Journal of ENVIRONMENTAL Treatment Techniques

J. Environ. Treat. Tech.
ISSN: 2309-1185

Journal web link: http://www.jett.dormaj.com

Estimating Water Footprint of Palm Oil Production: Case Study in Malaysia

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Received: 06/02/2020 Accepted: 19/07/2020 Published: 20/09/2020

Abstract

Malaysia is currently facing some issues in fulfilling the high demand in palm oil production, which inevitably led to a rapid expansion of palm oil industry in Malaysia. Therefore, water-related problems have become a major concern in environmental and social issues associated to palm oil industries. Inevitably, it is very important that the water consumption in this sector be analysed. Water footprint is one of the methods that can be used as a tool for sustaining appropriate freshwater resources. The main purpose of this study is to evaluate water footprint at palm oil mill from fresh fruit bunches to the production of crude palm oil. Water footprint revealed that the main potential impacts within the system boundary are dominated by water usage at the process through producing crude palm oil and wastewater effluent. At this stage, the total water input mainly comes from the nearest water resources such as rivers and lakes. In one operating day, the mill can produce wastewater of 3.81 m3/tonne of CPO. This amount is equivalent to 0.74 m3/tonne of average production rate of POME for each t of FFB process. At the end of this paper, strategies to optimise the use of water in palm oil mills are presented.

Keywords: Agricultural Industry, Water degradation, Water footprint, ISO 14046, Sustainable Palm Oil Plantation

1 Introduction

In Malaysia, oil palm plantation area production has markedly increased from 5.23 million ha in 2013 to 5.85 million ha in 2018 (1). Currently, after Indonesia, Malaysia is the second largest oil palm producer in the world with an oil palm planted area of 5.85 million ha. As one of the main contributors to the economic growth, annual high export of this industry was RM 77.85 billion in 2017, which has increased from RM 67.92 billion in 2016 (2). Oil palm (Elaeis guineensis) is cultivated in humid tropical regions in the world such as Indonesia, Malaysia, Thailand Columbia and Nigeria (3). This plant requires 100 mm of precipitation monthly or annual rainfall of 2000 mm and is able to tolerate drought period no longer than three months (4, 5). Moreover, palm oil is semi-solid and can stand high temperature (6).

Overcoming the obstacles faced by the world, FAO has made the sustainability of food production as 2030 Agenda's vision for a sustainable development in which food and agriculture, people's livelihood and the management of natural resources are addressed as one (7). Following this trend, all stakeholders including companies should ensure that the palm oil industry is sustainably structured to enter global market. Malaysia, one of the members of Roundtable for Sustainable Palm Oil (RSPO), is regularly associated with some sustainability issues including carbon emissions, deforestation, biodiversity loss, habitat fragmentation, reduction of freshwater and soil quality. Freshwater reduction and pollution have become some of the major problems related to oil palm industries. To evaluate and connect the performance of an oil palm industries under the outlook of three sustainability pillars (economic, social and environmental pillar), quantitative indicators have been proposed as a suitable and effective mean. Among the indicators concerning the assessment of environmental impacts, water footprint describes the impacts of a system or product on water resources from quantitative and qualitative perspectives. The water footprint (WF) is a useful indicator to report on total water consumption, water scarcity level and reduction achieved after implementing response strategies. Hoekstra et al. (2011) introduced this concept, which was implemented through Water footprint Assessment (WFA). WFA is divided into three sub-indicators of WF:

- Green WF - water from rainwater is stored in the root zone and used by plants through evaporation, transpiration and

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incorporation in the biomass.

- Blue WF - irrigation water uptake by plants.
- Grey WF – amount of fresh water required to assimilate the critical pollutants to meet specific water quality standards.

Studies related to WF have been improving over time and many methods have emerged for calculating and assessing possible environmental impacts from water consumption. In 2014, a research group of Water Use in Life Cycle Assessment (WULCA) from UNEP-SETAC developed a new water footprint framework. As defined in (8), LCA is a method used to assess possible environmental effects for a product or process over its entire life cycle. WF is a part of the whole LCA. Subsequently, the LCA-based WF includes the quantification of water effects related to freshwater use in terms of water availability footprint and water scarcity footprint as well as water quality in terms of ecotoxicity, eutrophication and acidification (9, 10). Both WFA and LCA are complement to each other and can be used to obtain sustainable freshwater.

The objective of this study is to investigate the water footprint in the milling process of crude palm oil production at selection palm oil mills.

2 Materials and Methods

This study assessed the Water Footprint (WF) of crude palm oil production according to the ISO 14046 standard, which adopted an LCA approach as the framework. The LCA framework consists of goal and scope definition, inventory analysis, environmental impact assessment and interpretation of the result (11). The whole process of this study is shown in Figure 1. This study adopted a functional unit of water required to produce 1 t crude palm oil. In determining WF at mill, the methods were divided into two categories, which were:

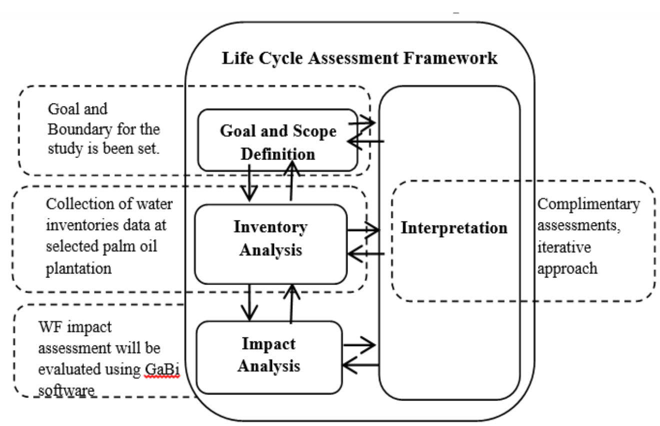

Figure 1: LCA Framework including the Significant Steps for WF

1. Total water consumption in each stage of CPO process = WF process (WFPr).

2. Total quantity and quality of wastewater = WF wastewater (WF_w).

Total consumption from both methods will be combined as total WF at mill (WF_M). Simplified water calculation stage can be referred to Figure 2. The water footprint (WF) of the production (WFPr) was determined using the data of water consumption in each step of palm oil mill. It was analysed using water balance approach by (12). In estimating this data, material balance by (13) was also used. For indirecting water use in palm oil mill, secondary data from (14) was used. Meanwhile, no water from rainwater or evapotranspiration is required at the palm oil mill. Usually, the water from these sources are used during nursery and plantation stage.

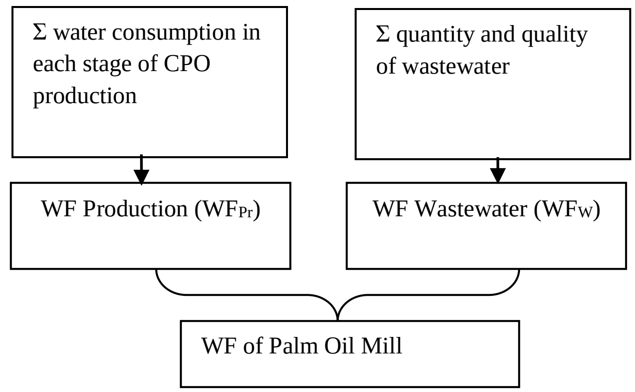

Figure 2: The Calculation Method of WF at Palm Oil Mill

For calculating wastewater that came out from CPO process, formula by (15) was used.

WF_w = (Ceffl - Cact)
(Cmax - Cnat)

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)

2.1 Boundary of Study

Figure 3 displays the diagram of the process in palm oil mill. The boundary of this study was until the production of crude palm oil (CPO). Therefore, the flow process is shown from the fresh fruit bunch to the sterilisation process where the bunches were fully cooked and the wet heat weakened the fruit stem, making it easy to remove the fruits from bunches by shaking or tumbling in the threshing machine. Then, the stripper was utilised to separate the fruits, nuts and fibre. After that, the fruits were sent to the digester. Digestion is the process of releasing the palm oil in the fruits through the rupture or breaking down of oil-bearing cells. At the clarification tank, fine suspended solids were separated and removed from crude oil. Raw crude oil from the settling tank (top oil) was combined with recovered oil from the treatment of the settling tank underflow. The flow process is highlighted with red arrow in Figure 3. Data for water input were given from the respondents using questionnaires and interview session. Primary and secondary data were used in this study. Primary data were collected by interviewing the stakeholders. Moreover, these data were collected based on direct observations at selected palm oil mills. Meanwhile, the secondary data were obtained by reviewing literature and documents related to this study. The followings are the detailed LCI description of the data collection as in Table 1. Figure 4 displays the site visit at one of the palm oil mills.

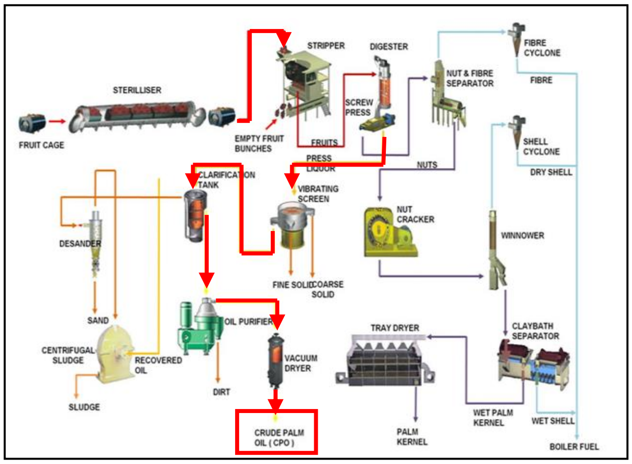

Figure 3: Palm Oil Mill Flow Process Diagram


Figure 4: Site visit at Kahang Palm Oil Mill, Kahang, Johor.

3 Result and Discussions

The input and output of materials for the process are represented in the material balance. Figure 5 shows the material balance for 1 t of CPO in palm oil mill. In material balance, there are three sources of POME namely steriliser condensate, separator sludge or sludge centrifuge and hydro cyclone wastewater or clay bath, which are used for cracked mixture separation (kernel separation). Table 2 shows the percentage of three POME sources of FFB processed and the value per 1 t CPO production. Meanwhile, Table 3 shows the water related life cycle inventory (LCI) for the production of 1 t CPO at the palm oil mill. These data were analysed based on data collection during site visit at the selected palm oil mills. Moreover, Table 4 illustrates the additional data derived from the LCI for WF of wastewater calculations.

Total WF_w can be summed up using the value of WF from production process and WF from wastewater as shown in Table 5. In one operating day, the mill can produce wastewater of 3.81 m^3/tonne of CPO. This amount is equivalent to 0.74 m3/tonne of average production rate of POME for each t of FFB process. One of the factors that influences the amount of wastewater is the final discharge maximum allowable limit by law. Palm oil mills in Peninsular Malaysia are allowed to discharge at a higher level (100mg/l) compared to mills in Sabah and Sarawak where their discharge limit is 20 mg/l. Based on the result, the major contributor to the water footprint is from the process followed by wastewater discharged. Rainwater feed gave nil value as water for the crop is only up until the plantation stage.

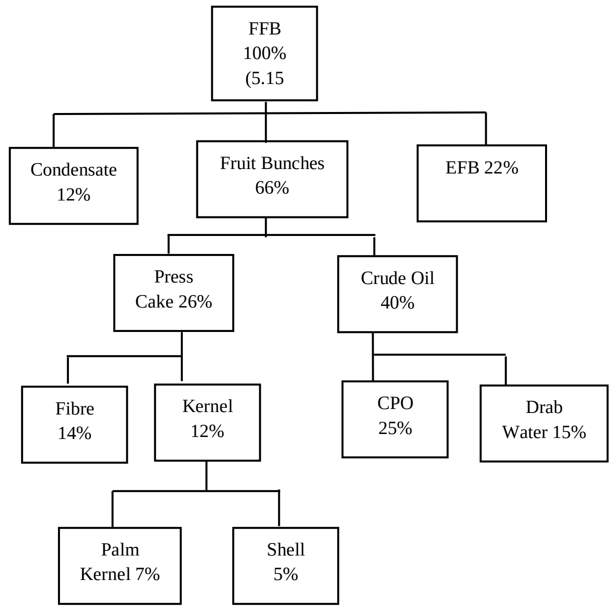

Figure 5: Material balance for 1 t CPO production

Table 1: Primary data and secondary information obtained.

Primary Data for 1t CPO		
Data Required	Source	Methods of Collection
Land area	Location of Study	Interview and site visit
Processing capacity	Location of Study	Interview and site visit
Steam input	Location of Study	Interview and site visit
FFB average (t)	Location of Study	Interview and site visit
Diesel for transportation (L)	Location of Study	Interview and site visit
Steam generation for boiler (m^3/yr)	Location of Study	Interview and site visit
Mesocarp fibre (t)	Location of Study	Interview and site visit
Shell (t)	Location of Study	Interview and site visit
Empty Fruit Bunch (t)	Location of Study	Interview and site visit
Palm oil mill	Location of	Interview and site

effluent (t)	Study	visit
Boiler Ash (t)	Location of Study	Interview and site visit

Table 2: Value of WF Production

Source of POME	% to FFB	Value WF Production per 1t CPO (m^3/ton)
steriliser condensate	12	0.62
sludge centrifuge	50	2.58
clay bath	5	0.26
Total	67	3.46

Table 3: Life cycle inventory (water related data) for the production of 1 t CPO

Inventory	Unit 1t per CPO
Water for milling process	7.4 m^3
Diesel (startup process and vehicles within mill)	1.8 kg
Electricity	2.47 kWhr

Table 4: The additional data derived from the LCI for WF of wastewater calculation (16)

Parameters	Amount
C_{effl}	40 mg litre^{-1} (for mills in Peninsular Malaysia)
C_{act}	30 mg litre^{-1}
C_{max}	100 mg litre^{-1} (limit set by law for palm oil mills in Peninsular Malaysia)
C_{nat}	1 mg litre^{-1} (17)

Table 5: Water footprint for the production of 1 t Crude Palm Oil (CPO)

	m^3/ton of CPO
Water from the process (material balance)	3.46
Wastewater (limit set by law at BOD:100 ppm)	0.35
Water from rainfeed	nil
Total	3.81

The result from cradle to gate system boundary (nursery-plantation-mill) as in Table 6 shows that the highest water footprint came from the plantation as expected since growing oil palm trees require a lot of water, which is almost 1652 m3/tonne. The second highest contribution to the water footprint was water consumption to assimilate pollutants from fertilisers and herbicides. The reduction of water footprint can be achieved by increasing best practice in cultivation process; hence, it will increase the water productivity. Water productivity is the amount of yield harvested per metre cubic of the irrigated water use. To reduce the water consumption in assimilating pollutants during cultivation stage, the use of inorganic fertilisers must be controlled. Precise dosage, timing, type and placement of fertilisers must be well applied and managed. Moreover, the mixing between organic and inorganic fertilisers have to be precise to optimise the yield and reduce leaching. As in industrial process, the use of efficient water becomes necessary. In order to minimise the potential environmental impact from water use, reducing the water during the process should potentially reduce the level of wastewater being discharged.

Table 6: Total water footprint for the production of 1 t CPO (nursery-plantation-mill)

	Water consumption from rainfeed (m^3/ton)	Water consumption from the water sources (m^3/ton)	Water consumption to assimilate pollutants (m^3/ton)	Sub-total WF by stage.
Nursery	310	6.1	28	344.1
Plantation	1509	nil	143	1652
Palm Oil Mill	nil	3.46	0.35	3.81
Sub-total by Water Category	1921.8	6.56	185.05	
Total Water Footprint	1999.91			

4 Limitations and Conclusion

The main aim for this paper is to determine the water footprint in milling process in crude palm oil production at selection palm oil mills. In addition, this paper is the sequence from previous study of WF at cultivation stage. To increase the accuracy of this study, more data and information from a lot of palm oil mills are needed.

Acknowledgement

The authors would like to acknowledge the support from UTM Research University Grant with Cost Centre No. Q.J130000.2544.04H76 provided by Universiti Teknologi Malaysia and the Zamalah Scholarship, which provided scholarship to the authors.

Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

References

1. Malaysian Palm Oil Board (MPOB); Economics & Industry Development Division. Oil Palm Planted Area (Internet). July 27,

2019. Available from: http://bepi.mpob.gov.my/index.php/en/statistics/area.html.
2. Kushairi, D. Overview of the Malaysian Oil Palm Industry 2017. MPOB Palm Oil Statistics. Malaysian Oil Palm Board (Internet). 2018. July 27, 2019. Available from: http://palmoilis.mpob.gov.my/index.php/overview-of-industry/593-overview-of-industry-2017.
3. Sylvester Chibueze Izah and Elijah Ige Ohimain. Comparison of Traditional and Semi-mechanized Palm Oil processing Approaches in Nigeria; Implications on Biodiesel Production. Journal of Environmental Treatment Techniques. 2015; 3: 82-87.
4. Silalertruksa, T., Gheewala, S. H., Pongpat, P., Kaenchan, P., Permpool, N., Lecksiwilai, N., Mungkung, R. (2017): Environmental sustainability of oil palm cultivation in different regions of Thailand: greenhouse gases and water use impact. Journal of Cleaner Production 167(Supplement C). 2017; 1009-1019.
5. Herda,S.D,K., Kris,R.D.L.,Chay,A. Estimating Water Footprint of Palm Oil Production in PTP Mitra Ogan Baturaja South Sumatera. International Journal on Advanced Science Engineering Information Technology. 2017; 7: 2115- 2121
6. Elijah Ige Ohiman and Sylvester Chibueze Izah. Physicochemical Characteristics and Microbial Population of Palm Oil Sold in Major Markets in Yenagoa Metropolis, Bayelsa States, Nigeria. Journal Environmental Treatment Techniques. 2015; 3: 143-147.
7. FAO. Transforming Food and Agriculture to Achieve the SDGs. 2018.
8. WULCA (Internet). 2014. August 5, 2019. Available from: http://www.wulca-waterlca.org/footprinting.html.
9. Bayart, J.B., Bulle, C.,Deschênes,L.,Margni,M.,Pfister,S.,Vince,F.,Koehler,A. A Framework for Assessing Off-Stream Freshwater use in LCA. International Journal Life Cycle Assessment. 2010; 15:439-453. doi.org/10.1007/s11367-010-0172-7.
10. Boulay, A.-M., Hoekstra, A.Y., Vionnet, S. Complementarities of Water-Focused Life Cycle Assessment and Water Footprint Assessment. Environmental Science Technology. 2013; 47: 11926–11927. doi.org/10.1021/es403928f
11. ISO 14044. Environmental management- Life cycle Assessment-Requirement and guidelines. International Standard Organization (ISO), Geneva. 2006.
12. Chukalla AD., Krol MS., A.Y. Hoekstra. Green and Blue Water Footprint Reduction in Irrigated Agriculture: Effect of Irrigation Techniques, Irrigation Strategies and Mulching. Hydrology and Earth System Sciences. 2015; 19: 4877–4891.
13. Ropandi,M., Astimar, A.A., Rohayu,M.H. Waste Minimisation for Palm Oil Mills: A Case Study. Palm Oil Engineering Bulletin. 2017; 122.
14. Vijaya,S.MA, A.N., Choo, Y.M., Nik Meriam, N.S. Life Cycle Inventory of The Production of Crude Palm Oil – A Gate to Gate Case Study of 12 Palm Oil Mills. Journal of Oil Palm Research. 2008; 20: 484-494.
15. Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M and Mekonnen, M.M. The water footprint assessment manual: Setting the goal standard. 2011. Earthscan, London,UK.
16. Vijaya, S.MA, Halimah,M., Zulkifli, H., Choo, Y.M. Water Footprint: Part 3- The Production of Crude Palm Oil in Malaysian Palm Oil Mills. Journal of Oil Palm Research. 2014; 6: 292-299.
17. Mohd Ekhwan, T., Mohd Khairul, A.K.,Muhammad Barzani, G., Mokhtar, J., Nor Azlina, A.A., Pan, L.L. Water Quality Status & Hydrological Analysis in Upper Tropical River Malaysia. International Journal of Agriculture and Crop Sciences. 2012; 4-2:33-39.