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Cost – Benefit of water resource use in biofuel feedstock production

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ABSTRACT

An increase in the output of crops such as cassava, sugarcane, and oil palm, is necessary for biofuels development. To increase the crop yield, a large amount of water is required which can have an impact on the net social welfare. This study aims to assess the benefit and cost of water resource use in biofuel crops production to support the cost-benefit analysis of biofuels development. Benefit of water is presented through the value of its marginal product estimated by using economic valuation methods. The loss due to water consumption is assessed and monetized based on life cycle impact assessment. To show how the approach is applied to the regional level, Thailand is considered as a case study. The results show that the economic gains from using a cubic meter of water in cassava, sugarcane, and oil palm production are 1.6–6.9, 1.0–5.0, and 0.8–2.9 Thai baht, respectively. However, using this amount of water can also bring about the external cost around 0.2 Thai baht, leading to the net benefits of using a cubic meter of water in cassava, sugarcane, and oil palm production between 1.5 and 6.7, 0.9–4.8, and 0.6–2.6 Thai baht, respectively. Gain and loss of the water used in cassava, sugarcane, and oil palm cultivation are expressed in monetary units for the first time by this study. Besides, this paper could be a guideline for future research towards an integration of life cycle impact assessment and the economic analysis tool, cost-benefit analysis.

1. Introduction

Water resource is an invaluable ecosystem service provided by nature. All organisms including humans cannot live without water. Because up to 65 percent of human's body is water, we cannot live so long as a week without water (Kimberly and Henken, 2009). Not only is water necessary for humans' direct consumption, but it is also the significant resource in agricultural industries. About 70% of the world's total water withdrawal is contributed by agriculture (FAO, 2015). The recent increase in the use of biofuels has also resulted in an increase in water demand.

Food crops such as cassava, sugarcane, and oil palm, are commonly used as feedstock for biofuels production in Thailand. Cassava and sugarcane are used as the feedstock in producing ethanol and oil palm for biodiesel. To produce 1000 L of ethanol, around 7 tons of cassava roots or 77 tons sugarcane is used; and approximately 4 tons of oil palm fresh fruit bunches (FFB) are required to obtain 1000 L of biodiesel (Silalertruksa and Gheewala, 2012; Thai Ethanol Manufacturing Association, 2013). In order to strengthen the energy security of the nation, several countries including Thailand have a projection to increase their biofuel consumption as well as production (Gheewala et al., 2013). Accordingly, there is the need of an increase in production of these biofuel crops, which will in turn require a larger amount of water for their cultivation as well.

Although water is a renewable resource, an appropriate management of water supply is still needed. The amount of water available annually is uncertain and as the demand for water is going to be increased due to the higher production of crops, the available water may not be sufficient to meet the demand. Moreover, as aforementioned, water is important to organisms and activities, an increase in water utilization in one activity (in this case, biofuel crops cultivation) thus affects the others. So, to maximize net social benefit, a concern about the cost as well as the benefit of water is necessary.

In order to support the decision-making on water management and to fulfil cost-benefit analysis (CBA) of biofuels development, this study focuses on assessing the cost and the benefit of the water used in biofuel crops cultivation. The pathways to estimate the cost and benefit are a hybrid of economic methods and life cycle impact

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assessment (LCIA). On the one hand, the benefit from utilizing water for crop production is measured through the value of the marginal product of water. On the other hand, the opportunity cost of using water is assessed and monetized based on the methods in LCIA. To facilitate future regional applications, this study uses Thailand as a case study. Since biofuels are being promoted in many countries including Thailand and drought is an issue in some regions having the potential to grow the feedstocks, the studies relating to biofuels development and water management are meaningful for all these countries (Gheewala et al., 2013).

The content of this paper is divided into six sections. Significance of the research is expressed in this first section. The amount of water required for biofuel crops production is estimated in Section 2. The methods to assess external cost as well as benefit of water use in biofuel crops production are explained in Section 3. In Section 4, the results from Section 3 are discussed. Recommendations for future research are indicated in Section 5, followed by Section 6 where the conclusion of this study is drawn.

2. Freshwater use by biofuel crops

There are several previous studies that have already assessed the volume of freshwater (rain and irrigation water) required for biofuel crops production in Thailand, covering cassava, sugarcane, and oil palm (Gerbens-Leenes et al., 2008; RID, 2010; Babel et al., 2011; Kongboon and Sampattagul, 2012; Jarernsook et al., 2012; Seewiseng et al., 2012), which are useful for this study. Kaenchan and Gheewala (2013) have summarized those volumes of water as shown in Table 1.

In Table 1, the freshwater use of biofuel crops are presented both in the range per ton of crop yield and per hectare of planted area. Gain and loss from using this freshwater will be assessed in the next section. It has to be noted that to facilitate valuation, rain water in this study will be considered the same as irrigation water due to the fact that both rain and irrigation water are perfectly substitutable between each other.

3. Methods

The approach to assess the gain and loss according to water consumption in biofuel crops production is a combination of economic valuation and LCIA methods. Benefit from water use can be evaluated through the marginal product of water; whereas, the loss from water use is indicated and monetized by relying on the LCIA methods.

3.1. Benefit from water use

Benefit from employing an input in production can be estimated through the value of the marginal product of that input, the value of the change in output that results from an added unit of input. In the case of biofuel crop production, the gain from using water thus can be expressed through the value of the additional crop yield accruing from the added unit of water.

To evaluate the value of the marginal product of water, the major applicable economic valuation methods are production function approach, residual imputation method (RIM), and value-added method (Agudelo, 2001). The most widely used method for evaluating the water used for agricultural purpose is RIM, for example in the research by Gregor et al. (2000), Mesa-Jurado et al. (2008), Helegers and Davidson (2010), and Al-Karablieh et al. (2012). However, this study considers all three approaches in order to show the sensitivity of the results to the method selection. Values of the marginal product of the water that is used for producing biofuel crops are computed method by method based on as follows.

3.1.1. Production function approach

In general, for the case of agricultural products, the production function can be written as Equation (1) where Y stands for output (in this case, biofuel crops), X denotes inputs aside from water, and W is water used in production (Agudelo, 2001).

$$Y = f(X_1, X_2, \ldots, W) \quad (1)$$

The value of the marginal product (VMP) of each input is defined as the price of product (P_y) multiplied by the marginal product (MP) of input (see Equation (2) for the case of the value of the marginal product of water, VMP_w). Since the marginal product of water (MP_w) is the additional output that results from a unit increase of water, Equation (2) then can be rewritten as Equation (3).

$$VMP_w = P_y \times MP_w \quad (2)$$

$$VMP_W = P_y \times \frac{\partial Y}{\partial W} \quad (3)$$

So, if the production functions of biofuel crops are known, the value of marginal product of the water used in each biofuel crop production can be estimated. Nonetheless, since the production functions (especially for the Cobb–Douglas production function) of cassava, sugarcane, and oil palm are not found in the literature, this study then uses the yield response to evapotranspiration (ET), as Equation (4), available in the FAO (Food and Agricultural Organization of the United Nations) Irrigation and Drainage Paper No. 66 (Steduto et al., 2012) instead. The yield response to evapotranspiration is the equation representing the relationship between crop yield (output) and water use (input) (Steduto et al., 2012). As production function expresses the relationship between inputs and output, the yield response to evapotranspiration is related to it where water is accounted as an input. Thus, in the absence of production function, the yield response to evapotranspiration is considered appropriate to estimate the marginal product of water. Regarding Equation (4), Y_x and Y_a are the maximum and actual yields (ton/ha), ET_x and ET_a are the maximum and actual evapotranspiration (mm), and K_y is the yield response factor representing the effect of a reduction in evapotranspiration on yield losses. Rearranging the terms in Equation (4) yields Equation (5), which is the applied production function.

$$\left(1 - \frac{Y_a}{Y_x}\right) = K_y\left(1 - \frac{ET_a}{ET_x}\right) \quad (4)$$

Table 1
Freshwater use for biofuel crop production in Thailand per year.

Biofuel crops	Yield (ton/ha)	Freshwater use (m^3/ton)	Freshwater use per hectare (m^3/ha)
Cassava (fresh roots)	15.9–23.6	409–455	7235–9652
Sugarcane (fresh cane)	59.1–72.8	162–276	11,630–16,312
Oil palm (fresh fruits)	5.5–16.0	965–2353	12,942–23,547

Source: Kaenchan and Gheewala (2013).