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Locational analysis of cellulosic ethanol production and distribution infrastructure for the transportation sector in Ghana

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ABSTRACT

Owing to the high availability of crop residues in Ghana, ethanol produced from cellulosic feedstock provides an opportunity to achieve energy security without competing with food crops. This study applied methods to identify the best locations in Ghana for biorefineries with 100 ML and 50 ML annual production capacity for cellulosic ethanol, by minimizing transportation costs involved in the biomass residue feedstock collection and distribution of the ethanol produced by the biorefinery. The potential for ethanol production in the 10 regions of Ghana from 11 major crop residues was determined. Brong Ahafo and Eastern were identified as the regions with the highest ethanol production potential from single crop residues (with ethanol production potential of > 120 ML/yr), and residue from maize crop was identified as the biomass with the highest potential as source material. Two ethanol distribution scenarios were considered assuming the ethanol would be mixed with gasoline to produce an E10 fuel blend (10% ethanol by volume). In one scenario, all ethanol from the biorefineries was transported to Tema and then distributed using the existing gasoline infrastructure. In the second scenario, ethanol was delivered from the biorefineries directly to the major demand cities. Total transportation costs were used to identify which of nine candidate locations for the biorefineries and which ethanol distribution scenario led to the lowest costs. The results showed the best configuration to meet supply- and demand-side constraints was to use three biorefineries of 50 ML/yr capacity each to supply individual demand locations across the country, and biorefineries located in Koforidua in Eastern and Sunyani in Brong Ahafo led to the lowest transportation costs regardless of distribution scenario. The recommended biorefinery locations showed low sensitivity to important input assumptions, indicating a low risk to the development of biorefineries at Koforidua and Sunyani based on minimizing transportation costs.

1. Introduction

In 2016, Ghana was the 10th largest producer of oil in Africa [1]; however, Ghana is almost entirely dependent on imported oil and petroleum products due to the lack of refining capacity currently within the country. Reducing the dependence on foreign imports and transitioning towards energy independence is a high priority for Ghana. Additionally, Ghana is a member of the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC). As per the National Inventory Report submitted by Ghana to the UNFCCC [2], the Ghana energy sector contributed 13.5 million metric tonnes of CO_2-equivalent (MT CO_{2e}) to greenhouse gas emissions which included 6.46 MT CO_{2e} from the transportation sector. The Strategic National Energy Plan developed by Ghana's Energy Commission targets 10% of petroleum fuels to be displaced by renewable biofuels by 2020 [3]. One approach to reducing the dependence on fuel imports while simultaneously reducing greenhouse gas emissions is to develop the national supply of renewable biofuels produced from crop residues sourced in Ghana.

Many nations around the globe are focusing on ethanol as an alternative fuel to reduce dependence on fossil fuels while also decreasing CO_2 emissions. While displacing 100% of gasoline or diesel demand is challenging for most countries, blends of ethanol and gasoline from 10% ethanol by volume (E10) to 85% ethanol by volume (E85) have been successfully demonstrated at commercial scales in several countries including Brazil, Canada and the U.S. Most of the ethanol currently produced around the world is considered “first generation,” i.e. produced from direct food sources such as corn and sugarcane. Second and higher generation biofuels are produced using non-food feedstocks. In Ghana, producing biofuels from first generation feedstocks presents

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Units

GHC	Ghana Cedis
Ha	Hectare
MGHC	Million Ghana Cedis
ML	Million liters
MT	Million ton
kT	Kilo ton
T	Ton = 1000 kg
ML/yr	Million liters per year

social challenges like land grabbing [4]. Also, the production of biofuels from food feedstocks could lead to food shortages and negative environmental impacts, including soil degradation, biodiversity reduction and eutrophication [5]. According to Wang et al. [6], in a study focused on U.S. ethanol production, ethanol produced from lignocellulosic biomass is more attractive from a long-term sustainability perspective due to significantly lower lifecycle greenhouse gas emissions (compared with grain ethanol) and the potential to address the conflict of food versus fuel. Several studies of Ghana resources indicate significant potential for producing ethanol from food and non-food feedstocks [7–10].

Commercial scale biorefineries for the production of ethanol from crop residues have been successfully demonstrated in the U.S. and Brazil and plants are planned in several other countries [11]. A disadvantage of cellulosic ethanol production is the higher investment and operating costs required compared with first-generation bioethanol [12]. Thus, successful development of cellulosic biofuels is critically sensitive to minimizing associated costs, and economic studies show a dramatic sensitivity of the profitability of cellulosic biorefineries to feedstock costs which include transportation costs [13]. While previous studies of bioresidue have shown significant potential for biofuel production in Africa in general [10,14] and Ghana in particular [7–9], there are no previous studies to propose specific locations for 2nd generation biorefineries in Ghana. The study by Osei et. al. [7] concluded that Ghana has the capacity to embark on a biofuels program specifically using ethanol production. Osei et. al. [7] identified ethanol production potential from first-generation food crops: cassava, yam and maize, but food crops have significant social and environmental challenges, as discussed above. A recent study by Kemausuor et al. [9] estimated Ghana's production potential for ethanol from lignocellulosic crop residues to be 2300 ML/yr, which is significantly more than the projected requirements to meet the Strategic National Energy Plan goal of 10% displacement of petroleum fuel (estimated at 336 ML [9]). Importantly, crop residues are the lignocellulosic parts of the plants that are inedible. Thus, the use of crop residues to produce ethanol does not compete with food production and instead, provide an additional value stream to the inedible cellulosic materials. The current study expands the work by Kemausuor et al. [9] from identifying the potential of cellulosic ethanol to assessing and recommending crucial infrastructural developments. Such an investigation has not been conducted previously and is vital for informing public- and private-sector development of a biofuel infrastructure in Ghana. In view of this, the objective of this study was to identify optimal locations for cellulosic ethanol production in Ghana based on transportation costs associated with feedstock supply and the distribution of the ethanol product. The approach leverages the regional data available for agricultural production (feedstock supply) and vehicle use (fuel demand) in Ghana.

2. Methodology and results

The analysis initially considered the supply and demand sides separately to estimate maximum ethanol production potential and gasoline fuel demand; both on regional and district levels. Once the gasoline fuel demand was determined, demand for ethanol was calculated assuming all fuel would be mandated to be a blend of 10% ethanol and 90% gasoline by volume (E10). The E10 blend level was selected for the case study due to the compatibility of E10 with the powertrain technology of most passenger vehicles and with most gasoline distribution infrastructure. After the regional information was determined for ethanol supply and demand, the total transportation costs including crop residue and ethanol transport were minimized to identify optimal biorefinery locations. The analysis used 2012 data, unless noted otherwise.

2.1. Regional potential to produce cellulosic ethanol

The regional potential of ethanol production from crop residues followed the same procedures used by Kemausuor et al. [9]. The process is briefly reviewed here; additional details are provided in

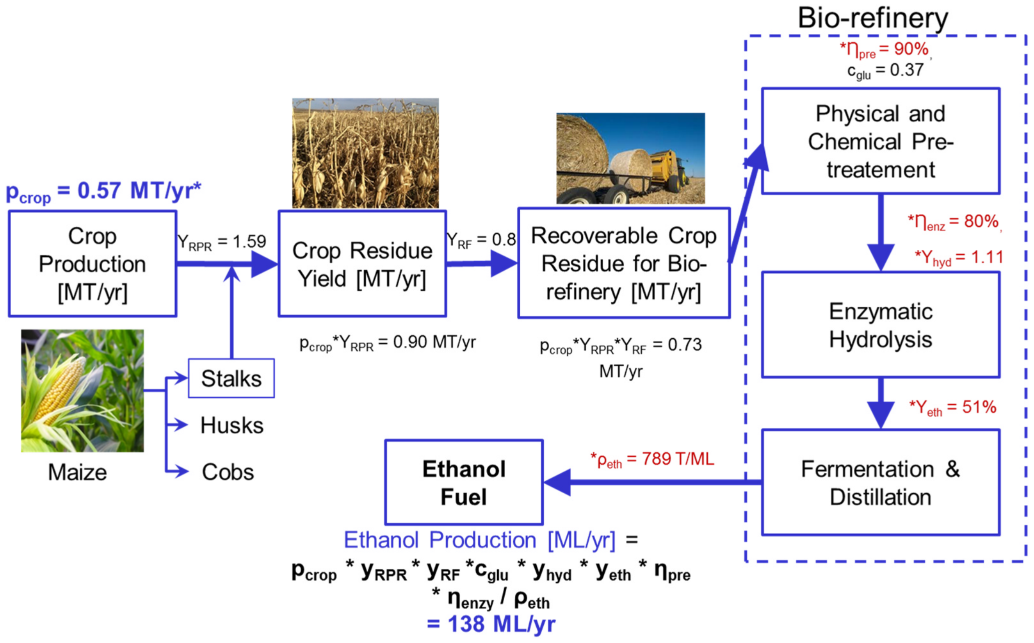

Fig. 1. Schematic of the method used to estimate the potential of cellulosic ethanol production from a single type of crop residue. Data for maize stalks from the Brong Ahafo region of Ghana are highlighted in this example. The definitions of the variables in the schematic are provided in Table 1. The values in red are constant for all types of crop residue. The values in black are crop specific. The values in blue are the annual input and output of the calculations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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