

Estimating Water Footprint of Palm Oil Production in PTP Mitra Ogan Baturaja, South Sumatera

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Abstract— Rising demand for palm oil has led to the rapid expansion of palm oil industry in Indonesia. Consequently, the environmental and social issues including water-related problems have become a major concern. Inevitably, water consumption in this sector is very important to be analyzed. Water footprint is one of the methods that can be used as a tool for the sustainable appropriation of freshwater resources. Here we investigated the water footprint in both oil palm cultivation and milling processes carried out by PTP Mitra Ogan, the largest plantation companies in South Sumatera. The goal eventually was to formulate the strategies to reduce the water footprint in the palm oil production based on the best practice criteria. This study reveals that the total water footprint of oil palm done by PTP Mitra Ogan (487 ton) is 980.9 m³/ton, while that of Crude Palm Oil (CPO) (5.7 ton) is 3,818.6 m³/ton and processing kernel (0.74 ton) is 2,174.3 m³/ton. This study reveals that the intensive use of inorganic fertilizers during the cultivation process caused the high value of the water footprint in the farming stage, so that the use of inorganic fertilizers must be controlled. In the industrial processes, total water use in all stages of the production of CPO and kernel was 1.36 m³/ton of fresh fruit bunch produced, whereas the wastewater produce was approximately 306.81 m³/ton. It reveals that there was an inefficient use of water in the milling processes so that the implementation of the steam accumulator and reuse of wastewater discharged can be alternatives in reducing the water footprint in the palm oil milling process for better water resource management.

Keywords— water footprint; palm oil; sustainable water resources; water resource management

I. INTRODUCTION

Currently, global production of palm oil in the world is estimated at over 45 million tones with Indonesia as one of the major producer and exporters. In 2016, its export has reached 27 million tons per year with the increasing trend [1]. As the most significant agricultural export, palm oil industry in Indonesia has developed rapidly which was twice higher from 4.2 million ha in 2000 to be 8.0 million ha in 2010. In 2020, the Government of Indonesia has targeted to export Crude Palm Oil (CPO) at 52 million tons. Consequently, the oil palm plantation in Indonesia was projected to reach 13 hectares by 2020.

In realizing the target, all stakeholders, including companies should ensure that the palm oil industry is sustainably organized. It is because sustainable practices of palm oil industry become one of the requirements for a palm oil industry to enter the global market. In Indonesia, however, palm oil sector is often associated with some sustainability issues due to the standards set up by RSPO (Roundtable for Sustainable Palm Oil). The issues include

carbon emissions, deforestation, biodiversity loss, habitat fragmentation, reduction of freshwater and soil quality as well as negative impact on local communities [2].

Among those problems, freshwater reduction and pollution have become major concerns. In a plantation, for example, oil palm needs relatively high water use which requires an annual rainfall of 2000 mm which is evenly distributed throughout the year. During the dry period with a relatively low rainfall, the freshwater consumption will be increasingly higher [3]. This condition potentially causes conflicts in water utilization with other sectors, especially in the dry season which has occurred in several regions in Indonesia. Villagers in Jambi, for instance, living nearby palm oil plantations faced water problems because of the palm oil plantation activities [4]. The problems include reduced water debit and diverted water flow due to the constructions of channels and dams developed for the palm oil irrigation. Chemical fertilizers and pesticides used during its cultivation also affect the environmental equilibrium, which pollutes surface and groundwater sources [5].

Meanwhile, for every metric tone palm oil produced, 5 to 7.5 tons of effluents from 1 ton of CPO are generated in the

palm oil mills [6]. Direct release of the effluent to the stream may potentially cause freshwater pollution and affect the people and downstream biodiversity [2]. Those impacts indicate the urgency of applying sustainable water resource management in palm oil industry, which takes the efficiency and the renewability of sources into account. One of the methods that can be used as a tool for the sustainable appropriation of freshwater resources is water footprint analysis.

The water footprint is a useful indicator to report on total water consumption, water scarcity levels and reductions achieved after the implementation of response strategies. Government, companies, consultants, and accountants use the same definitions and methods of calculation which create a common language [7]. Wise water governance is no longer the exclusive domain of government. All stakeholders, including consumers, companies, and investor play an essential role as well [8]. For companies, the results of water footprint in their activities will provide insight, information, and knowledge to consider the strategies to reduce the use of water. In this case, reducing water can give benefits for companies and for the environment in general [9].

Several studies related to the water footprint in palm oil sector have been done throughout the world. In Indonesia, however, there is no sufficient detailed water footprint information in that sector. Meanwhile, water footprint analysis is geographically, technologically, and temporally dependent.

The objective of this study is to investigate the water footprint in both oil palm cultivation and milling processes carried out by PTP Mitra Ogan, South Sumatera by analyzing climate data, soil characteristics and water consumption in both agricultural and industrial stages based on the concepts of the water footprint. In addition, this research also aims to formulate the strategies to reduce the water footprint in the palm oil production based on the best practice criteria.

II. MATERIAL AND METHOD

PTP Mitra Ogan as a unit analysis in this study was one of the largest plantation companies in the South Sumatra. It was located in Peninjauan District, Ogan Komering Ulu Regency, South Sumatera, Indonesia whose land was about 65.678,95 ha in 2013. Since 1988, this company established two processing mills and developed an integrated palm oil production from cultivation to processing CPO at a processing capacity of 60 tons per hour. This study identified the nucleus plantation area of 655,64 ha. By identifying the nucleus plantation area, the same method of cultivation was applied as well as the doses of fertilizers used.

A. Water Use in Palm Oil Production

Palm oil production can be divided into two stages namely cultivation and palm oil milling process. During the cultivation period, water becomes a major substance needed to allow the physiological growth of young oil palm trees. The average of water needed during this period is equivalent to the rainfall of 3.4 mm per day. This amount equals 34,000 litres/ha/day or 2.25 litres per container [10]. Besides, during fertilizer application in the pre-nursery stage, 25 g of urea in

10 litres of water per 1,000 seeds can be applied weekly with light watering [11].

Water also plays a significant role in the palm oil milling process. It is used as the feed for the boiler in generating power and for product treatment [12]. Fig. 1 illustrates stages in CPO and Kernel processing that involves water.

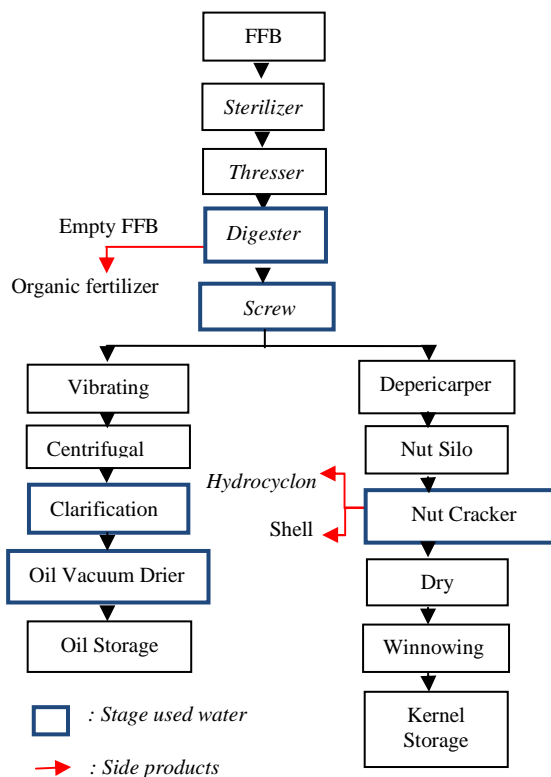


Fig. 1 CPO and kernel processing

B. Methodology of Water Footprint for Palm Oil Production

This study focuses on three stages of palm oil production, i.e. nursery, plantation and palm oil milling processes. Analysis of water footprint for nursery and plantation is very influenced by the specific geographical conditions, the type of local climate and agricultural technologies used during the production process of the plant [13].

Both primary and secondary data were used in this research. Primary data were collected by interviewing the stakeholders involved in the production of palm oil in PTP Mitra Ogan. In addition, these research data were collected based on direct observation. It aimed to get information related to the methods of cultivation, sources of water use, amount of water use, amount of fertilizers and pesticides used at each stage, amount of yields, use method and amount of water use in the palm oil mill. The secondary data were obtained by reviewing literature and documents dealing with the production of palm oil. The followings are the description of the data collections and its analysis.

TABLE 1
PRIMARY DATA AND SECONDARY INFORMATION REQUIRED

Primary Data		
Data Required	Source	Methods of Collection
Puddling Depth	Location of Study	Field Experiment
Soil Texture	Location of Study	Laboratory Testing
Location Coordinate & Altitude	Location of Study	Field Experiment
Maximum Crop Height & Maximum Rooting Depth	Location of Study	Field Experiment
Types of Fertilizers	Location of Study	Interview
On-site Water Quality	Location of Study	Laboratory Testing
Effluent Quality	Location of Study	Laboratory Testing
Water Consumption in Each Step of Palm Oil Mill	Location of Study	Field Experiment
Existing Practices of Palm Oil Production	Location of Study	Interview

Secondary Data		
Data Required	Source	Methods of Collection
Rainfall	Location of Study	Documentation Study
Land Area	Location of Study	Documentation Study
Growing Period	Location of Study	Documentation Study
Yields	Location of Study	Documentation Study
Crop Coefficient (Kc)	Internet, Books, Relevant Literature	Documentation Study
Product Fraction	Location of Study	Documentation Study
Minimum & Maximum Temperatures, Relative Humidity, Wind Speed and Intensity of Solar Radiation	Computer Software, New_Loclim version 1.1	Simulation
Amount of Inorganic Fertilizers and Pesticides	Company Documents	Documentation Study
Ambient of Water Quality Standards, Effluent Quality Standards	Government Documents	Documentation Study

The calculation method of WF of oil palm cultivation can be depicted in Fig. 2. To calculate the water footprint of oil palm, determination of evapotranspiration is the initial step. Different amount of evapotranspiration will be produced by different climatic conditions [14]. Total evapotranspiration will affect the amount of generated water footprint. The FAO Penman-Monteith method has been used to calculate the reference evapotranspiration, which is the evapotranspiration of reference grass in the situation with an

abundance of water [15] and the approximation of the total water involved in the actual evapotranspiration [16].

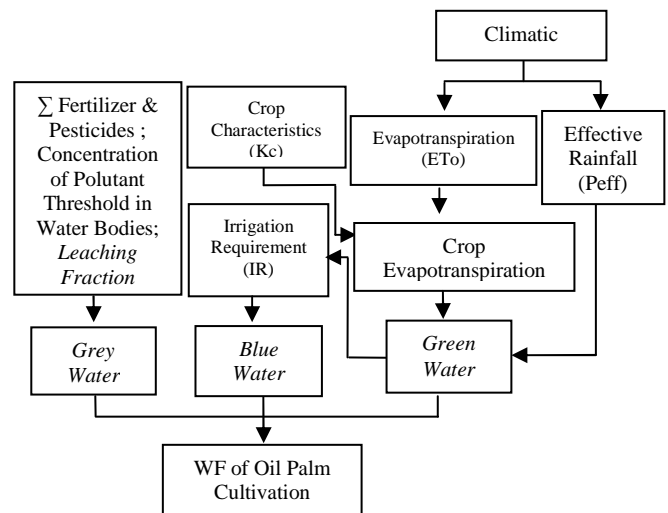


Fig. 2 The calculation method of WF of oil palm cultivation

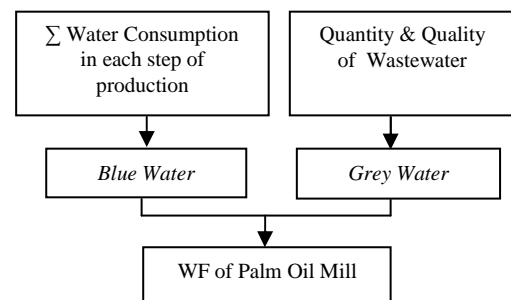


Fig. 3 The calculation method of WF of palm oil mill

Data of location coordinate, latitude, rainfall, soil texture, puddling depth, growing period, land area, amount of yields, maximum crop height, maximum rooting depth, and Crop Coefficient (Kc) were analysed by using CROPWAT 8.0, from which the values of the green and blue water evapotranspiration, ET_g and ET_b , were generated.

$$CWUg = 10x \sum ETg \quad (1)$$

$$CWUb = 10x \sum ETb \quad (2)$$

The values of ET_g and ET_b obtained from CROPWAT 8.0 were used to estimate the value of Crop Water Use (CWU) by using Equation 1 and Equation 2. Eventually, the value of CWU was used to calculate the values of green and blue water footprints, WF_g and WF_b by using Equation 3 and Equation 4 respectively.

$$WFg = \frac{CWUg}{Y} \quad (3)$$

$$WFb = \frac{CWUb}{Y} \quad (4)$$

The grey water footprint of oil palm is defined as the volume of freshwater that is required to assimilate a load of

pollutants based on ambient water quality standards. It is calculated as the volume of water that is required to dilute contaminants to such an extent that the water quality is higher than the water quality standard requirement [17]. Natural water used in this study (Cnat) comes from a tributary of Ogan River providing the source of water for irrigation in the study site. Data on inorganic fertilizers and pesticides amounts per ha yield (AR) and leaching fraction (α) were used to estimate the grey water footprint of oil palm by using Equation 5.

$$WF_{grey} = \frac{(\alpha x AR) / (C_{max} - C_{nat})}{Y} \quad (5)$$

The value of blue water in the mill was predicted by using data of water consumption in each step of palm oil mill (Fig. 3). It was analysed by using water balance approach [18]. In estimating this data, a product fraction value, a value representing the fraction of water lost during the process in each step in the mill was also used.

Meanwhile, the grey water footprint was estimated based on data of the volume of wastewater having quality lower than the ambient water quality. The value of grey water in the mill can be assumed to be equal to the amount of the waste if the industry has applied the waste treatment before it is discharged to the environment. In determining whether the volume of wastewater was calculated or not, data of on-site water quality (Cnat), effluent quality (Effl), ambient of water quality standards, effluent quality standards (Ceffl) and the yields (Y) were used. The grey water footprint in this analysis was determined by using Equation 6.

$$WF_{grey} = \frac{Effl (C_{effl} - C_{nat}) / (C_{max} - C_{nat})}{Y} \quad (6)$$

To represent the existing water use in the palm oil company, the values of water footprints of palm oil production both in the cultivation and mill generated in this study were then used. Information of existing water use was utilized as the basis for formulating strategies in reducing water footprint in the palm oil company. Field notes obtained from the interview were studied and compared with the best practice criteria. In this study, the implementation of palm oil production in PTP London Sumatera as a certified palm oil company was identified to get information related to the strategies of water footprint reduction. The strategies could be the best practice criteria having possibilities to be implemented in the palm oil company based on existing conditions in term of technical and technological, managerial, human resource, and economic aspects.

III. RESULTS AND DISCUSSIONS

A. Oil Palm Cultivation and Processing in PTP Mitra Ogan

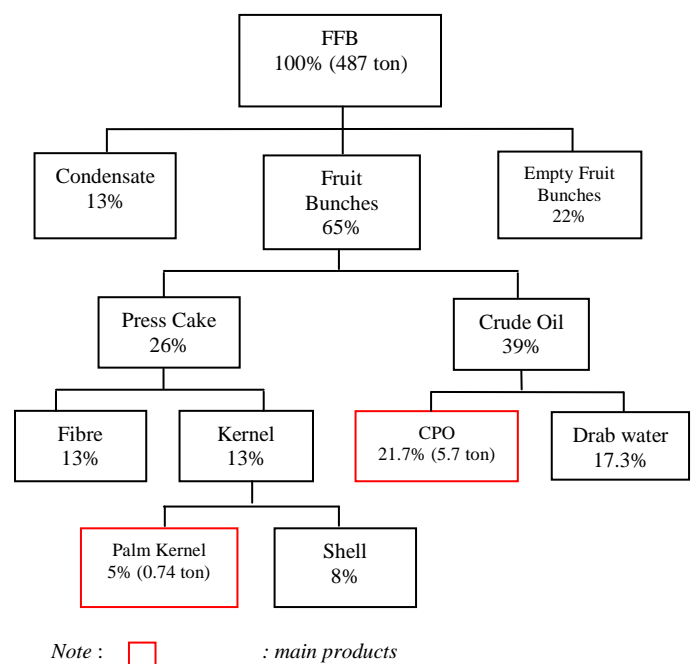
Based on the interview with the Manager of PIN PTP Mitra Ogan, palm oil trees averagely planted in every hectare of land are about 135 trees with a productivity of 0.5 to 1.5 tons of FFB per hectare per month. It was known that the plantation was conducted gradually for each afdeling. The first plantation was done in January 1991. The prenursery is done in a small polybag until 3 months. Afterwards, the plants are moved into a larger polybag

whose process is called the main nursery. The nursery plants of ages 10 – 12 months are then moved to the estate land. The plants are maintained since the prenursery until harvesting at the age of 36 months. This step is also called productive step.

The initial plantation was conducted in January 1990, and the first harvesting was done in January 1994 after the plants were 48 months old. Harvesting can be done for every month and harvesting in a month is usually done twice until the plants reach 20 years. Afterwards, the harvesting productivity is increasingly lower, and the plants become fruitless (unproductive) anymore.

The average production of FFB per year reaches 14.81 tons per hectare which are produced by the central estate of PTP Mitra Ogan. In first five years of harvesting, the average production of FFB is relatively low, i.e., ranging from 1 to 7 tons per hectares and increasing at an average of 20 tons per hectare per year in 20 years of harvesting. After this period, the production is increasingly lower until reaching 25 to 30 years.

The production of Crude Palm Oil (CPO) and Palm Kernel in PTP Mitra Ogan mills are about 5.7 ton and 0.74 ton in every hectare of FFB harvested. With the processing capacity of 30-ton FFB per hour, it can process for about 487 ton of FFB during 22 operating hour in a day. The mass balance of palm oil production in PTP Mitra Ogan milling process is depicted in Fig. 4.



Source: Documentation of PTP Mitra Ogan Mills

Fig. 4 Palm oil processing in PTP mitra ogan

To obtain the derivative value of the water footprint component per ton of FFB, the product and value fractions were calculated. The product fraction is used to represent the mass balance when processing the raw materials, while the value fraction is used to allocate loads between co-products based on the economic value [19]. Table 2 summarizes the data used for all materials, including product and value fractions.

TABLE II
THE PRODUCT AND VALUE FRACTIONS OF PALM OIL AND ITS DERIVATIVE PRODUCTS (2014)

Primary Products	Derivative Products	Average Price	F_p	V_p
FFB	Condensate of Water	0	0.13	0
	Fibre	100	0.13	0.006
	Kernel	4,708	0.05	0.11
	Shell	500	0.08	0.019
	Palm oil	8,306	0.22	0.85
	Drab of Water	0	0.17	0
	Midrib	100	0.22	0.01

B. Water Footprint of Oil Palm

The results of analysis by using Cropwat 8.0 show that the value of green evapotranspiration (ET_g) and blue evapotranspiration (ET_b) in the location of study. The results of estimation obtained based on the amount of water consumption by the plants (CWU) during the cultivation period is presented in Table 3.

TABLE III
THE AVERAGE VALUES OF GREEN AND BLUE WATER COMPONENTS FOR OIL PALM TREES DURING THE PRODUCTIVE PERIOD (20 YEARS)

Components	Values
$\sum ET_g$ (mm/growing period)	1.215,60
$\sum ET_b$ (mm/growing period)	34,50
$\sum CWU_g$ (m ³ /ha)	12.156
$\sum CWU_b$ (m ³ /ha)	345
\sum Yield (ton/ha)	14,81
WF Green (m ³ /ton)	820,79
WF Blue (m ³ /ton)	23,29

The value of green water in this research is not really different compared with the analysis of water footprint done by [19] to oil palm in Indonesia as the raw material of producing margarine, namely 714 m³/ton. Meanwhile, it is predicted the average value of green water footprint in Indonesia is 802 m³/ton. The difference in the values of green water happens because this method is a specific location in which there is the difference in the climatic conditions [20]. Moreover, the difference in the amount of harvested fruits due to the farming methods and the use of technology becomes the factors affecting the value of green water.

In addition, the value of green water is also influenced by the characteristics of the soil at the sites where the sand-less soil has an ability to hold water better than soil containing more sand, so the percolation rate in the soil will be smaller than in soil containing more sand. The soil will also be easier to lose water through evaporation because the soil containing more sand has a relatively small surface area, so its ability in holding water is low [21].

Meanwhile, based on the interview the average amount of NPK that is the source of nitrogen is applied as much as 418.5 kg/ton in which the average content of nitrogen is about 192.5 kg/ton/year. The grey water footprint based on

the results of the calculation is 136.821 m³/ton (Table 4). It describes the amount of "virtual water" reduced for assimilating the pollutants that enter the water body.

The results of this study indicate that the value of grey water in the oil palm cultivation is greater than the global value of grey water, i.e., 40 m³ / ton [22], and the average value of the provincial grey water in Indonesia, i.e., 51 m³ / ton [20]. This indicates that inorganic fertilizers are more intensively used by PTP Mitra Ogan. This is usually done by an estate company in order to reduce the risk of low productivity and crop failure. The intensive use of inorganic fertilizers and pesticides is expected to improve crop yields and crop resistance to pests and diseases.

TABLE IV
THE COMPONENTS AND VALUES OF GREY WATER FOR OIL PALM TREES FROM NITROGEN FERTILIZERS

Components	Values
Parameter	NO ₃ -
α^*	0.1
AR (N) (kg/ha/growing period)	192.5
C _{max} (kg/m ³)	0.01
C _{nat} (kg/m ³)	0.5x10 ⁻³
Yields (ton/ha)	14.81
WF _{grey} (m ³ /ton)	136.821

* α : leaching fraction [17]

C. Water Footprint of CPO and Kernel

Fertilization enables a relatively high water footprint due to the occurrence of water contamination during the production process and the occurrence of the nitrogen leaching into water bodies. As a result, greater nitrogen retention in the soil through the use of natural fertilizers can reduce the level of nitrogen leaching into water bodies [23].

TABLE V
THE VALUES OF BLUE WATER COMPONENT FOR CPO AND KERNEL

No.	Processes	Water Quantity (m ³ /ton FFB)	Water Quantity (m ³ /ton Prod)
1	Boiler	0.90	3.38
2	Hot water tank (press station)	0.18	0.68
3	Clay bath Mixing (Kernel Station)	0.01	0.043
4	Hot Water Tank (Clarification Station)	0.11	0.35
5	Vacuum Drier Pump (Clarification Station)	0.15	0.55
	Total	1.36	5.08

The national standard of water use in the PKS unit is equal to 1.1 to 1.2 m³/ton of FFB [12], [24]. In addition, the amount of blue water in the extraction of CPO is larger than the value blue water that has been estimated, i.e., 2.9 m³/ton of production [19]. This result indicates that there is an inefficient use of water in the processing of palm oil in PTP Mitra Ogan mills.

Meanwhile, based on observations in the study location, the wastewater from palm oil extraction in the PTP Mitra

Ogan is treated before it is discharged into the environment. So, it was assumed that the concentration of pollutants in the effluent is within the standard of the ambient water quality value. As a result, according to its classification, the grey water footprint of the process is the same as the volume of wastewater generated. Due to the limited access to primary data, the data volume of wastewater produced was estimated based on the documentation from preliminary studies in PTP Mitra Ogan done by the Estate Department of Baturaja.

Effluent generated in the mill is one of the by-products derived from the condensate of the sterilization process, the water from the clarification process, and hydrocyclone (clay bath) water. In one operating day, the mill will produce wastewater of approximately 306.81 m³ / ton. This amount is equivalent to 0.63 m³ / ton of FFB processed or 2.36 m³ / ton of waste per ton of production (Table 6).

TABLE VI
THE VALUE OF GREY WATER COMPONENT FOR CPO AND KERNEL

Source of Liquid waste	Percentage (%)*	WF _{proses, grey} (m ³ /ton)
Condensate Water	13	63.31
Clarification Station	45	219.15
Hydrocyclone (Clay Bath)	5	24.35
Total	63	306.81
Average / ton TBS processed		0.63
Average /ton production		2.36

*Source: Company document

Note: - Total amount of CPO & kernel produced per day: 130.03 ton

Total values of oil palm water footprint and its derivative products (CPO and kernel) can be depicted in Fig. 5. It can be summed up that the value of water footprint for oil palm was 980.90 m³/ton, while the value of kernel and CPO was 2,174.3 m³/ton and 3,818.6 m³/ton, respectively. The values of water footprint for CPO and kernel are larger than that of the previous input. This occurs because of the loss of mass in each stage of processing derivative products. The greater the value of the product fraction showing the smaller fraction of the initial products used in the final products, the larger the value of the water footprint of the final product.

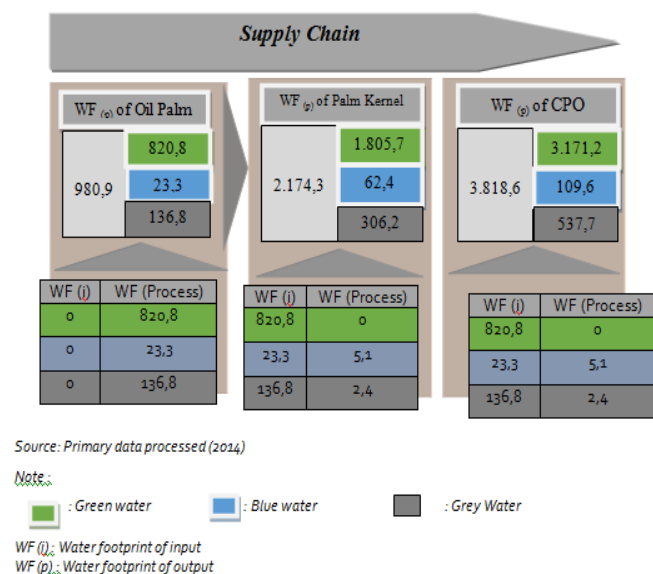


Fig. 5 Water footprints of oil palm and derivative products

D. Strategy of Reducing Water Footprint of Oil Palm Production

Based on former study [14], [25], the reduction of blue water footprint can, in general, be achieved by increasing yield and on reducing non-beneficial evapotranspiration through the development of cultivation practices that can increase the water productivity. Water productivity is the amount of yield harvested per meter cubic of the irrigated water use.

To reduce the grey water in cultivation, the use of inorganic fertilizers must be controlled. It requires a management of applied fertilizers which use the precise dosage, timing, type and placement of fertilizers. The mixing use of organic and inorganic fertilizers which will reduce the soil pollutants can be applied as well.

Hence, a more efficient use of water for an industrial process becomes necessary. In addition to minimizing the impact on the environment, reducing the use of water in the treatment process will also reduce the discharging of waste. This means that decrease the water use during the process potentially reduce the level of water pollution. Several strategies such as reuse of palm oil effluent and use of clean production technologies can be implemented to lower the value of blue water in the palm oil production.

Another advanced strategy, i.e., the use of steam accumulator may be used to decrease the amount of blue water according to a study conducted in the mill of PTP London Sumatera, Banyuasin in August 2014. Besides, a previous study [26] has proposed steam accumulator to stabilize the steam pressure fluctuation in palm oil mill, especially at the demand sites. However, further studies are required to ensure the possibility of installing a steam accumulator in PTP Mitra Ogan mills since the size of Back Pressure Vessel (BPV) and the capacity of steam consumed vary.

Saving water in the pressing station and reuse of effluents can also be applied based on the recommendations of the manual of Environmental Impact Control Technology Palm Oil Industry issued by BAPEDAL in 1988 [27], key informant (machinist head assistant) and the amount of discharged water, as well as previous studies in the POM of Sei Mangkei, North Sumatera [27]. The strategy based on the study in POM of Sei Mangkei can also be applied in PTP Mitra Ogan because both companies have similarities in term of production capacity, production process and the types of machines used.

Furthermore, to reduce blue water, the machinist head assistant recommended the recycling of water from the turbine. The concept of water recycling is the process of reusing the cooling water coming from the turbine, so the water can be recovered for cooling after being collected in the collector and then returned to the hot well tank for the purposes in the clarification unit. Water as much as 0.20 m³ / ton of FFB is directly discharged into the environment during this process. Nevertheless, those aforementioned strategies require further study so that those can properly applied based on the technical, financial and environmental aspects of PTP Mitra Ogan mills.

IV. CONCLUSIONS

The average value of the oil palm water footprint in Indonesia from the previous study showed a value that is not different. The difference in magnitude of the values of water footprint occurs because the climatic conditions in each region of cultivation are different. In addition, the productivity due to the differences in the use of technologies, ways of cultivation, applications of fertilizers and ways of caring influences the variation of the water footprint.

This study also found that the high value of the water footprint in the nursery stage is caused by the use of inorganic fertilizers during the cultivation process. The high intensity of inorganic fertilizers causes the level of water contamination/ pollution and leaching of nitrogen into the water a body increase. This causes a high amount of the grey water footprint of oil palm cultivation in the study site. Reducing the use of inorganic fertilizers through the use of organic fertilizers can be an alternative to reduce the amount of grey water.

In the industrial processes, there is an indication of wasteful use of water during the CPO and palm kernel production. Increase use of the blue water, the potential contamination by the waste of palm oil will be larger. Reuse of wastewater and implementation of clean technology are expected to minimize the inefficient use of freshwater by the company accordance with the reduction of effluent discharged.

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