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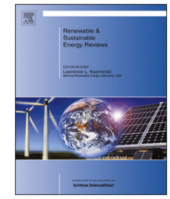

Carbon footprints of production and use of liquid biofuels in Tanzania

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Tanzania being a prospective producer and exporter of liquid biofuels, information on local contribution of this sector to the environmental burden of the country is highly required in order to ensure sustainable liquid biofuels. Therefore, this paper evaluates a life cycle carbon footprint (or greenhouse (GHG) gas emissions) of liquid biofuels (biodiesel produced from *jatropha* oil and bioethanol produced from sugarcane molasses as alternative to fossil fuels in Tanzania. The functional unit (FU) of the study is defined as 1 Giga Joule (GJ) of output energy when a biofuel is combusted in the engine. The study found a positive GHG emissions related to biofuels. A carbon footprint (in CO_2 equivalents) of *jatropha* biodiesel is 23.9 kg FU^{-1} while that of molasses bioethanol is 17.4 kg FU^{-1}. Biodiesel combustion found to be a major contributor to carbon footprint by 41% which is attributed to methanol used during transesterification of *jatropha* oil followed by the use of chemical fertilizers (31%). Sugarcane production phase on the other hand found to be the highest contributor to carbon footprint of molasses bioethanol accounting for more than 80%. This is due to the use of diesel fuel, chemical fertilizers and burning of sugarcane prior to harvesting. Sensitivity analysis indicates that higher market prices of molasses increases carbon footprint of bioethanol same as higher market price of biodiesel. For the same energy output of 1 GJ, molasses bioethanol observed to have lower carbon footprint than *jatropha* biodiesel by 27.2%. Both biofuels observed to save GHG emissions by $>70\%$ when used as fossil fuel replacement. The study recommends further research on socio-economic implication of large scale biofuel production; impact of land use change and land use competition and sustainability of biofuels to be carried out in near future.

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1. Introduction

Tanzania is one of the East African countries relying on imported fossil fuels for transportation, agricultural, industrial and domestic use. Currently, Tanzania imports a total of approximately 1.5 Gt yr^{-1} of petroleum products for local consumption with an increase rate of about 30% per year [1]. Such importation costs the country about 1.6 billion US $ per year accounting almost 25% of total foreign exchange earnings [2]. The prices of petroleum products at the global market and locally have been increasing at a rapid rate which threatens the country's economy. Due to fact that, petroleum is a limited source that means its price will continue rising, production and use of liquid biofuels such as biodiesel and bioethanol are highly promoted worldwide so as to supplement imported fossil fuels [3–5]. In addition, biofuel investments are expected to offer employment opportunities to local citizens while export of the same is expected to increase foreign exchange earnings, thus increase economy of producing country.

The Government of Tanzania is currently promoting production of biofuels from raw materials that may not interfere with food security of the country. Raw materials such *Jatropha curcas* L. (henceforth *jatropha*) a non-edible oil crop, sugarcane molasses, a waste from sugar production, croton megalocarpus and *Pongamia pinnata* have been observed as the best for biofuel production in Tanzania [6]. Thus, *jatropha* a non-edible oil crop has been observed as one of the potential raw materials for biodiesel production. This crop is believed to grow on degraded agricultural soils, infertile wastelands and even in arid conditions; thus its growth is believed to have minimum negative impact on food security as well as on the environment of growing country [7]. However, for large scale plantations where *jatropha* oil is being used as feedstock for biodiesel, it may require good fertile soil and enough rains which may be supplemented by irrigation for better crop yield, hence high yield of biodiesel [8]. Tanzania being one of the countries with very low sugar production, sugarcane juice is not recommended for bioethanol production. Therefore, sugarcane molasses which is a by-product in sugar factories that has been regarded as waste and sometimes used as animal feed has been considered as a potential raw material for bioethanol production.

Presently, Tanzania has opened her doors to foreign companies to engage in large scale biofuels investments. For instance, companies such as Bioshape Tanzania Ltd and Sun Biofuels Tanzania Ltd, aimed at large scale biodiesel production from *jatropha* oil and SEKAB BioEnergy Tanzania Ltd, a company aimed at large scale bioethanol production from sugarcane analogous to Brazil commenced farming of bioenergy crops since 2008 [6]. Other companies such as BioEnergy Resource Tanzania Ltd, Africa Green Oil, Mitsubishi Corporation and Kapunga Rice Project did show the interest to invest on liquid biofuels since year 2008 [9]. Though such companies have started growing raw materials for biofuels production, there are no local information on estimated greenhouse gas (GHGs) emissions for such investment which are very important to the government, policy makers and bioenergy stakeholders. In addition, considering the fact that biofuel should contribute to sustainable development of a producing country, it is very important to assess its local contribution to the environmental burden particularly GHG emissions, so that this sector may be included in national GHG emission inventory. Though, biofuels are being promoted worldwide with a notion that biomass based fuels are carbon neutral, thus can mitigate GHG emissions in comparison to fossil fuels, yet their production still requires use fossil fuels which are not carbon neutral; farming of bioenergy crops requires nitrogen fertilizers which are the major source soil N_2O emissions; burning of bioenergy crop residues also results into emissions of GHGs in large quantity [10]. Several studies [7,11,12] have been conducted to evaluate net GHG emissions of *jatropha* biodiesel while [13–15] have investigated the same for sugarcane molasses bioethanol. These studies found positive net GHG emissions of such biofuels but their results may not be replicated to Tanzania and other African countries due to such factors as geographical differences, different farming practices etc. Therefore, this study aims at evaluating carbon footprints (GHG emissions) of production and use of *jatropha* biodiesel and molasses bioethanol in Tanzania. The results of this study are meant to be used by policy makers, bioenergy stake holders, researcher in the East African region and may also be used as reference by other African countries with similar environmental conditions.

2. Methodology

In this study carbon footprints of biofuels were defined as GHG emissions from production and use of biofuels. Greenhouse gas emissions were evaluated in line with International Organization for Standardization (ISO) standards on life cycle assessment (LCA) [16]. The inventory analysis was carried out in a Chain Management by Life Cycle Assessment "CMLCA" software developed by Dr. R. Heijungs of Leiden University, the Netherlands.

2.1. Goal and scope definition

The goal of this study is to assess the GHG emissions of *jatropha* biodiesel and sugarcane molasses bioethanol for use as alternative to gasoline and diesel fuels respectively in Tanzania. The fuels are assumed to be used for running small engine generators that may be used domestically and commercially. Functional unit (FU) in this study has been defined 1 GJ of output energy (in lower heating value (LHV)) when a biofuel is combusted in the engine. The LHV of biodiesel and bioethanol are 37.3 MJ kg^{-1} [17] and 26.87 MJ kg^{-1} [1], respectively. Therefore, the reference flows required to deliver the FUs are 37.22 kg and 26.81 kg of bioethanol and biodiesel, respectively. The scope of the study is limited to GHG footprints emitted at country level which is of interest to policy makers, thus, GHG emissions from production of inputs which are not locally produced such as, fossil fuels, fertilizers, insecticides and industrial chemicals were not accounted. However, the study gives an indication of how production of such inputs may affect GHG emissions if it was considered.

2.2. System boundaries and data source

The system boundaries for this study are presented in Figs. 1 and 2 for *jatropha* biodiesel and molasses bioethanol, respectively. Major processes analysed in *jatropha* biodiesel system include (i) *jatropha* cultivation, (ii) transport of farm inputs and outputs, (iii) *jatropha* oil extraction, (iv) biodiesel conversion and (v) the end use of biodiesel in a diesel engine. Other processes modelled in *jatropha* biodiesel system include production of electricity from hydropower and natural gas, manufacturing of seed cake briquettes, steam generation and wastewater treatment in waste stabilization ponds. Main processes modelled in molasses bioethanol system are: (i) sugarcane farming, (ii) transport of farm inputs and outputs, (iii) sugarcane milling, (iv) molasses conversion to ethanol and (v) ethanol combustion in a gasoline engine. Other processes modelled in molasses ethanol system include power cogeneration by using fuel bagasse and treatment of industrial wastewater in waste stabilization ponds. In both biofuel systems, emissions from processes which do not directly influence the system such as storage of fossil fuels, farm inputs and industrial chemicals were also accounted.

2.2.1. *jatropha* biodiesel system

Data on farm production of *jatropha*, oil extraction and briquettes production from *jatropha* seed cake collected by Eshton [17] were