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Techno-economic analysis of integrating sweet sorghum into sugar mills: The Central American case

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ABSTRACT

This paper aims to evaluate the potential for electricity and ethanol production in Central America using sweet sorghum, performing a techno-economic analysis. The study proposes the integration of sweet sorghum into Central American sugar mills, by using the existing machinery to process this crop during off-season. A process simulation and a cost model were developed to estimate the technical and economical feasibility of sweet sorghum integration. The data on various parameters used for techno-economic assessment were collected from an existing sugar mill and distillery in Central America. The results show that a sugar mill operating 2 months during off-season could obtain an average revenue of US$ 3 M for a crushing rate of 6500 t/d. Ethanol production costs are estimated to be 24.76 ¢US$/L. In case a new CHP plant is built, a sugar mill operating under the integrated scenario would have a payback period of 4.49 years, as compared to 7.47 years for a sugar mill using sugarcane bagasse as the only fuel. Although several studies highlight the potential of sweet sorghum for ethanol production, the results from this work prove that sweet sorghum must also be seen as a viable feedstock for electricity production. A sensitivity analysis was also performed to determine the variation of the average cost of electricity and ethanol with the variables used in the economic analysis. For all analysed scenarios the effects of installed capacity and crop yield prevailed over the increasing costs of land and transportation.

1. Introduction

Fossil fuels provide about 35% of the total electricity supply in Central America, where about 78% of this energy comes from diesel and fuel oil generators [1]. This dependence on fossil fuels leaves the region in a vulnerable position in front of the rise of fuel prices and supply shocks.

In recent years, the search for alternative energy sources has gained a lot of importance to ensure global energy security, especially the use of local resources such as biomass for energy production. There are a total of 62 countries in the world currently producing electricity from biomass [2]. In 2008, the United States was the top biomass-based electricity producer with 26% of world production, followed by Germany (15%), Brazil and Japan (both 7%) [2]. In the long term, it is

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expected that biomass will play an important role in the world's energy portfolio, primarily in Latin America due to its availability and low cost [3]. So far, biomass resources (sugarcane bagasse) provide about 4% of Central America's energy through Combined Heat and Power (CHP) plants [4]. This technology has become an important part of the Central American energy matrix over the last years. This is in part due to the fact that with the collapse of the sugar market in 1998 [5], sugar mills were pushed to focus on the use of sugarcane by-products (bagasse and molasses) for the creation of value-added products, i.e., electricity and ethanol. As a result of this, in the decade of 2000–2011, Central America's cogeneration installed capacity grew enormously from 205 to 759 MW [4], which represented an increase of 369%. However, in the case of CHP plants that rely on biomass to operate, which is the case of sugar mills, the production of electricity and ethanol strongly depend on the length of the sugarcane crushing season, which varies between 100 and 200 days. Therefore, in recent years, the sugar industry has become interested in the use of supplemental feedstocks that would enable them to operate more flexibly and to extend their operation period.

The studied feedstocks vary from fast-growing tree species to short rotation agricultural crops [6]. The main disadvantage of forestry species is that with the current technology in Central America they can only be processed for electricity generation. Meanwhile, among the agricultural crops, sweet sorghum stands out due to its short growing cycle and because its by-products (bagasse and molasses) can be used in the same manner as sugarcane's to produce process heat, power and ethanol [7]. Sweet sorghum-based electricity can be sold to the national grid, while ethanol can be employed for transport purposes.

From an industrial point of view, the major benefit of sweet sorghum is that it can be processed using the harvesting, transport and processing equipment of sugar mills [8–10]. Therefore, sugar factories in Central America could benefit from the use of a short rotation agricultural crop to extend their energy production period once sugarcane season is over. This increase will not only lead to higher annual revenues for the sugar factories but will also help to create job opportunities. For example, only in Guatemala, the sugar industry generates around 65 000 full-time jobs which support around 250 000 people [11]. Approximately 50% of these jobs are for sugarcane harvesters, which only work during the harvesting season [11]. Thus, by extending the sugar mills' operation, job positions related to the harvesting process would be able to earn extra income during sorghum season.

It should be pointed out that sweet sorghum here is not considered as a dedicated energy crop due to the fact that a higher value product such as sweet juice or molasses (raw material for syrup or ethanol production) is obtained before firing bagasse to generate electricity.

This paper focuses on determining the potential production of a sugar mill processing sweet sorghum, performing a techno-economic analysis. The primary aims are to (1) use equipment which is not used for sugarcane during off-season and (2) evaluate whether the production and use of sweet sorghum is technical and economical feasible under Central American conditions. The calculation method presented here can be used as a tool to estimate the potential juice, molasses, ethanol and electricity production of a sugar mill. This evaluation was conducted using typical operating parameters and cost data of existing sugar mills in Central America. To determine the weight and effect of the variables considered in the economic model, a sensitivity analysis was also performed.

1.1. *Sweet sorghum*

Usually sweet sorghum is cultivated in areas where the rain is not abundant for crops like maize to grow, and where the temperature is too high to obtain profitable productions [12]. The crop can also be grown successfully on clay (vertisols) or in moderately leached soils (alfisols) [13], and it has better tolerance to drought, soil salinity and water logging [14]. Sweet sorghum is considered a high biomass and sugar yielding gramineous crop, which contains approximately equal quantities of soluble (glucose and sucrose) and insoluble carbohydrates (cellulose and hemicelluloses) [15].

As sugarcane is the reference crop to produce sugar, ethanol, process heat and power in Central America, Table 1 presents a comparison between sugarcane and sweet sorghum.

As can be seen from Table 1, sugarcane is an annual crop (under Central American conditions), while sweet sorghum has a 3.5 month crop cycle and can be harvested three times per year. Although, according to studies made by PRAJ Industries Ltd., higher yields can be obtained when sweet sorghum is harvested twice a year [16].

Besides its short rotation cycle, sweet sorghum cultivars also have the ability to produce during their second rotation extremely high stalk yields of up to 110 t/ha/cycle and a yield of fermentable sugars of up to 12.487 t/ha/cycle. Note that these values are significantly higher than the values reported for sugarcane (Table 1).

The crop also requires minimal water and fertilizer for its cultivation, about four and two times less than sugarcane, respectively. These characteristics allow sweet sorghum to grow on marginal or non-arable lands. According to Calvino and Messing [17], sweet sorghum can be cultivated with little or no N application without having a negative impact on sugar yield. This is one of the most remarkable crop characteristics of sweet sorghum due to nitrogen fertilizer accounts for a big portion of energy consumed by arable crops, attaining 50% of total energy inputs [18]. The low agronomic requirements of sweet sorghum translate into low production costs, which make it a very interesting crop for the production of electricity and biofuel. The cost of cultivating sweet sorghum is about 50% less than sugarcane (Table 1).

2. Material and methods

2.1. *Integrating sweet sorghum into a sugarcane mill*

This integration refers to using the existing machinery found in a typical sugar mill in Central America to process sweet sorghum. In order to evaluate this integration, sugarcane production has to be compared with a theoretical mill processing sorghum. For this purpose, the techno-economic