



Do biofuels require more water than do fossil fuels? Life cycle-based assessment of jatropha oil production in rural Mozambique



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ABSTRACT

Biofuels are advanced to replace fossil fuels in order to reduce emissions of greenhouse gases and other environmental impacts. Yet freshwater scarcity is another growing concern and increased production of biofuels may increase this problem. In order to assess whether biofuels truly have a higher water use than do fossil fuels, a life cycle assessment study of a low input jatropha plantation in northern Mozambique was conducted. In addition to different water use indicators, the fossil energy use and global warming potential were assessed for 1 MJ of jatropha oil. The analysis compares results for jatropha oil with fossil diesel, generally showing lower global warming potential and fossil energy use for jatropha oil. However, aspects related to land use may alter the global warming potential of jatropha oil. Regarding water use, the choice of the water use indicator strongly influences the results. Specifically the indication of (1) so-called green water flows, (2) formation of so-called blue water and (3) water scarcity show crucial influences on the comparison. Depending on these specific features, jatropha oil may have higher or lower water use than fossil diesel. A number of uncertainties, such as the jatropha oil yield, are also shown to have a considerable impact on the results.

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1. Introduction

1.1. General background

The development of energy systems that are less dependent on fossil fuels is an important ongoing transformation. Biofuels constitute parts of this transformation and the last decade has seen a rapid expansion in biofuel production and a parallel increase in awareness of related environmental impacts, including issues such as greenhouse gas (GHG) emissions, pesticide use, land use, and biodiversity. In addition, the water use of biofuels is a recent focus (Berndes, 2010). The method of life cycle assessment (LCA) has been developed to assess environmental impacts of products and services by cumulative allocation of all direct and indirect environmental impacts along the so-called product life cycle. This method has been extensively used to assess the environmental performance of biofuels, including vegetable oil fuels (Arvidsson et al., 2011a), ethanol from different sources (Farrell et al., 2006; Leng et al., 2008; von Blottnitz and Curran, 2007), different types of biodiesels (Arvidsson et al., 2011b; de Souza et al., 2010; Pleanjai et al., 2009) and many others (Edwards et al., 2007).

In this context, *Jatropha curcas* L. (henceforth referred to as jatropha only) has been promoted as a high yield, multi-purpose biofuel feedstock plant that can survive on marginal land with little input of water and nutrients (Achten et al., 2008; Francis et al., 2005). Despite the expansion of jatropha cultivation, the knowledge of its production is in its infancy (Trabucco et al., 2010). Only a few LCA studies based on site-specific data have been published, focusing on energy use and global warming (Achten et al., 2010a; Gmunder et al., 2010; Ndong et al., 2009; Prueksakorn and Gheewala, 2008; Wang et al., 2011). These studies generally conclude that jatropha performs rather well for these two environmental impacts. However, the view of jatropha as a crop with low environmental impacts has been questioned. Some studies suggest its land use, net energy balance, global warming potential (Lam et al., 2009) and water use (Gerbens-Leenes et al., 2009) to be unfavorable compared to other energy crops. To the best of our knowledge, Gerbens-Leenes et al. (2009) is the only existing study investigating the life cycle water use of jatropha-based fuel.

1.2. Scope of the study

With this study, we want to contribute to the understanding of the environmental life cycle performance of jatropha, in particular regarding water use. The product studied is jatropha oil produced

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in the Northern Province of Niassa, Mozambique. The region suffers from poor infrastructure, rendering supply of fossil fuel unreliable. In order to become less dependent on the unreliable delivery of fossil diesel, the local company Chikweti Forest of Niassa (henceforth referred to as Chikweti only) established a jatropha plantation close to the Luambala River to provide their cars, and ultimately also their forestry machines, with fuel. At the time of this study, 208 ha of jatropha had been planted and the production of jatropha oil was in an upstart phase. The aim of this study is to evaluate the life cycle environmental impacts of producing jatropha oil under these circumstances and to compare the impacts to those of fossil diesel. Considering the worry that increasing use of biofuels may lead to water scarcity (Berndes, 2010), this study includes the water use impact category in addition to the more commonly included impact categories of fossil energy use and global warming potential. The comparison to fossil diesel also enables us to give a partial answer to the more over-arching question of whether biofuels require more water than fossil fuels, as indicated by the results of Gerbens-Leenes et al. (2008). Of specific interest is that the production system in this study receives neither synthetic fertilizers nor irrigation, whereas in the studies claiming that jatropha does not perform well compared to other energy crops, the production systems received high inputs of synthetic fertilizers and irrigation (Gerbens-Leenes et al., 2009; Lam et al., 2009). It is thus possible that this 'low input' production system has a lower environmental impact.

1.3. Water use in LCA

Developing water use indicators for LCA has proved to be a considerable challenge (Bayart et al., 2010; Milà i Canals et al., 2009; Owens, 2001) and a number of water use indicators have been advanced in the literature. The water use indicator perhaps most widely used in LCA studies today is the water footprint (Hoekstra et al., 2011), with users such as the Coca Cola Company and the World Wide Fund for Nature (Water Footprint Network, 2012). The water footprint is a sum of at least two other water use indicators, namely the green water footprint and the blue water footprint. Green water is the soil moisture that is available for plants due to rain, whereas blue water is the water that can be withdrawn from water sources such as lakes, streams and aquifers. In addition to these, a third indicator, called the grey water footprint, can be included in the water footprint. Grey water is the water that would be required in order to dilute emissions along the life cycle to legal threshold concentrations.

Although easy to communicate, the water footprint has been criticized for not including several crucial aspects related to water scarcity. The blue water footprint says nothing about the size or recharge rate of the water source and thus says little about the scarcity of blue water resources. The nature of the green water footprint results in very large total water footprint for most agricultural crops (Gerbens-Leenes et al., 2009), and thereby gives a high water use for biofuels compared to fossil fuels. But the green water footprint may be a misleading indicator of water scarcity as rain cannot be used faster than it falls and would have been used regardless of the crop (Peters et al., 2010). Thus, the local hydrological cycle may in reality be little affected by the use of green water in agriculture. As for the grey water footprint, it is a rather abstract concept as it does not include actual, physical use of water, but rather the theoretical use of water for dilution of pollutants. In addition, legal threshold concentrations may vary considerably between different geographical areas.

In response to this criticism, modifications of the water footprint have been proposed. In order to better account for water scarcity, a method for modifying the blue water footprint according to local

water stress was developed by Ridoutt and Pfister (2010). Essentially, all processes contributing to the blue water footprint are separately multiplied by the local water stress index. The water stress index varies between 0.01 and 1 depending on the ratio of local water withdrawal and availability. The result is a stress-weighted blue water footprint, a volumetric measure incorporating local water scarcity.

As mentioned above, rain falls regardless of the land use, and thus the green water footprint has been questioned as an indicator of water scarcity. But the evapotranspiration can be altered by land use, thereby altering the fraction of the rain that is turned into blue water, which may cause downstream impacts (Bayart et al., 2010; Milà i Canals et al., 2009). This interconnectedness between green and blue water has been acknowledged by others, to the extent that a recent publication referred to soil moisture as 'cyan water' (Sandin et al., 2013). The change in blue water formation may thus be a water use indicator that includes rainwater in a way that better captures water scarcity aspects.

In addition to the water footprint indicator and variants thereof, a number of other life cycle-based water use indicators have been suggested (Bayart et al., 2010; Milà i Canals et al., 2009; Owens, 2001; Peters et al., 2010). Although slightly different by definition, most of these indicators are in practice similar to the blue water footprint in the sense that they consider use of water from sources that can become depleted such as lakes, rivers and aquifers. For a more extensive review of water use indicators, see Hagman and Nerentorp (2011).

We recognize that many of these suggested water use indicators have their merits and provide interesting perspectives. Accordingly, our response to the multitude of water use indicators has been to apply a number of different indicators to see whether they point in the same direction. The indicators applied in this study are (1) the blue water footprint, (2) the green water footprint, (3) the stress-weighted blue water footprint and (4) blue water formation (calculated in two different ways). The calculation of these four water use indicators is further described below. For reasons discussed above, the grey water footprint is not calculated. As other suggested water use indicators in LCA tend to resemble the blue water footprint, or the sum of the blue and green water footprints, the value of including additional water use indicators would be limited.

2. Materials and method

In this study, the method of LCA is applied (Baumann and Tillman, 2004). It has been developed to account for environmental impacts of products and services by cumulative allocation of all direct and indirect environmental impacts along the so-called product life cycle, from raw material extraction, production and usage to waste treatment.

2.1. System boundaries and functional unit

This LCA study covers jatropha oil produced as illustrated in Fig. 1. An important difference to several earlier LCA studies of biofuels from jatropha is that we study the production of jatropha oil rather than jatropha biodiesel. The main reason for this is the local infrastructure in the Niassa province. Transesterification requires input of chemicals and energy, for which supply is unreliable. Production of jatropha biodiesel is thus not a realistic alternative in the near future at the location. There have, however, been concerns raised regarding the technical feasibility of using pure vegetable oil, such as jatropha oil, directly as fuel in diesel engines with direct injection. The problem is primarily related to the higher viscosity of pure vegetable oils as compared to diesel.

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