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Sugarcane ethanol production in Malawi: Measures to optimize the carbon footprint and to avoid indirect emissions

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ABSTRACT

Sugarcane ethanol is considered to be one of the most efficient first-generation biofuels in terms of greenhouse gas (GHG) emissions. The carbon footprint (CF), however, increases significantly when taking into account emissions induced by indirect land-use changes (ILUC). This case study investigates sugarcane ethanol production in the Republic of Malawi, in Sub-Sahara Africa (SSA); the research objectives were to identify and quantify direct and indirect emissions and to identify measures to optimize the CF. The CF has been calculated with a life cycle approach and with data obtained from the involved companies; our estimations with regard to ILUC take into account further expansion plans for sugarcane crop production. Under existing production conditions ethanol produced in Malawi leads to GHG emissions expressed as CO_{2eq} of 116 g MJ^{-1} of ethanol. However, high optimization potentials exist when the vinasse is used as an input for biogas production and the harvesting switches from pre-harvest burning to green harvesting. ILUC induced by prospective sugarcane expansions in the Southern Region will, according to current planning, probably not occur since these expansions are linked to the implementation of a large-scale irrigation project. However if ILUC takes place, high levels of additional CO_2 emissions of about 77 g MJ^{-1} of ethanol are to be expected. Although the case study results are only valid for a specific region, some of the findings, such as the high compensation potential regarding ILUC through investments in irrigation systems, may be transferable to other regions in SSA.

1. Introduction

The worldwide expansion of biofuel production is driven by several forces, including first and foremost diminishing natural resources, rising oil prices, energy security concerns, and rural development [1]. The aim to reduce greenhouse gas (GHG) emissions in the mobility sector has been another important driver. In the European Union (EU) this has led to a 10% renewable energies quota in the mobility sector to be achieved by 2020, according to the Renewable Energy Directive (RED) [2]. In developing countries such as Malawi, rising fuel prices and the promotion of a secure energy supply are doubtlessly more influential than the target to reduce the country's GHG emissions; however, the Clean Development

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Mechanism under the Kyoto Protocol, which allows industrialized countries to purchase reduction credits by financing mitigation projects in developing countries [3], encourages developing countries to contribute to GHG mitigation. In the long term, ethanol exports might, furthermore, gain economic importance in SSA countries, especially, however, in coastal states such as Mozambique and Tanzania. All companies involved in biofuel production will then have to fulfill existing international standards regarding GHG emissions. The RED, for example, requires that biofuels save 35% GHG emissions over the whole life cycle as compared to fossil fuels [2]; by 2018 this value will increase to 60% [2].

Sugarcane ethanol is considered to be one of the most efficient first-generation biofuels in terms of GHG emissions [4]; however, most studies addressing the carbon footprint (CF) of sugarcane ethanol so far relate only to South America, especially Brazil [5–7], which supplies the largest share in the worldwide production of sugarcane ethanol [8], or Asia [9,10]. Information on the CF of sugarcane ethanol produced in SSA countries is still lacking, although it is particularly these countries that have a comparative advantage in terms of the availability of labor and good climatic conditions [11]. Typical GHG emission reductions for sugarcane ethanol are around 70% compared to conventional gasoline [4,12]. The CF, however, worsens significantly if we take into account emissions induced by direct and indirect land-use changes (DLUC, ILUC) [13,14]. Biofuel production-related DLUC occurs when natural habitats, degraded land, or managed land uses such as pasture land are converted to biofuel crop production. ILUC occur when biofuel feedstock cultivation replaces other crops and, consequently, natural habitats are then converted to arable land in order to meet the demand for the displaced commodities [14,15].

To include ILUC-induced emissions in the CF is a highly complex matter given that ILUC are tied to global market dynamics. The theoretical assumption behind ILUC is that if a crop is displaced the prices for this crop will increase and farmers will react by creating new arable land [16]. However, because of increasing global market prices, ILUC can occur anywhere in the world and not only in the country where biofuels are being produced [15,16]. Three basic approaches to quantifying ILUC have been developed during recent years: economic models, i.e. partial or general equilibrium models that have been adjusted for the calculation of ILUC [14,17]; deterministic or descriptive-causal models that attempt to estimate ILUC based on a set of simplified assumptions [18,19]; and regional models that aim to take into account regional influences on ILUC [20]. Knowledge of regional factors or characteristics influencing ILUC is still lacking though, since until now only a few studies have used case studies to observe indirect effects.

This case study provides the CF for sugarcane ethanol produced in the Southern Region of Malawi. The paper additionally contributes to the knowledge about regionally observable indirect effects related to biofuels production. The main research objectives, therefore, were to identify and quantify direct and indirect GHG effects, to identify optimization potentials regarding GHG emissions, and to identify measures by which to avoid or at least minimize ILUC on a regional level. Although the findings of the Malawian case study are obviously valid only for a specific region, some of the findings may be transferable to other regions in the SSA. Future economic modeling might also benefit from defining more adequate assumptions for specific regions with the help of the present investigation.

2. Material and methods

2.1. *Ethanol production sites in Malawi*

In Malawi, sugarcane ethanol is produced at two locations. In Dwangwa, in the Central Region (12°29′57.84″S; 34° 9′0.39″E), an ethanol plant has been operating since 1982. A second plant, in the Chikhwawa District, in the Southern Region (16°12′18.45″S; 34°50′24.94″E), has been producing ethanol since 2004. Altogether sugarcane for sugar and ethanol production covers an area of 23,000 ha [21]. The Malawian government promotes ethanol production with a mandatory blending rate that increased in February 2011 from 10% to 20%—further regional expansions in crop production are thus to be anticipated. One already planned expansion of about 9000 ha will take place in Shire Valley in the Southern Region.

The planned expansions in the valley are presumably linked to a large-scale, government-driven-and-sponsored irrigation scheme, the Shire Valley Irrigation Project (SVIP). Planning for the project, which will likely be financed through a public-private partnership, has been underway for several years, and feasibility studies and environmental impact assessments have already been conducted. Still, it is not yet clear, whether, when or precisely how the SVIP will be realized. The calculations conducted within the scope of this case study thus present scenarios to help appraise the opportunities such projects present.

2.2. *System boundary and data sources*

GHG emissions are quantified as CO_2 equivalent (CO_{2eq}) emissions by using the life cycle approach of carbon footprinting, which is more or less a LCA reduced to one impact category [22]. In this study, the functional unit chosen to compare ethanol and conventional gasoline is 1 MJ of ethanol or gasoline, respectively. System boundaries partly include upstream production processes such as agrochemical manufacturing, but not the nutrients used in the fermentation process since these amounts are negligible. Input and output data referring to buildings, machines, or equipment have not been taken into account; this is in line with the methodology described in the RED. Emissions released by the disposal of sludge from the ethanol plant have also not been considered given that information about the conditions at the specific landfill was lacking.

For the cultivation stage, data on fuel, agrochemicals, electricity use for irrigation, emissions regarding pre-harvest burning, and soil nitrous oxide (N_2O) emissions are required. In the process of sugar milling and ethanol production various chemicals are used and have to be considered. Although a combined sugar mill-ethanol operation would be more profitable, both locations, Dwangwa and Nchalo, have separate sugar mills and ethanol production plants. Given that the