Energy 48 (2012) 442–454

Contents lists available at SciVerse ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

# Techno-economic analysis of bioethanol production in Africa: Tanzania case

Julián A. Quintero [a], Carlos A. Cardona [a,*], Erika Felix [b], Jonathan Moncada [a], Óscar J. Sánchez [c], Luis F. Gutiérrez [c]

[a] Instituto de Biotecnología y Agroindustria, Departamento de Ingeniería Química, Universidad Nacional de Colombia sede Manizales, Cra. 27 No. 64-60, Manizales, Colombia
[b] Food and Agricultural Organization of the United Nations, Viale delle Terme di Caracalla, 00153 Rome, Italy
[c] Instituto de Biotecnología Agrícola y Pecuaria, Departamento de Ingeniería, Universidad de Caldas, Calle 65 No. 26-10, Manizales, Colombia

ARTICLE INFO

*Article history:*
Received 29 September 2011
Received in revised form
11 August 2012
Accepted 11 October 2012
Available online 7 November 2012

*Keywords:*
Bioethanol
Tanzania
Sugar cane
Molasses

ABSTRACT

In this paper a techno-economic analysis for bioethanol production in Africa for Tanzania case is presented. It is shown conversion pathways from sugar cane juice and molasses, at three levels of technological schemes, where the first one includes a selection of widely conventional technologies, the second level with a more sophisticated fermentation technology and the third level using a different broth and solid treatment for ethanol production. A simulation procedure was taking into account in order to evaluate the conversion pathways schemes using different scenarios of raw material pretreatment, using Aspen Plus software, that include productivity analysis and energy requirements for each process configuration. Also an economical evaluation of each technology level and each scenario is shown. A comparison and discussions for each technological level and each scenario for bioethanol production in Tanzania is presented. These results served as the basis to draw recommendations on technological and economic feasibility aspects for the implementation of a national biofuel production programme in Africa. The study helped to identify the best technological schemes for producing fuel-grade alcohol from the various raw materials analysed.



## 1. Introduction

Tanzania, situated on the Eastern Coast of Africa, is one of the continent's most politically stable countries. The country is categorized as a least developed and low-income food deficit country. Tanzania is in the bottom 10 percent of the world's economies in terms of per capita income. The economy depends heavily on agriculture, which accounts for approximately 25% of the gross domestic product (GDP), providing 85% of exports, and employs 80% of the work force [1].

Tanzania remains a poor country with a per capita GDP of 362 USD in 2008, consistently below the sub-Saharan regional average since 2000, and 58% of its population living below 1 USD a day, compared to the regional average of 42%. Tanzania's population reached a total of 42.5 millions in 2008 and is growing at a rate of 2.9% a year. While the agriculture sector grew at 4% per year in 2007, it represents the slowest growing sector [1].

While most of Tanzania's population relies on agriculture for their livelihood, agricultural incomes remain low and are growing at a slow rate which partially explains the small effect that relatively large and consistent macroeconomic growth have had on poverty reduction and food security in Tanzania [2]. Stimulating growth in the agriculture sector, through means such as bioenergy development, would therefore have an impact on a large portion of the population, and is consequently essential in the government's goals of reducing poverty and increasing food security. Of total land available, 9.2 million ha are cultivated annually (excluding permanent crops), 85% of which is under food crop cultivation. Food crop production dominates the agriculture economy in Tanzania. The major staples include maize, sorghum millet, rice, wheat, pulses (mainly beans), cassava, potatoes, bananas and plantains. The main export crops are coffee, cotton, cashew nut, tobacco, sisal, pyrethrum, tea, cloves, horticultural crops, oil seeds, spices and flowers.

On the energy front, Tanzania struggles to meet its own energy needs and access to modern energy is still very limited. Over the last ten years, domestic energy demand has grown rapidly due to both the increase in economic activity and population growth. Access to energy is extremely limited and the energy balance is dominated by biomass based fuels particularly fuel wood (charcoal and firewood), which are the main source of energy in both urban and rural areas. The estimated total energy consumption is more

* Corresponding author. Tel.: +57 6 8879300x50417; fax: +57 6 8879300x50199.
*E-mail address:* ccardonaal@unal.edu.co (C.A. Cardona).

0360-5442/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.energy.2012.10.018

than 22 million tonnes of oil equivalent (TOE) or 0.7 TOE per capita. To date, a large share of current energy use is still met by traditional biomass, namely 90% of total use. The remaining share of energy use comes from fossil fuels, 6.6%, gas, 1.5%, hydro, 0.6%, and coal and peat, 0.2%. All of the fossil fuels are imported in Tanzania and 75% of these are used by the transport sector.

Tanzania continues to rely on imported petroleum products. Electricity generation is mainly hydro-based, while thermal plants provide electricity for peak loads. Development of natural gas for electricity is ongoing. The dissemination of renewable energy technologies has been limited to the promotion of improved stoves, improved charcoal production techniques, solar, biogas and windmills and to a lesser extent photovoltaics. Initiatives to increase utilization of coal for electricity are being explored. Biofuel developments have local, national, regional and global impacts across interlinked social, environmental and economic domains. A key concern for many poor countries is the effect that biofuel production will have on food security. The interface between bioenergy and food security is complex. Biofuel production may compete with food production for land and other agricultural resources. On the other hand, biofuel developments could play a pivotal role in promoting rural development through increased local employment and energy supply. Implementing bioenergy production can result in improvements or a worsening in the food security conditions depending on the bioenergy pathway chosen. The precise effects on food security will depend on many factors ranging from the land used for bioenergy production, type of feedstocks, agricultural management practices, the industrial set-up of the sector as well as developments in global agricultural and energy markets. The majority of Tanzania's poor people live in rural areas and continue to rely on conventional biomass for basic energy services. In common with many African countries, Tanzania's dependence on agriculture is likely to remain high for some time to come. But if agriculture is considered as a source to provide the basis of future growth and poverty reduction, the sector requires urgent modernization in order to improve productivity and generate growth. In Tanzania, there is a real willingness to exploit bioenergy developments to improve energy security which in turn impacts on food security. There are strong theoretical arguments for promoting bioenergy but for Tanzania the real issue lies in managing the development of the sector in a manner that promotes more equitable growth.

The advantages for promoting biofuels in Tanzania are numerous. The diversification of domestic energy supply would lead to increased energy security as well as hedge against energy price fluctuations, overcome energy access shortages and the resulting negative effects on overall development. As Tanzania is a net importer of oil, domestically produced biofuels may remove some of the uncertainty associated with development budgets because of reductions in the oil import bill while increasing foreign exchange savings. The returns generated by the industry could have a positive impact on food security especially if small holders in rural areas play a key role in supplying feedstocks. Moreover, the dependency on firewood for fuel needs would be reduced, considering that thermochemical technologies such as gasification and combustion are able to use biomass residues to produce energy. Those technologies integrated to cogeneration systems are able to produce efficiently, the heat and power required by chemical processes. In addition, electricity surplus can potentially be used to provide energy to surrounding rural or urban communities. The development of agro-industry can offer new rural employment opportunities. The combined effect would be to increase the standard of living of the rural poor and also improve the linkages between agriculture and other sectors in the economy. Understandably there are concerns about biofuels because of the competition it creates for the resources needed to produce food crops. Secondly, given the interests of largely private investors there is a risk that small holders may be overlooked in biofuel developments in favour of large-scale production units. These are valid concerns. However, the issue is less about food-feedstock competition but rather one of how to regenerate a stagnant agricultural sector so that yields increase improving the incomes of poor farmers. Maintaining the status quo of Tanzanian agriculture is not an option. This will not improve livelihoods nor will it protect natural ecosystems. The integration of food crops with biofuel production could offer a solution for sustainable land use. Capital, technology transfer and capacity building are essential ingredients of an agricultural revolution. Biofuel investors can bring in these necessary requisites to Tanzanian agriculture to address both food and energy security. However, to achieve this is important to consider that suitable area for sugar cane varies between 202,673 and 2,487,957 ha, depending on the features of agricultural configurations [1].

The Food and Agriculture Organization of United Nations (FAO) is leading a number of studies to evaluate the feasibility for producing fuel-grade alcohol under Africa conditions, without impairing the continent's food security [1]. The comparisons of the alternative technologies for producing fuel-grade alcohol are based on modern process-engineering tools for modelling and process analysis simulation [3–7]. The present study reviewed a variety of secondary information sources relating to the situation and conditions in Africa for ethanol production. It also used primary information collected by FAO staff. The data collected were of particular importance for setting up the scenarios for bioethanol and carry out the various technical-economic calculations.

A variety of models and analytical approaches were used to choose the best technologies, considering the various levels of technological access and development for the proposed processing technology configurations. The different technologies and process configurations with potential for application in Africa conditions were then selected. A commercial process simulator was used, in conjunction with special software designed by the authors, to analyse specific stages of the production process, i.e. fermentation and distillation. An analysis on the energy consumption of the various proposed technological schemes was carried out, and the biofuel per litre production cost was estimated. These results served as the basis to draw recommendations on technological and economic feasibility aspects for the implementation of a nationals biofuel production programmes in Africa.

The study helped to identify the best technological schemes for producing fuel-grade alcohol from the various raw materials analysed. The study was analysed in the context of implementing a national 10% blending gasoline oxygenation programme with fuel-grade alcohol. The objective of the blending mandate was on one hand seen as an opportunity to reduce fossil fuel imports and on the other to promote rural development. The rural development dimension was considered from the perspective of having the participation of small scale producers as feedstock suppliers in the various production systems considered in the study.

The objective of this study is to define the best biofuel production technological option under the specific conditions found in Africa. As such, it was necessary to find a flexible methodology to allow changes in the evaluation of technical parameters that adapt to the continental conditions. The proposed methodology is applied through the sequential execution of a series of evaluation criteria taking into account the entire biofuel production system. The assessment takes into consideration feedstock options and suppliers, industrial processing technologies as well as the management of industrial wastes and effluents. All these steps are taken into consideration to determine the production costs related