprint refers to the consumption of water that is associated with the production of energy, raw materials, use of transportation, *etc.* which are used in the production of CPO. These water data were sourced from the Ecoinvent database.

Green Water Footprint

The green water footprint is the crop water use and is calculated by accumulation of daily evapotranspiration (over the complete growing period). Green water footprint is nil at the palm oil mill as it is related to the water used by the crop. The green water footprint will be obtained from upstream in the nursery and oil palm plantation.

Grey Water Footprint

The grey water footprint is the waste water that comes out from the processing of the CPO at the palm oil mill. The grey water footprint formula is as follows (Hoekstra *et al.*, 2011):

$$\text{Water footprint Grey} = \frac{\text{C effl} - \text{C act}}{\text{C max} - \text{C nat}} \times \text{Effl [volume/time]}$$

Effl = Effluent volume (volume/time)
Ceffl = Concentration of pollutant (mass/volume)
Cact = Actual concentration of the intake water (mass/volume)
Cmax = Maximum concentration allowed (mass/volume)
Cnat = Concentration in natural form (mass/volume)

System Boundary and Functional Unit

This study has a cradle-to-gate system boundary as shown in *Figure 3*. This article is linked to water footprint for the production of oil palm seedlings in Malaysia (part 1) (Halimah *et al.*, 2014) and water footprint for FFB production for oil palm planted in Malaysia (part 2) (Zulkifli *et al.*, 2014). This study quantifies the water footprint of the production of CPO from nursery to plantation to palm oil mill. The functional unit for this study is 1 t CPO produced at the palm oil mill.

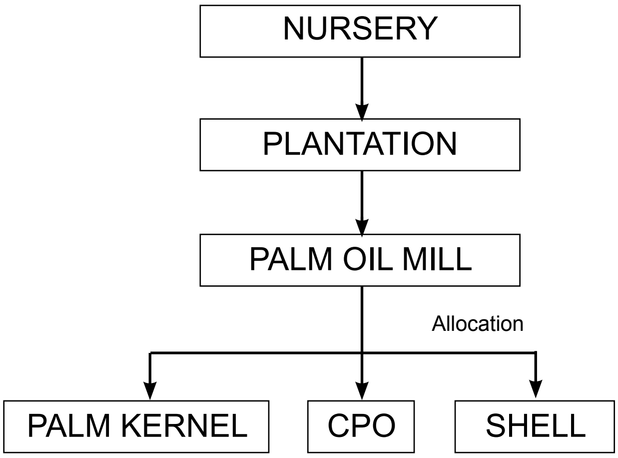


Figure 3. System boundary.

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 are palm kernel and palm shells. The kernels are subsequently sent to kernel-crushing plants for extraction of CPKO while the excess palm shell are sold for use in other biomass boilers. In view of this, weight allocation has been conducted to allocate part of the input and output to palm kernel and palm shell. The allocation between CPO, palm kernel and palm shell is 61% to 25% to 14%, respectively.

In this study, all processes are considered relevant unless excluded based on the exclusion criteria shown in *Table 1*. 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.

Inventory data were collected directly from the palm oil mills and millers through questionnaires 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 through on-site visits, on-site measurements and interviews to obtain evidence and to verify the reliability of the collected data.

For this study, data were obtained from 243 palm oil mills which were located in Peninsular Malaysia, Sabah and Sarawak. This represents about more than 50% of the total palm oil mills in Malaysia.

There were a few distinct differences between the palm oil mills as follows:

1. Palm oil mills that practise dilution where water is added at the clarification step during their process to get better oil separation versus palm oil mills which practise no dilution and do not add water but still manage to get good oil recovery, and in the process reduce their water consumption as well as the palm oil mill effluent (POME).
2. The location of the palm oil mills. The palm oil mills located in Sabah and Sarawak have to adhere to a lower biological oxygen demand (BOD) final discharge standard of 20 ppm as compared to palm oil mills located in Peninsular Malaysia which have to adhere to the final discharge standard of BOD 100 ppm.

TABLE 1. SYSTEM BOUNDARY DEFINITION CRITERIA

Processing category	Included	Excluded			
		Insignificant environmental impact	Difficult to obtain representative data	Part of a different system	Not directly relevant to scope and goal of study
Water treatment and supply	✔	-	-	-	-
Extraction of crude palm oil from FFB	✔	-	-	-	-
Management of solid waste in mill	✔	-	-	-	-
Electricity generation	✔	-	-	-	-
Production of fuel for boilers	✔	-	-	-	-
Processing of co-products *e.g.* palm kernels, palm shell		-	-	✔	-
Waste water treatment	✔	-	-	-	-

Note: FFB – fresh fruit bunch.

RESULTS AND DISCUSSION

Table 2 shows the water related life cycle inventory (LCI) for the production of 1 t CPO at the palm oil mill while *Table 3* shows the additional data derived from the LCI for the grey water calculations.

For the system boundary of the palm oil mill as shown in *Table 4*, there is a decrease in the water footprint of about 4.0 m^3 t^{-1} CPO produced at the palm oil mill that does not practice dilution as compared to a palm oil mill that practices dilution. This directly also reduces the amount of effluent by 1.25 m^3 t^{-1} CPO at a palm oil mill with no dilution. This effluent reduction also reduces the grey water footprint as shown in *Table 4*. Another factor that influences the grey water is the final discharge maximum allowable limit by law. Those mills at Peninsular Malaysia which are allowed to discharge at a higher level have a lower grey water footprint as compared to mills in Sabah and Sarawak which have to comply with a more stringent final discharge level of BOD 20 ppm. Even though these mills meet the regulated limits but because the level is set so low, based on the volume and concentration of the final discharge the grey water footprint is higher in these zones. On the whole, the levels are lower without dilution. For the palm oil mill system boundary, the major contributor to the water footprint is the blue water followed by grey water. Green water is nil as water for the crop is only up till the plantation stage.

The results for the cradle-to-gate system boundary (nursery-plantation palm oil mill) as in *Table 5* shows that the contributions from nursery is rather small and almost negligible. The highest water footprint comes from the plantation as expected as growing of oil palm trees does require a lot of water, almost about 5275 m^3 water per tonne CPO. Fortunately, as discussed in Zulkifli *et al.* (2014), this water comes from the rain as the oil palm are rain fed. The second highest contribution to the water footprint is from the grey water, again from the plantation in the form of leachates from fertilisers and pesticides. The water footprint without dilution is lower than with dilution for mills in Peninsular Malaysia at final discharge BOD level of 100 ppm.

As mentioned earlier, at the palm oil mill weight allocation is performed with the by-products palm kernel and palm shell. *Figure 4* shows the reduction in the water footprint when allocation is performed where part of the burden is shifted to the by-products. The total water footprint reduces drastically when allocation is performed where the value for BOD limits at 100 ppm is taken as a base case.

The results clearly show that the best scenario for reduction in water footprint is to avoid dilution in the palm oil mills. The best water footprint is obtained when there is no dilution and with allocation to co-products.

Uncertainties

This study is based on the data that are collected from over 50% of the palm oil mills and only the scenarios with and without dilution which directly affects the water reduction are taken into consideration at the palm oil mill. There may be other technologies or methods used by some mills to reduce the water consumption which are not discussed as those systems are not widely used. Since this study is meant to be a national study, only the normal widely used systems are considered. This study was conducted based on the Hoekstra *et al.* (2011) methodology and all the quantifications are based on this methodology.

TABLE 2. LIFE CYCLE INVENTORY (water related data) FOR THE PRODUCTION OF 1 t CRUDE PALM OIL (CPO) (system boundary: palm oil mill)

Inventory	Unit t^{-1} CPO
Water for milling process (with dilution)	7.5 m^3
Water for milling process (without dilution)	3.5 m^3
Diesel (start up process and use by vehicles within the palm oil mill)	4.47 kg
Electricity	2.778 kWhr
POME (with dilution)	3.50 t
POME (without dilution)	2.25 t

Note: POME - palm oil mill effluent.

TABLE 3. ADDITIONAL DATA FOR GREY WATER CALCULATIONS

Parameters	Amount
POME:	42 t hr^{-1} (with dilution) 27 t hr^{-1} (without dilution)
C effl	40 mg $litre^{-1}$ (for mills in Peninsular Malaysia) 20 mg $litre^{-1}$ (for mills in Sabah and Sarawak)
Cact	30 mg $litre^{-1}$ (actual data of water bodies at outlet at palm oil mill)
C max	100 mg $litre^{-1}$ (limit set by law for palm oil mills in Peninsular Malaysia) 20 mg $litre^{-1}$ (limit set by law for palm oil mills in Sabah and Sarawak)
C nat	1 mg $litre^{-1}$ (Mohd Ekhwan *et al.*, 2012)

TABLE 4. WATER FOOTPRINT FOR THE PRODUCTION OF 1 t CRUDE PALM OIL (CPO) WITH AND WITHOUT DILUTION AT BIOLOGICAL OXYGEN DEMAND (BOD) LIMITS 100 ppm AND 20 PPM (system boundary: palm oil mill)

	With dilution (m^3 t^{-1} CPO)	Without dilution (m^3 t^{-1} CPO)
Direct blue water for milling process	7.50	3.50
Grey water (limit set by law at BOD:100 ppm)	0.35	0.30
Grey water (limit set by law at BOD:20 ppm)	1.83	1.57
Green water	0.00	0.00
Indirect blue water (diesel, electricity)	0.19	0.19
Total		
BOD:100 ppm	8.04	3.99
BOD:20 ppm	9.52	5.26

TABLE 5. TOTAL WATER FOOTPRINT FOR THE PRODUCTION OF 1 t CRUDE PALM OIL (CPO) (nursery-plantation palm oil mill) WITH AND WITHOUT DILUTION AT BIOLOGICAL OXYGEN DEMAND (BOD) LIMIT 100 ppm AND 20 ppm

	With dilution (m^3 t^{-1} CPO)			Without Dilution (m^3 t^{-1} CPO)		
	Blue	Green	Grey	Blue	Green	Grey
Nursery (Halimah *et al.*, 2014) (part 1)	0.79	1.55	0.009	0.79	1.55	0.009
Plantation (Zulkifli *et al.*, 2014) (part 2)	17.00	5 273.45	535.00	17.00	5 273.45	535.00
Palm oil mill (part 3)	7.69	0.00	-	3.69	0.00	-
(Max limit BOD:100 ppm)		-	0.35		-	0.30
						1.57
(Max limit BOD:20 ppm)	-	-	1.83	-	-	-
Sub-total by water category	25.48	5 275.00	-	21.48	5 275.00	-
BOD:100 ppm	-	-	535.36	-	-	535.30
BOD:20 ppm	-	-	536.84	-	-	536.58
Total water footprint						
BOD:100 ppm		5 835.84			5 831.78	
BOD:20 ppm		5 837.32			5 833.06	

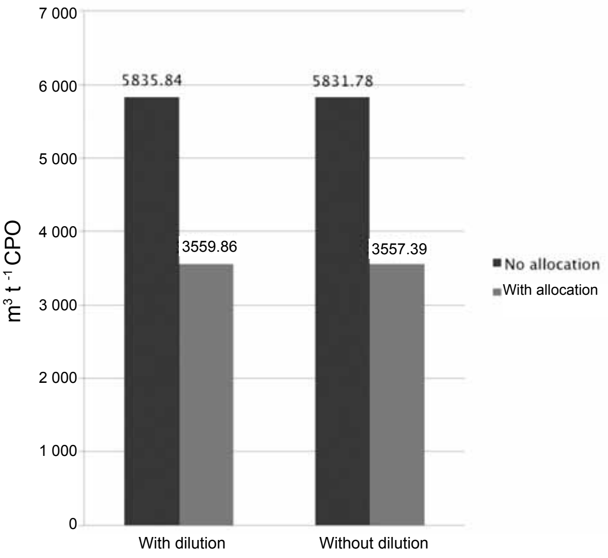


Figure 4. Water footprint of the production of 1 t crude palm oil (CPO) with and without allocation to palm kernel and shell with and without dilution at biological oxygen demand (BOD) 100 ppm final discharge limit (system boundary: nursery-plantation-palm oil mill).

CONCLUSION

In the past, more often than not environmental management was conducted more for image enhancement. However, recent developments show a trend towards wanting a greener earth which has transformed environmental demands into marketing tools. Increasingly it has become a non-tariff trade barrier and a determining factor for use of products. Results show that the best scenario to obtain the best water footprint for the production of 1 t CPO is for palm oil mills to avoid dilution. The results showed that much of the water footprint comes from the oil palm plantation upstream in the form of green water which is used by the oil palm which are rain fed. When allocation is performed, this further improves the water footprint of the production of 1 t CPO. The authors hope that the findings of this study can be used to formulate suitable guidelines for the best management and reduction of water consumption in the palm oil mills in Malaysia. The next step will be to conduct the study to calculate the impact of the use of this amount of water in Malaysia.

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