A Review of the Water Footprint of Biofuel Crop Production in Thailand

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Abstract: Increase of biofuel production is an important component in the development of alternative energy in Thailand. To meet the higher amount of biofuel (targeted by Thailand Department of Alternative Energy Development and Efficiency, DEDE), a lot of biofuel feedstock production is needed which in turn requires a large volume of water for irrigation. This study assesses the water footprint (WF) of three key biofuel crops in Thailand- cassava, sugarcane, and oil palm, based on previous studies. The WF varies considerably for each region, which is characterized by different climatic conditions and agricultural production systems. The results show that the water uses per hectare of cassava, sugarcane, and oil palm lands are in the range of 7,235-9,652, 11,630-16,312, and 12,942-23,547 m^3, respectively; and, the ranges of freshwater consumption in Thailand for cassava, sugarcane, and oil palm production are between 409-455, 162-276, and 965-2,353 m^3 per ton of product, respectively. Although Thailand uses water for biofuel crop cultivation more efficiently than some other countries, good water management practices are still required in order to avoid the conflict between water for energy and food. These results have implications for both policy makers and farmers in terms of water management and planning.

Keywords: biofuel crops, water footprint, cassava, sugarcane, oil palm.

1. Introduction

Most of Thailand's primary energy relies on energy import from foreign countries. According to Thailand's Department of Alternative Energy Development and Efficiency (DEDE)'s report, in 2011, 80 percent of crude oil consumed by the whole nation was imported (equivalent to 927 million baht) costing substantial amount of foreign exchange [1].

Thailand has continually developed alternative energy to reduce the energy import as well as to strengthen the energy security of the country. Recently, DEDE presented the Alternative Energy Development Plan (AEDP) for the year 2012–2021 with the aim to increase the alternative energy consumption from 7,413 ktoe in 2012 to 25,000 ktoe in 2021 (raised by 25 percent in 10 years) [1].

Biofuels are one form of alternative energy used in the transportation sector where the AEDP targets to increase the production capacity from 1.3 and 1.62 million liters per day in 2012 to reach 9 and 5.97 million liters per day in 2021 for ethanol and bio-diesel respectively [1]. To achieve this goal, there has to be an increase in biofuel feedstock production which may require an expansion of cultivated area and irrigation.

According to the historical report presented by Thailand's Hydro and Agro Informatics Institute (HAII), the volume of rainwater and water in dams in 2009 (most recent year in the report) was lowest in five years (2005-2009) [2]. The volume of water did not continuously decrease but fluctuated between the five observed years, which indicates that the amount of water available in the country is uncertain and there may be a drought in some years. So, since fresh water is a scarce resource, the information of water usage for biofuel crop production is essential for an effective policy. An interesting question is that how much is the water needed for cropping each kind of biofuel feedstock in Thailand?

Many studies have been conducted to answer this question. Most of them used the water footprint (WF) concept to assess freshwater required for crop production. However, there were some differences between WF calculation methods of each study. Besides, because the previous studies were in different locations with different weather conditions and soil qualities, WF of the same crop categories in different places was also different [3-10]. Therefore, this study intends to identify range of the WF of biofuel crop production in Thailand based on previous related studies and presents an overview of the results.

All in all, since water resources have an implication to environmental sustainability, the water resource use estimation will benefit policy makers and farmers in terms of water resource management in the future.

2. Water Footprint of Biofuel Crops

2.1 Biofuel crops concerned

In this study, three key biofuel feedstocks: (1) cassava, (2) sugarcane, and (3) oil palm, are taken into account since these three have been adopted by Thailand's biofuel sector for several years [11].

2.2 Water footprint concept and calculation

Water footprint (WF) is a tool used for quantifying the water required for the production of a product. This tool has been introduced by Hoekstra and colleagues [3]. The WF of product is the total volume of freshwater that is used to produce the product; it consists of three components: blue, green, and grey water. The blue water footprint refers to the volume of surface and ground water consumed (evaporated) as a result of the production of a good; the green water footprint refers to the rainwater consumed. The grey water footprint of a product refers to the volume of fresh water that is required to assimilate the load of pollutants based on existing ambient water quality standards [4].

Many studies employed the WF concept to estimate the water use in energy crop production. For example, Gerbens-Leenes and colleagues studied the global WF of ethanol and biodiesel as well as the WF of energy from biomass [3,5]. Mekonnen and Hoekstra indicated the global green, blue and grey WF of crops including biofuel feedstocks. Thailand's Royal Irrigation Department (RID) reported the water requirement of crops in Thailand, and Babel and colleagues used the WF to assess the hydrological impact of biofuel production (in terms of water quantity) at Khong Phlo watershed in Thailand [4,6-7]. Also, the recent researches by Kongboon and Sampattagul, Jarernsook and colleagues, and Seewiseng and colleagues presented the WF of sugarcane and cassava in northern Thailand, the WF of oil palm in some provinces in the North and South, and the WF of oil palm in a restoration project, respectively [8-10].

Even though all previous studies used WF as a tool to assess the volume of water used for biofuel crop production, according to their specific research objectives, they applied the WF calculation in different ways. Nonetheless, all studies basically calculated the WF of particular biofuel crop using these following steps.

Step 1: The calculation of the crop water requirement of crop c (CWR[c], m^3/ha). This is calculated by accumulation of daily crop evapotranspiration (ET_c, mm/day) multiplied by factor 10 as Equation (1) [3,12]:

$$CWR[c] = 10 \times \sum_{d=1}^{lp} ET_c[c,d] \quad (1)$$

where the factor "10" is applied to convert the unit from mm into m^3/ha, and "lp" stands for the length of growing period in days.

ET_c is measured over the growing period of crop from day 1 to the final day of growing period using CROPWAT model developed by the Food and Agriculture Organization of the United Nations (FAO) which is based on the FAO Penman-Monteith method [8]. ET_c can be derived from Equation (2) [12]:

$$ET_c = K_c \times ET_0 \quad (2)$$

where K_c is the crop coefficient that includes effects that distinguishes evapotranspiration of field crops from grass, and ET_0 is the reference crop evapotranspiration (mm/day) of a hypothetical surface covered with grass not short of water [3, 12].

Crop water requirement is classified into green and blue water use. The green water use is equal to the sum of daily volume of rainwater evapotranspiration provided by the rainwater stored as soil moisture. Then, the blue water use (irrigation water) can be known by subtracting the green water from the total amount of crop water requirement as calculated in the Equation 1 [5,7].

Step 2: The calculation of the green and blue water footprint for growing the crop (WF, m^3/ton). These are calculated as the green and blue water use (m^3/ha) divided by the crop yield (Y, ton/ha) [8]:

$$WF_{green} = \frac{\text{Green water use}}{Y} \quad (3)$$

$$WF_{blue} = \frac{\text{Blue water use}}{Y} \quad (4)$$

Step 3: The grey water footprint (WF_{grey}, m^3/ton) is calculated for the growing crop by multiplying the chemical application (i.e. fertilizers, pesticides, etc.) rate per hectare (Appl, kg/ha) with the leaching-run-off fraction (α) divided by the maximum acceptable concentration (c_{max}, kg/m^3) minus the natural concentration for pollutant considered (c_{nat}, kg/m^3) and then dividing by the crop yield (Y, ton/ha) [8]:

$$WF_{grey} = \frac{(\alpha \times Appl)/(c_{max} - c_{nat})}{Y} \quad (5)$$

Step 4: The total water footprint of the process of growing crops (WF_{Proc}) is the sum of green, blue, and grey water footprints and its unit is m^3/ton (water volume per mass) [8]:

$$WF_{Proc} = WF_{green} + WF_{blue} + WF_{grey} \quad (6)$$

The studies that projected to quantify the water required for biofuel crops per total biomass yield (m^3/ton), e.g. Kongboon and Sampattagul, Jarernsook and colleagues, and Seewiseng and colleagues [8-10], stopped the computation at this stage, while many studies that aimed to compare the water resource use to the derived energy from crops did further calculations in order to convert the unit of final result into m^3/GJ.

Besides, Gerbens-Leenes and colleagues and RID did not do the calculation for the grey WF of bioenergy crop production because the study only took water consumption by the crops into account; substances leached away from cultivation fell outside the study scope [3,5-6]. So, it can be summarized that the computation of WF between the studies can be different depending on objective and scope of the studies.

2.3 Data Collection

As the aim of this study is to estimate the water used in biofuel crop production in Thailand based on previous studies, this study collects the data (the water footprints) by reviewing related papers; the data of this study are from the results of related papers.

There are six related papers regarding the WF of Thailand biofuel crop production directly [5-10]. The differences between the study scope of each related paper are summarized in Table 1.

From the Table 1, Gerbens-Leenes and colleagues did the first paper regarding WF of bioenergy crop in Thailand. The paper showed the whole nation WF of particular biofuel crops by using 5-year (1997-2001) average annual crop yield and crop water requirement (from selected weather stations: Nakhon Ratchasima for cassava, and Chiang Mai for sugarcane) of the country as data [5].

Table 1. Study scope of related literature.

Study	Study area	Studied crops	Blue WF	Green WF	Grey WF
Gerben-Leenes et al. (2008) [5]	Nakhon Ratchasima (cassava) and Chiang Mai (sugarcane) province, Thailand	Cassava and sugarcane	Yes	Yes	No
Thailand's Royal Irrigation Department (2010) [6]	Thailand	Sugarcane and oil palm	Yes	Yes	No
Babel et al. (2011) [7]	Khlong Phlo sub-basin, Rayong province, Thailand	Cassava, sugarcane, and oil palm	Yes	Yes	Yes
Kongboon and Sampattagul (2012) [8]	Northern provinces, Thailand	Cassava and sugarcane	Yes	Yes	Yes
Jarernsook et al. (2012) [9]	Northern and Southern provinces, Thailand	Oil palm	Yes	Yes	Yes
Seewiseng et al. (2012)[10]	Chaipattana-Mae Fah Luang Reforestation Project, Phetchaburi province, Thailand	Oil palm	Yes	Yes	Yes

Another paper that also presented the crop water requirements for the whole country was by Thailand's Royal Irrigation Department (RID). However, RID did not analyze the water requirement of cassava [6].

The specific study areas in Thailand are shown in the papers of Babel and colleagues, Kongboon and Sampattagul, Jarernsook and colleagues, and Seewiseng and colleagues. Babel and colleagues selected 202.8 km^2 of Khlong Phlo sub-basin located in the eastern part of Thailand as the study area while the whole northern part of Thailand (covering 14 provinces) was considered in the case study by Kongboon and Sampattagul. However, both studies took the same duration of collecting data which is 3 years; 2006-2008 for Babel and colleagues and 2008-2010 for Kongboon and Sampattagul. Besides, unlike Babel and colleagues that concentrated on all three key biofuel crops, Kongboon and Sampattagul did not take oil palm into their consideration [7-8]. Jarernsook and colleagues presented the average WF of oil palm planted in three provinces in the northern and thirteen provinces in the southern part whereas Seewiseng and colleagues, the WF of oil palm planted in Chaipattana-Mae Fah Luang Reforestation in Phetchaburi province [9-10].

All the previous studies considered here took all three components of WF into consideration except for the study of Gerbens-Leenes and colleagues and RID that assessed only the green and blue WF.

Not only does this study analyze an approximate volume of the water used for each kind of biofuel crop cultivation in Thailand, but it also makes the comparison of the WF among major planting countries and other food crops. To compare the WF of biofuel crops among major producers, the data such as international ranking by production, the amount of WF and the yield of cassava and sugarcane cultivation of other countries were obtained from the research by Gerben-Leenes et al. (2008) [5]. The USDA Foreign Agriculture Service (USDA) provided the information on oil palm production ranking [13]. Oil palm WF in Indonesia was from Bulsink et al. (2009) [14], while its yield was from FAO (FAOSTAT) [15]. The global average WF of all three feedstocks from Mekonnen and Hoekstra (2010) was also added into this analysis [4]. To compare the WF of biofuel crops to other typical food crops in Thailand, the WF data of other food crops were obtained from RID whereas the yields were derived from FAO and the Office of Agricultural Economics (OAE) [5,15-16].

The results of WF of biofuel crop cultivations in Thailand and the comparison among the major producing countries and other food crops are shown in the next section.

3. Results and Discussion

3.1 Water used in biofuel crop cultivation in Thailand

Even though there are some differences in scope among the six related papers, the results (the water footprints) from all related papers do not have much difference and are comparable to each other as illustrated in Tables 2-4.

From Table 2-4, all the studies other than that by Babel and colleagues presented the results in m^3/ton of crop yield. The study by Babel and colleagues showed that it requires 103, 144, and 177 m^3 of water to produce 1 GJ of biofuel energy from cassava, sugarcane, and oil palm, respectively [7]. To convert the study results from m^3/GJ to m^3/ton, the required water of each crop per energy (m^3/GJ) is multiplied by its respective energy yield: 4.22 GJ/ton for cassava, 1.64 GJ/ton for sugarcane, and 7 GJ/ton for oil palm, computed from the information presented in the paper [7].

According to Table 2, the largest and lowest volumes of water required to produce a ton of cassava appear in the studies of Kongboon and Sampattagul, and Babel and colleagues, respectively [7-8]. However, because grey WF was out of Gerbens-Leenes and colleagues' consideration, this study then adds 13 m^3/ton of grey water, which is the global average grey WF indicated by Mekonnen and Hoekstra (2010), to 455 m^3/ton [4]. So, in other words, the range of the WF of cassava production in Thailand is 435–509 m^3/ton.

Grey water is sometimes not taken into discussion, such as in the study of Gerben-Leenes and colleagues and RID [5-6], since grey water does not actually indicate the amount of water necessary for crop growth. The WF of cassava production excluding grey water is in the range 409-455 m^3/ton of fresh root. The largest volume of water used for growing cassava per hectare is in the eastern region (9,243 m^3/ha) while the lowest is in the Northeast (7,235m^3/ha, Nakhon Rachasima province). High yield of cassava in the East results in the low amount of water consumption per ton, vice versa for cassava in the Northeast. It can be seen that cassava production in the East and the North can use the water more efficiently than in the Northeast. Moreover, one important point of consideration is that in the northern part, much irrigation water is required. Hence, from Table 2, it can be summarized that cassava should be cropped in the East most since it uses the least water per mass, gives the highest yield, and does not require much irrigation water.

From Table 3, in the same way as for cassava, because grey WF was out of Gerbens-Leenes and colleagues and RID's consideration [5-6], this study added 6 m^3/ton of grey WF, which is the global average grey WF of sugarcane indicated by Mekonnen

Table 2. Water footprint of cassava production based on previous studies

Study	Yield (ton/ha)	Water footprint of cassava (fresh roots) (m^3/ton)				Green + Blue WF (m^3/ton)	Green + Blue WF per hectare (m^3/ha)
		Blue	Green	Grey	Total		
Gerben-Leenes et al. (2008) [5]	15.9	42	413	-	455	455	7,235
Babel et al. (2011) [(a)] [7]	23.6	100	309	26	435	409	9,652
Kongboon and Sampattagul (2012) [8]	21.8	232	192	85	509	424	9,243

(a) The paper by Babel et al. provides only the total value and approximate percentages of green, blue and grey water [7].

Table 3. Water footprint of sugarcane production based on previous studies.

Study	Yield (ton/ha)	Water footprint of sugarcane (fresh cane) (m^3/ton)				Green + Blue WF (m^3/ton)	Green + Blue WF per hectare (m^3/ha)
		Blue	Green	Grey	Total		
Gerben-Leenes et al. (2008) [5]	59.1	128	148	-	276	276	16,312
Thailand's Royal Irrigation Department (RID) (2010) [6]	71.7[(b)]	95	67	-	162	162	11,630
Babel et al. (2011)[(a)] [7]	62.1	81	147	9	237	228	14,159
Kongboon and Sampattagul (2012) [8]	72.8	87	90	25	202	177	12,886

(a) The paper by Babel et al. provides only the total value and approximate percentages of green, blue and grey water [7].
(b) The number from FAOSTAT [15]

Table 4. Water footprint of oil palm production based on previous studies

Study	Yield (ton/ha)	WF of oil palm (fresh fruits) (m^3/ton)				Green + Blue WF (m^3/ton)	Green + Blue WF per hectare (m^3/ha)
		Blue	Green	Grey	Total		
Thailand's Royal Irrigation Department (RID) (2010) [6]	16.0[b]	491	474	-	965	965	15,440
Babel et al. (2011) [a] [7]	12.4	421	756	62	1,239	1,177	14,595
Jarernsook et al. (2012) [9]	16.7	339	1,071	729	2,139	1,410	23,547
Seewiseng et al. (2012) [10]	5.5	1,829	524	1,636	3,989	2,353	12,942

[a] The paper by Babel et al. provides only the total value and approximate percentages of green, blue and grey water [7].
[b] The number from FAOSTAT [15]

and Hoekstra (2010), leading to a total WF of 276 m^3/ton and 162 m^3/ton, respectively [4]. So, the range of the WF of sugarcane production in Thailand is 168–282 m^3/ton as shown in the papers by RID and Gerbens-Leenes and colleagues. Without considering grey water, the water actually used for growing sugarcane is between 162–276 m^3 per ton of fresh cane and the area using the greatest amount of water in sugarcane cultivation is Chiang Mai (16,312 m^3/ha). The low yield of sugarcane production in Chiang Mai results in the large volume of freshwater consumption per ton of fresh cane (276 m^3/ton) while the higher yield of sugarcane production in the Northern provinces result in less required freshwater on average (177 m^3/ton) [5,8]. Thus, it can be concluded that the water use in Chiang Mai (which is also in the Northern region) is less efficient compared to other provinces in the same region. Moreover, this also illustrates that a high amount of water does not necessarily imply a high yield of sugarcane since the yield depends on the optimal amount of water consumed [17]; the yield also depends on other factors such as soil quality and agricultural technology, etc.

Comparing WFs of sugarcane presented by RID and Babel and colleagues, the WF indicated by RID has more efficiency since it presents a lower volume of water required to produce a ton of fresh cane (162 m^3/ton). Nonetheless, this number is presented for the whole nation; so it does not give direct implication which area is suitable for sugarcane cultivation. Anyhow, from this value, it can be at least implied that sugarcane is largely planted in the northern part of Thailand since the value shown by Kongboon and Sampattagul is very close to that presented by RID and the Northern region is the most suitable area for planting sugarcane in Thailand.

From Table 4, in the case of oil palm, since grey WF was out of RID's consideration [6], this study then adds 6 m^3/ton of grey WF, which is the global average grey WF of oil palm indicated by Mekonnen and Hoekstra (2010), to 965 m^3/ton [4]. So, it can be roughly defined that to produce a ton of oil palm fruit the water required in production is between 971-3,989 m^3. The range of the WF of oil palm excluding grey water is 965-2,353 m^3 per ton of fresh fruit bunches. Similar to the case of sugarcane, even though RID provides the most efficient value of WF, it does not give any implication to specify the suitable area to plant oil palm tree. However, it can be concluded from the other three papers that the appropriate areas for oil palm agriculture are in the eastern and the southern part of Thailand; even though water consumption in the southern oil palm production is not so efficient as compared to the eastern production. But oil palm production in the South provides a higher yield (16.7 ton of fresh fruit bunch per hectare) and requires less irrigation water than the production in the East. A lot of rainwater consumption is presented by Jarernsook and colleagues because almost all study areas of the paper are in the southern provinces which have more abundant rainfall than the other provinces. Thus, there is hardly any demand for water from irrigation for oil palm cultivation in this region [9,11]. Moreover, oil palm tree is unsuitable to be planted in the central province like Phetchaburi since it provides very small yield and requires very high amount of irrigation water.

All in all, to produce a ton of biomass yield, oil palm needs larger amount of water compared to cassava and sugarcane; the water required for oil palm cultivation is approximately twice as much as that required for cassava and 5 times that for sugarcane. On a land area basis, oil palm and sugarcane consume more water than cassava. The most favourable regions to plant biofuel crops are the East for cassava, the North for sugarcane, and the east and south of Thailand for oil palm. Nevertheless, other factors also have to be taken into consideration for the determination on land use, such as efficiencies and benefits of biofuel crops as compared to other cash crops in specific regions.

3.2 Comparison of the WFs between countries

Thailand is one of the world's leading biofuel crop producers. The water resources used for biofuel crop cultivation of Thailand is compared to the other countries as shown in Table 3. The Table 3 illustrates the WF of biofuel crops of the top producing countries as well as their production per hectare.

Table 5. Water footprint of biofuel crop cultivations of top producers.

Country	Rank by production volume	Yield (ton/ha)	Green + Blue (m^3/ton)	Green + Blue per hectare (m^3/ha)
Cassava				
Nigeria	1st	10.7	578	6,185
Brazil	2nd	13.1	610	7,991
Thailand[b]	3rd	15.9-23.6	409-455	7,235-9,652
Congo	4th	8.1	769	6,229
Indonesia	5th	12.4	502	6,225
Global Avg.[a]			550	
Sugarcane				
Brazil	1st	68.6	230	15,778
India	2nd	69.0	274	18,906
China	3rd	68.4	193	13,201
Pakistan	5th	46.5	303	14,090
Thailand[b]	6th	59.1-72.8	162-276	11,630-16,312
Global Avg.[a]			197	
Oil palm				
Indonesia	1st	17.9	802	14,356
Thailand[b]	3rd	5.5-16.0	965-2,353	12,942-17,484
Global Avg.[a]			1,057	

Source: The Statistics Division of FAO (FAOSTAT) [11], the USDA Foreign Agriculture Service [13], Bulsink et al. (2009) [14], [a] Mekonnen and Hoekstra (2010) [4], [b] Information from Table 2-4

Not many studies on the WF of oil palm were available in the literature; only the WF of oil palm cultivation in Indonesia and Thailand could be found [6-7,9-10,13]. This is probably because water consumption by perennial tree crops is much more difficult to address and CROPWAT cannot be used properly for that. The data on WFs, production ranking, and yields of cassava and sugarcane for Thailand are from [5,7-8] whereas those for other countries are only from [5]. The data about oil palm production ranking and the average yield of oil palm in Indonesia are searched from the USDA, Babel et al. (2011) and the FAOSTAT [7,13,15]. Besides, the global average WFs were from the paper by Mekonnen and Hoekstra (2010) [4]. Since grey water does not indicate the fresh water required for crop growth, it is not taken into account in this stage.

The volume of WFs is different among regions depending on the climatic condition of each region. From Table 3, the water used for cassava production in Thailand (7,235-9,652 m^3/ha) is larger than other major cassava producers whereas the amount of water used in sugarcane and oil palm cultivation is only slightly higher, though very much in the same range. Although Thailand is not the largest producer of cassava and sugarcane, it seems that Thailand could use the water more efficiently in cassava and sugarcane cultivation. The total amount of water for cassava as well as sugarcane used to produce a ton of biofuel crop in Thailand are smaller than some countries; this might be because the high yield of both crops in Thailand. Conversely, compared to Indonesia, the volume of water required for producing a ton of oil palm in Thailand is larger. This result indicates that in the future, Thailand should be able to improve the technology to increase oil palm yield and/or develop water management plan to reduce the water consumption in oil palm agriculture as Indonesia has done.

3.3 Comparison of the WFs between typical food crops

Biofuel crops are also the food crops; cassava flour is the product of cassava, sugar is the product of sugarcane, and vegetable oil is the product of oil palm. Different crops consume different amounts of water. Comparing the water consumption of biofuel crop to some typical food crops can bring about a better understanding on the different water consumptions in different crops.

Table 6 illustrates the amount of fresh water needed for growing the typical food crops including three key biofuel crops. The WF data of food crops other than the biofuel feedstocks are derived from RID [6]. From the table, based on land area, the water required in biofuel crop production is much higher than the other food crops, except coffee. It is not surprising that coffee uses a lot of water since it is a tree crop like oil palm; tree crops normally consume more water compared to annual crops. RID also provides data about water consumption of rubber tree, which is another tree crop. Rubber tree requires around 14,860 m^3 water/ha which is not much different that required by oil palm and coffee [6]. So, not only are oil palm and coffee suitable to be planted in the southern region that has abundant rainfall, but so also is rubber.

Most of crops consume more green water than blue except for off-season rice, soybeans, and maize since these three crops are normally cultivated in the Northeast where there is not much rainfall. Oil palm is expected by AEDP to be expanded to the Northeast [1]; but, the northeastern region may have insufficient rainfall to grow oil palm and will then need irrigation water instead. However, Table 6 shows that large amounts of irrigation water are already needed for the food crops in the region. So, the expansion of oil palm may worsen the demand on water resources in the Northeast.

Moreover, switching land use to the biofuel crops can also result in the larger water requirement. For example, rice consumes 6,950 m^3 of water per hectare; when converted into the oil palm field, the water consumption will increase to 11,630-16,312 m^3 per hectare. Hence, the availability of water in that region as well as good water management practices will be important determinants of biofuel crop expansion.

3.4 Biofuel crops' WF and policy

According to AEDP, unlike cassava and sugarcane whose production is intended to be raised by increasing their yield, the large increase in oil palm output will require increase in cultivation area [1]. The very suitable area for planting oil palm is located in the South region which is largely already dedicated to rice and rubber in addition to oil palm. Since rubber is a high value cash crop with the margins reportedly greater than oil palm, there is no point that the government will encourage rubber farmers to switch their land to oil palm. However, following land suitability classification by the Land Development Department (LDD), another suitable area for oil palm cultivation is in the Northeast; financial analysis conducted by LDD suggests that oil palm may provide better returns for farmers in this area than some of the key crops like rice and maize currently under cultivation [11].

As aforementioned, oil palm requires a lot of green water (rain water); but, as per the statistical data from the past, amount of rain water in the northeast is not so much as in the south, especially in the dry spell [2]. Thus, oil palm that will be planted in the Northeast may require a lot of irrigation water. Even if the policies to promote the expansion of oil palm plantation to the northeast may result in rural development, there has to be a good practice for water resource management in order to ensure that oil palm crops will receive sufficient water and will not outcompete the other cash crops in that area.

Moreover, because a ton of cassava, sugarcane, and oil palm can produce energy yields of 5.20, 10.0, and 7.05 GJ respectively [4], the fresh water used for producing cassava, sugarcane and oil palm are respectively 78.65-87.50 m^3, 16.20-27.60 m^3, and 136.88-333.76 m^3. It can be seen that to produce 1 GJ oil palm uses much more water than the others while sugarcane uses the smallest amount. Therefore, if the country targets the higher energy production to serve demand in the future, the policy makers have to set the proportion of each biofuel crop cultivation considering also the volume of water along with other parameters.

Table 6. Water footprint of typical food crops.

Crops	Yield (ton/ha)	Blue WF (m^3/ton)	Green WF (m^3/ton)	Green + Blue WF (m^3/ton)	Green + Blue WF per hectare (m^3/ha)
Wet season rice	2.6[(a)]	874	1,799	2,673	6,950
Off-season rice	4.1[(a)]	1,268	64	1,332	5,460
Soybeans	1.6[(b)]	1,648	227	1,875	3,000
Maize	4.2[(b)]	778	86	874	3,670
Coffee	0.9[(b)]	4,876	9,280	14,156	12,740
Cassava	15.9-23.6	42-232	192-413	409-455	7,235-9,652
Sugarcane	59.1-72.8	81-128	67-148	162-276	11,630-16,312
Oil palm	5.5-16.0	421-1,829	474-1,071	965-2,353	12,942-17,484

[(a)] The number from OAE [16]
[(b)] The number from FAOSTAT [15]

Following the AEDP's long-term plan, Thailand should be able to produce 9 million liters ethanol /day and 5.97 million liters biodiesel/day, which requires cassava, sugarcane, oil palm output of 35 million tons/year, 105 million tons/year, and 3.05 million tons/year respectively [1]. To actualize these numbers in 2021, Thailand will require fresh water up to 34,268 million m^3 a year or more than 94 million m^3 a day. With this output of crops, more food products from cassava, sugarcane, and oil palm will also be obtained. Even though food products from biofuel crops will be increased, more land and fresh water used in their production will affect the output of other food crops. Besides, because food consumption patterns are changing with increasing affluence towards the increased consumption of meat, dairy and beverages, more land and fresh water for other food production will also be required [3]. What's more, not only will the economic development cause an increase in the demand for energy (including bioenergy) but it will also raise the demand for food, exacerbating the competition between water for biofuel feedstock production and food supply [3, 18-19]. So, in the future, good water management will be essential for sustaining the national food security, economic growth, and energy development all together.

3.5 Uncertainty

It is stressed that the data collected in this study are based on rough estimates of freshwater requirements in crop production from the previous studies. For assessment of WF of the crops, each previous study integrated information from several sources which adds a degree of uncertainty. For example, the CROPWAT model requires input of planting dates that are based on an assumption of data from the Department of Agriculture which are not the same as actual planting dates; farmers actually plant cassava and sugarcane in the rainy season which may differ from the reference in the calculation [8].

Moreover, some papers employed the different calculation methods depending on their own research objective. Also, the site of each study has different weather conditions and soil quality. These therefore make the comparison of the WF from various studies not perfectly aligned. Nevertheless, the comparative results show a remarkable similarity which brings more confidence. Also, since this study presents the water footprints in the form of ranges, the precise water footprints are less important, and the results of this study are still able to contribute useful information for the formulation of suitable guidelines for management of water resources in Thailand.

Another important shortcoming is that the WF estimations are based on water requirement of crops (CWR[c]) that normally refer to the evapotranspiration under optimal growth conditions as Equation 1. Thus, there can probably be overestimation in the case that actual water availability is lower than the crop water requirement. In other words, the calculated WFs are overestimated since there are water deficiency conditions in reality and crops are still able to be grown under those conditions [12,20].

3.6 Future research recommendation

The suggestion for further study is to improve the water footprinting approach by taking the water availability into consideration along with water consumption to have a better idea on the possibility of water stress occurrence. In the studies presented in this paper, only the volumetric water consumption is included without considering the availability of water in the study areas. So the impact of the water consumption cannot be ascertained. There have been techniques developed, for example, in life cycle assessment (LCA) that attempt to correlate the water consumption in a region with the availability which may give more information on water scarcity that could lead to social and environmental impacts. Under the LCA method, the water stress characterization factors is able to be added into the water footprint calculation, which will provide the comparable impact of water consumption for different region [19,21-22].

Apart from above mentioned issues, the economic evaluation of the water resources should also be considered. Monetary value of water can reflect the cost of non-market goods and services like water supply which will encourage the people to better understand and appreciate the impact of water consumption; for many cases people can relate to the economic value of something more easily that just its quantity. Even though there are not many papers yet on the economic valuation of irrigation water, some studies have been conducted to address this issue. All the mentioned studies employed the same technique which is the residual imputation method (RIM), the most commonly applied valuation technique. This valuation can represent the cost of irrigation water used (blue water) in biofuel crop cultivation from the production function of each crop [23-25]. For the grey water, methods for valuing water's waste assimilation services can be employed. Even though the authors have not seen the previous studies investigating the economic value of green water yet, the green water can be evaluated by using, for example, the stated preference methods – the methods allow the individuals to reveal their willingness to pay for the environmental goods [25-26]. Water resource economic valuation will reflect the cost of water used in each kind of biofuel crop cultivation and be another way to make the comparison between water consumption in agricultural activities.

4. Conclusions

Since biofuel feedstock production has to be increased to serve a higher demand of biofuels in the future, a large amount of water used for irrigation is needed. This study shows the range of water required for biofuel crop production covering three key feedstocks, which are cassava and sugarcane for ethanol, and oil palm for biodiesel, based on the WF concept. The results show that the water use per hectare for cassava, sugarcane, and oil palm lands is in the range of 7,235-9,652, 11,630-16,312, and 12,942-23,547 m^3, respectively. The ranges of freshwater consumption in Thailand for cassava, sugarcane, and oil palm production are between 409-455, 162-276, and 965-2,353 m^3 per ton of root, cane and fresh fruit bunches, respectively; to produce one ton of biomass yield, oil palm needs much more fresh water than the other two crops,

The comparison between components of WF reveals that even if almost all considered crops require irrigation water (blue water), the most water used in crop production is from rainwater (green water), especially for oil palm. This is because oil palm is planted in the locations that have sufficient rainfall and not much water is required from irrigation.

In the context of energy obtained, to produce 1 GJ, oil palm requires larger amount of water than the other two biofuel crops. Hence, it is important to define an appropriate cultivation area, proportion of each kind of crop cultivation, and technologies regarding the energy needed and the water availability.

Comparison of WF values for crops in Thailand with other countries revealed that there is scope for improvement in efficiency of water consumption in biofuel agriculture. Moreover, the results of the comparisons between the WF of biofuel crops and the other typical food crops show that the water used in a hectare of biofuel crop lands is greater than those used in a hectare of other food crops. Thus, expanding biofuel crop cultivation to the dedicated land can result in a higher amount of water required. Hence, since water is a scarce resource and there will be the requirement of more water for both biofuel feedstock and food production, appropriate water management is still significant for avoiding the conflict between 'water for food' and 'water for energy'. This study results can provide guidance for the policy makers and farmers in terms of water management planning which has the connection to sustainable bioenergy production in Thailand.

Nevertheless, for further study, since the volumetric water footprint approach only presents the volume of water used in the crop production, the regional water availability, which is more meaningful in terms of displaying the impacts of the water consumption on regional scarcity, should be considered. Also, it will be more interesting if the economic value of the water used for biofuel crop cultivation is evaluated. This could facilitate the comparison of information and then be easier to raise awareness of people about the volume of water used for planting the cash crops in terms of the scarcity of water resources and money.

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