

## Water Assessment of Agrofuels Feedstock Cultivation: Methodology Approaches

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### Abstract

The promotion of agrofuels for transportation may exacerbate the water demand especially due to increased agriculture. Water Footprint (WF) and Life Cycle Assessment (LCA) are the two well-developed approaches for evaluating quantities and potential impacts of water used for the entire product system and its supply chain. WF defines water based on source and pollution as green, blue and gray water while LCA accounts for water based on types of water use. Considering a result interpretation for water inventory, WF gives a more meaningful result than LCA in terms of water resource management. Likewise, LCA is more appropriate than WF for assessing impact via cause and effect relationship. As more water is usually required for growing the feedstock during cultivation rather than for processing agrofuels, WF and LCA can be applied together for water assessment of agrofuels feedstock cultivation. WF is applied at the inventory level to reflect the competition for water due to agriculture for food, feed, fibre and fuel. Then LCA is conducted using impact assessment for quantitative evaluation of water use with respect to water scarcity. Spatial data, meteorological data, agricultural practices and land use are required. The alternative results for expansion of the feedstock cultivation areas can be obtained through a scenario analysis. In conclusion, it is seen that both these methods are useful for assessing water and may likely be developed further for sustainability assessment of agrofuels.

*Key words:* Agrofuels feedstock/ Cultivation/Water footprint/ Life cycle assessment

## 1. Introduction

### 1.1 Energy crisis and Thailand's energy plan

Increasing energy demands and environmental crisis have resulted in changing energy consumption patterns at both national and global levels. One of the highly-focused changes is a shift from conventional fossil to alternative energy and its trend has rapidly increased so as to achieve energy security and help to alleviate the current energy crisis as well as to mitigate global warming. Alternative energy from agricultural feedstock such as oil palm, sugarcane, cassava, etc. is now widely promoted in many countries whether or not they have a potential for agriculture themselves.

The use of alternative energy in Thailand has been promoted and supported by the Ministry of Energy through the Alternative Energy Development Plan (AEDP) for 10 years (2012-2021). The target plan of biofuels for transportation is 5.97 and 9 million liter per day of biodiesel and ethanol, respectively by 2021. To push forward this plan, agrofuels feedstock has to be expanded by means of cultivation and production (EPPO, 2010; DEDE, 2012; Sarochawikasit, 2009). For Thailand, the cultivated area is managed by the Ministry of Agriculture and Cooperatives (MOAC) and their policy is planned to manage the area of agriculture for food and fuels according to the target plan of increasing the cultivated area at 11,200 million m<sup>2</sup> for sugarcane and cassava and

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8,800 million m<sup>2</sup> for oil palm (Sarochwikasit, 2009; MOAC, 2011).

### 1.2 Water scarcity

As this time, not only energy and greenhouse gas emissions but also water use is becoming a critical issue of serious concern in the world as a result of global climate change and increasing demand for human activities.

Many countries including Thailand, especially in the northeastern part, have faced a crisis of water stress and water scarcity because of depletion of water resources, quality of water and impacts of flood and drought due to extreme climate (IHP, 2011; BMPC, 2010). Water use by humans, a critical factor causing the water crisis, is classified by consumption and utility, agriculture, industrial, household, recreation and environmental activities (Liu et al., 2011). The main sector of global water contributing to water consumption as reported by UNESCO is agriculture (IHP, 2011). Even in Thailand, the main use of water is for the agricultural sector contributing around 95% as 41% of the total area is under farm holding land<sup>1</sup> (Bhatrasataponkul, 2007; OAE, 2010). Therefore, agricultural water management is certainly important for sustaining a proper balance between water demand and water supply. As available water is supplied for one use, it may or may not be enough for another use. Then, this issue will become a problem of competition for water use in the future.

As mentioned above, the trend towards agrofuels use will contribute to increasing agrofuels feedstocks which in turn will bring with it a need for more crop yields or cultivated areas and more water for cultivation. Then, this shift will put additional demands on water

resources for both cultivation and production and will be a cause of competition or water shortage with claims on water of agriculture for food, raw materials, and energy. These claims will become a big problem particularly in areas where water management is inefficient and unsustainable. So, several methods for water assessment have been developed. Consequently various indicators associated to water resources, ecosystem, human requirements, socio-economic, and policy are introduced such as Falkenmark indicator, Water Scarcity Index, Social Water Stress Index, Watershed Sustainability Index, etc (Brown et al., 2011; Berger and Finkbeiner, 2010).

Life cycle assessment and water footprint are also put in as environmental tools for water assessment in term of scarcity or water use impacts (Pfister et al., 2009; Hoekstra, 2003). These tools have developed as an approachable standard in addition to energy use, carbon footprint, and so on in order to support policy makers on sustainable water management.

## 2. Agrofuels feedstock and water uses

The volume of water used for agrofuels feedstock cultivation and agrofuels production differs by location and production technology. More water is required for growing the agrofuels feedstock than for processing agrofuels (Sexton and Zilberman, 2008; Fingerman et al., 2010; Gheewala et al., 2011; Powers et al., 2010). Regarding expansion of agrofuels feedstock cultivation areas, accessible water resources, irrigation system, seasonal variation and geographical conditions coupled with traditional practice and technology on crop cultivation affect the volume of water demand for cultivation. Besides, water leached from cultivated areas may be contaminated with agrochemical

<sup>1</sup> Farm holding land includes housing area, paddy area, under field crop, under vegetable and flowers, grass land, idle land, other (OAE, 2010).

compounds (Gheewala et al., 2011; Powers et al., 2010).

Water demand and impacts vary at the national and local level based on the policies on alternative energy development in each country and bioenergy technologies, scale of the plan and even geography (De Fraiture and Berndes, 2009). Therefore, the connection between agrofuels and water system will induce a need for considerably more water that will increase the conflict between water for food and water for energy. This connection is not only due to volume and sources of water use and discharge but also depends on land use due to feedstock cultivation and water flow direction which affect the water volume and its quality, and ecosystem thresholds limitation. Hence, these issues are recommended for consideration as pointed by Gheewala et al. (2011).

### **3. Water assessment of agrofuels**

As a result of these issues, there have been many studies on water assessment in terms of water inventory or water security (Brown et al., 2011; Berger and Finkbeiner, 2010; Pfister et al., 2009; Hoekstra, 2003). The proposed methods have been developed based on volume of water with respect to water withdrawals from water resources in terms of scarcity or stress because “scarcity” or “stress” is a well-known criterion for assessing and characterizing water resource security in terms of vulnerability and availability. Several indicators on water assessment related to water scarcity or water stress have been proposed linked to significant variables for instance water requirements for human activities and water resources sustainability, water resources system, socio-economic and policy at different levels of concerned area. Not only the proposed methods but also environmental tools have been developed and adjusted

with respect to water issues. Life cycle assessment and water footprint are the most prominent environmental tools well-developed relevant to assessing quantity of water use and its potential impact.

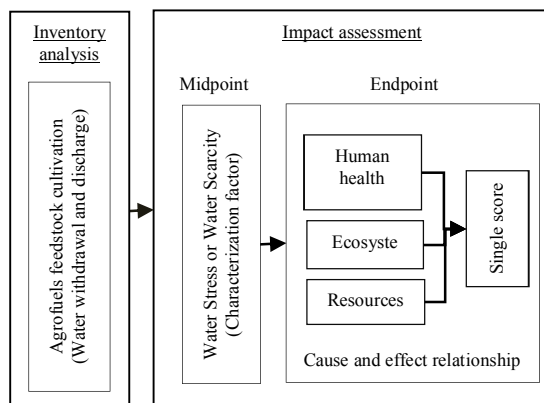
#### **3.1 Water assessment in life cycle assessment**

Life cycle assessment (LCA) is a tool for assessing the environmental impacts of a product throughout its lifespan. Actually, water aspect was not highly focused initially in the methodology of LCA. However, with the increase of water stress in many parts of the world, water assessment by life cycle approach is being developed by the UNEP/SETAC Life Cycle Initiative based on the LCA framework defined by the ISO standards 14040-44.

Based on LCA methodology, goal and scope also play an important role that will define system boundary and results or outcomes as well as data inventories. Then, inputs and outputs of each process in the system boundary are collected and analyzed. Impact assessment is conducted to evaluate and understand the magnitude and significance of potential impacts as in general measured by the level of cause and effect relationship in terms of problem-oriented (midpoint) or damage-oriented (endpoint) effect. Level and importance of the potential impacts are evaluated by classifying inventory data into environmental impact categories to which they contribute and characterizing the data into a reference pollutant for each environmental impact category (Berger and Finkbeiner, 2010; Gheewala et al., 2011; Jeswani and Azapagic, 2011).

Generally, characterization factors for calculating the potential impacts with regard to cause and effect relationship of water use quantity are not taken into account in most of the currently available LCIA methods. Therefore the framework

on water inventory and impact assessment including different areas of protection for assessing off-stream freshwater use are being developed (Figure 1) (Bayart et al., 2010). Regarding water in LCA based on the terminology developed by the UNEP/SETAC Life Cycle Initiative, “freshwater use” is referred to total freshwater put in the system boundary. This water use can be divided into in-stream (dams, reservoirs, water transportation, hydroelectricity production) and off-stream (any use of freshwater removed from the water body or groundwater), and/or it can be separated into degradative use (use of freshwater removed from the watershed and discharged with a change of water quality after use into the same watershed) and consumptive use (use of freshwater removed from the watershed including evaporation and water incorporated in a product, discharged water into a different watershed or sea) (Berger and Finkbeiner, 2010; Quantis, 2010).



**Figure 1** LCIA framework of water assessment (Quantis, 2010)

Therefore, types of water use are firstly specified in accordance with the goal and scope; then water use is inventoried as volume of water used for producing a product and its supply chain in the system boundary accounted as input (water use) and output (water effluent) of all related stages together with resource types of water use. In case of including water quality, distance-to-target and

functionality approaches are suggested. Moreover, variables such as land use, topography, community location, etc are highly recommended to be taken into account due their effect on water use (Quantis, 2010; Bayart et al., 2010). Assessment of problem-oriented (midpoint) effect is generally derived from water scarcity or water stress that is significant on local scale as a result of consumptive use and degradative use. Moreover, the potential impact obtained from midpoint level can be further evaluated in terms of damage-oriented (endpoint) effect using impact assessment methods such as Eco-factors based on Swiss Ecological Scarcity by Frischknecht et al. (2008), Freshwater ecosystem impacts and freshwater depletion by Mila i Canals et al. (2009), and, Water Stress Index and Eco-Indicator 99 by Pfister et al. (2009) (Jeswani and Azapagic, 2011; Pfister, 2010).

### 3.2 Water assessment in water footprint

Water Footprint introduced by Hoekstra (2003) is a terminology for assessing the volume of freshwater use for producing a product and its supply chain in terms of water use.

Direct and indirect water uses related to a producer, are taken into account defined by three types of water namely; freshwater removed from available water sources such as rivers, lakes and groundwater including evaporation and water incorporated in a product, discharged water into the different watersheds or sea are defined as the blue water. Rainwater excluding run-off and evapotranspiration is referred to as green water. Finally, the volume of water needed for treating the load of water pollutants by dilution to acceptable limits is represented as gray water (WWF-UK and SABMiller, 2009).

This method also provides the guideline of water assessment divided

into the 4 following steps; setting goal and scope is an important step that basically contributes to system boundary or study scale, data collection and analysis results in the further steps. Purpose or target is a key to specify product, process, consumer, producer, or area of interest in the first step. In the second step (water footprint accounting), data are accounted based on the goal and scope along levels of consideration based on spatial and temporal scale. In the third step (water footprint response formulation), data are analyzed according to point of view indicated in the first step in order to obtain results on action plan, strategies, or policies. Then hotspots in terms of environmental, social, and economic aspects are identified and the final results are formulated in the fourth step (water footprint sustainability assessment) (WWF-UK and SABMiller, 2009; Hoekstra et al., 2011).

In case of agriculture, green, blue, and gray water are taken into account at watershed or river basin level. To obtain volume of green and blue water, crop water use and crop yield are required. For gray water, amount of agrochemical compounds, leaching, acceptable concentration, and crop yield are needed. Regarding the crop water use or crop water requirement, this term refers to crop evapotranspiration during crop growth that can be obtained by experimental measurement or calculation.

For the calculation, significant parameters such as spatial data, meteorological data, crop parameters, cropped areas, soil maps, irrigation maps, agrochemicals use, water quality, etc. are required (FAO-LWDD, 2012; Tungsombun, 2006). For the sustainability assessment, environmental, social, and economic perspectives are accounted for identifying water impacts (Hoekstra et al., 2011).

## 4. Discussion

### 4.1 Methodology approach

Water Footprint and Life Cycle Assessment (LCA) are currently the most well-developed approaches for evaluating quantities and potential impacts of water used for the entire product system and its supply chain.

The first step of these two methods are similar as goal of study plays an important role in defining scope and scale of assessment as well as data analysis in order to achieve the targets. Moreover, data collection at the second step of the two methods is a volumetric measure even though water footprint measures volume of water as green, blue and gray water, while LCA accounts for water as volume of water use and discharge. Accordingly, types of water defined in water footprint can be used as indicators in LCA (Hoekstra et al., 2011). For data collection, not only water quantity and quality but also relevant variables are taken into account based on the scope of study. The significant variables affecting the relationship between water demand and water supply have to be considered and incorporated for accurately measuring all related water quantities (Pfister et al., 2009). It should be noted that three types of water are related as green water can substitute blue water as well as contribute to gray water after use. In the third step of these two methods, both of them aim for assessing environmental impacts with respect to water scarcity or water stress although these two methods are different in terms of the assessment method. Water footprint is mainly concerned about contribution of water quantity whereas LCA considers both contribution and aggregation of environmental impacts. By means of LCA, assessing at the midpoint level for obtaining the result contribution or the endpoint level for acquiring the

result aggregation through a single index depends on the goal and scope.

Consequently the meaningful results obtained in the fourth step of each method will be useful in the future according to purpose and application that will define criteria, principles, system boundaries and relative variables. Some studies take only water footprint (Gerbens-Leenes et al., 2009a-2009b; Ridoutt et al., 2009; Pongpinyopap and Mungcharoen, 2011) or LCA (Emmenegger et al., 2011) approach while others combine both with different spatial scale (Berger and Finkbeiner, 2010; Pfister et al., 2009). For combination of these two methods, water footprint is applied at the data collection or data inventory level and LCA is conducted at the impact assessment level (Pfister et al., 2009; Jeswani and Azapagic, 2011; Quantis, 2010; Jefferies et al., 2009).

#### ***4.2 Application of water assessment for agrofuels feedstock cultivation***

Several studies have been conducted for assessing water use in agrofuels feedstock cultivation. Some studies apply both water footprint and LCA such as the study on assessing water use impacts of bioethanol from corn cultivated in 12 countries (Jeswani and Azapagic, 2011). Only the blue water use in the cultivation phase is taken into consideration due to opportunity cost. For assessing the water use impacts, LCA is applied by using three different impact assessment methods; freshwater ecosystem impact coupled with land use effect, water stress index and Eco-Indicator 99 method which is a damage-oriented method for impact assessment, and ecoscarcity method. The results reveal that significant factors affecting variation of corn water requirement are weather conditions, seasonal variations and amount of rainfall. Regarding the

impact assessment methods, the impacts of water use are different due to different levels of water scarcity and characterization factors. Additionally, the study considers only blue water while water from rainfall or green water is not taken into account in term of water use impacts. The green water is mainly used for crop cultivation in some countries due to high availability of rainfall. So requirement of blue water is lower than other countries which mainly use irrigation. Moreover, the results assessed at river basin level cannot connect the water use impacts to the upstream and downstream as well as at national level as the result of a large variation. Therefore, it is recommended that the actual data of specified site at watershed level be used when assessing the water use impact.

Furthermore, some studies conduct only water footprint such as the study on water footprint of bioenergy (Gerbens-Leenes et al., 2009a-2009b). 12 crops used for energy in terms of bioelectricity, bioethanol, and biodiesel from various countries are investigated. The water footprint of crops accounted only in cultivation phase can be determined by dividing the total water (green and blue) with crop yields. For assessing water footprint of bioenergy, considering some parts of the crops used for bioenergy production is more efficient than considering all parts. Comparing the results show that the water footprint of bioethanol and biodiesel are higher than that of bioelectricity because some parts of the crop were used for biofuel production while all parts of the crop were used for bioelectricity generation.

An example of the LCA method in water use is the study considering water use for irrigated rapeseed cultivation in a water-scarce area, non-irrigated rapeseed cultivation in a water-rich area, and methyl ester-based rapeseed production in Argentina which uses Eco-Indicator 99 by

Pfister et al. (2009) (Ridoutt et al., 2009). The results show that water use of non-irrigated rapeseed is lower than of irrigated rapeseed. In addition, seed and climate are influential to the volume of water use and ecosystem quality is the main impact.

In Thailand, water assessment mainly focuses on agricultural products and industries like corn, rice, maize, field crop, microalgae, cassava, oil palm, rubber, and sugarcane. Most of the studies mainly apply water footprint method for assessing water use of products. Water assessment in terms of assessing water use and water use impact is still in the preliminary stage in Thailand with most studies still under progress. One of the completed studies is on the water footprint of ethanol-based cassava (Pongpinyopap and Mungcharoen, 2011). Green, blue, and gray water are taken into account for characterizing water use. In addition, scenario analysis is used for forecasting volume of water use and cultivated area. The results show that the volume of green water use is higher than the blue water use due to efficient use of rainfall. Besides, increasing yield will reduce cultivated area. Another study was on the monthly water footprint of major maize cultivation areas of Thailand (Sukumalchart et al., 2011). 40 provinces of major cultivation areas of maize are selected as study sites and climate data, crop parameters, crop yield, and soil type are used for calculating monthly blue and green water of maize based on water footprint equations. The results show that maize cultivation mainly relies on rainfall or green water rather than irrigation. Significant factors; yield, crop coefficient, cultivation period and area, evapotranspiration, and soil water balance are influential to the total water footprint of maize (Sukumalchart et al., 2011).

Consequently, water footprint and LCA can be applied together for water

assessment of agrofuels feedstock cultivation even though these two methods are different by means of water use definition and impact assessment. Water footprint is applied for reflecting the competition for water due to agriculture for food, feed, fibre and fuel or indicating what types of water use, green or blue water that each area or country depends on. Then LCA is conducted for quantitative evaluation of water use with respect to water scarcity. Ridoutt and colleagues recommend combining water footprint with LCA method using a regional water stress index as a characterization factor proposed by Pfister and colleagues (Brown et al., 2011). For both methods, significant variables such as geography, agricultural practices, meteorology, economics, and demographics are influential to the relationship between water demand and supply as also the variation of collected data (Gheewala et al., 2011); it is therefore recommended to assess water at a local level or natural unit of geographic perspective such as watershed rather than at a larger scale. The alternative results for expansion of the feedstock cultivation can be obtained through a scenario analysis.

## **5. Conclusion**

Water footprint and LCA provide their own informative results according to the methodology itself. Therefore, the selection of a proper method with relevant variables and system boundary or scale of analysis depends on the goal or the final result application. In view of a result interpretation for water inventory, water footprint gives a more meaningful result than LCA in terms of water resource management. Likewise, LCA is more appropriate than water footprint in the sense of impact pathway via cause and effect relationship. Consequently, to

provide significant results of water aspects when making a decision for agrofuels feedstock cultivation, it is seen that both these methods are useful for assessing water in terms of water resource management and environmental impacts assessment and may likely be developed further for sustainability assessment of agrofuels.

## 6. Acknowledgement

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