Journal of Energy Technologies and Policy
ISSN 2224-3232 (Paper) ISSN 2225-0573 (Online)
Vol.3, No.2, 2013

Potential of Bioethanol as a Household Fuel for Middle-Income Urban Kenya: A Case Study of Nairobi City.

Joseph Mbothu Machandi[1], Benson Gathitu[2] & John Kihoro[3]

1. Department of Mechanical & Automotive Engineering
Technical University of Mombasa, Box 90420- 80100, Mombasa- Kenya,

2. Department of Mechanical Engineering
Jomo Kenyatta University of Agriculture & Technology, Box 62000-00200, Nairobi - Kenya

3. Department of Statistics and Actuarial Sciences
Jomo Kenyatta University of Agriculture & Technology, Box 62000-00200, Nairobi - Kenya

* E-mail of the corresponding author: josmboth@yahoo.com

Abstract

Access to clean sources of energy constitutes a necessary condition for poverty alleviation. Provision of modern energy services is essential to improving the livelihood of households in the developing world. This study addresses both the demand and supply of bioethanol as a household fuel in urban Kenya. On the demand side, the study establishes that there is demand for clean fuels. The study establishes that households prefer the clean and convenient fuels. Even though LPG and electricity are indicated as expensive, they are the preferred fuels for cooking and lighting respectively. On the supply side, the study reviews the production of bioethanol from sugarcane and sweet sorghum. It is established that Kenya has suitable climate and land is available to grow sugarcane and sweet sorghum to supply bioethanol. Bioethanol is a modern clean fuel similar in characteristics to LPG and therefore can replace it as a household fuel. Bioethanol production and use will stimulate rural development.

Keywords: bioethanol, household fuel, Kenya

1. Introduction

Energy is essential to and a hallmark of societal development. Countries with access to abundant and affordable modern energy have significantly larger GDP, higher capital income levels, longer life expectancies, increased literacy rates and greater educational attainment (UNF, 2008). Without modern energy services, it will be impossible to alleviate poverty and achieve the UN millennium development goals (UNF, 2008).

Traditional fuels (firewood & charcoal) and petroleum fuels (kerosene & LPG) are the popular cooking fuels for rural and urban households in developing countries. These fuels have a number of problems associated with them. On combustion, these fuels emit gases and particles which are contributors to global warming, acid rain, smog and cause health problems to humans. Kenya imports oil from Middle East and whenever there is a crisis in this region the price of petroleum products go up. This has the effect of threatening our economic stability. Historically, inflation in Kenya has been mainly caused by increases in oil prices (Wanambwa, 2005).

Efforts to substitute fossil fuels for alternative fuels are gaining attention in a world threatened by climate change, rural economic decline and instability in major oil producing countries (EPI, 2005). Replacing fossil fuels with biofuels can reduce the problems associated with the former. Biofuel production can also improve rural economies by creating employment and raising farm incomes. Also, domestically produced biofuels have the potential to diversify energy portfolios, lower dependence on foreign oil and improves trade balances in oil-importing nations (EPI, 2005). The European Union, by setting targets of carbon emissions reduction and increase in the use of renewable energy before 2020, made an extraordinary attempt to achieve more sustainable energy production (Gnansounou & Dauriat, 2004; Watanabe, 2009).

Bioethanol is a form of renewable energy source. World bioethanol production tripled between 2000 and 2007 from 17 billion to more than 52 billion litres (UNEP, 2009). In 2009, worldwide bioethanol fuel production reached 73.9 billion litres (RFA, 2010). Several reasons such as energy security, environmental concerns, foreign exchange savings and socio-economic issues related to the rural sector justifies bioethanol to be considered a relevant technology by both developing and industrialized countries (Demirbas , 2008; Gnansounou, & Dauriat , 2004).

2. Methodology and Data

2.1. Methodology

To attain the objective of this study, descriptive statistics is used on primary data from households to investigate the demand for fuels. The study then uses secondary data to establish the bioethanol feedstock resource potential as well as the socio-economic value of bioethanol production.

2.2. Population and Sample

The population from which the sample was drawn from was the middle-income households within Nairobi city. Convenient sampling was done within these households. The data was collected from 313 households in six estates in Nairobi i.e. Githurai, Kahawa, Umoja, Buru Buru, Satellite and Ngumo. These areas comprise mainly of the middle income households where majority of city residents live. The study avoided households in the extremes i.e. slums and high income households.

3. **Results and Discussions**

3.1. Modern Technology

For this study, 313 households were sampled of which 99.7% of the households had mobile phones, 94.6% had TV sets, 94.2% had radios, 59.4% had computers and 31% had smokeless jikos (a jiko is a popular Kenyan stove that works by combusting wood charcoal using convection to provide oxidation air) (see figure 1). Thus, a high proportion of urban households have modern technology gadgets and/or equipment. Mobile phones are fast and convenient means of communication. Radios and television sets make households informed of recent news and developments. Computers can be used for communication as well as sources of information. The use of smokeless jikos makes households to save on energy, thus lowering energy costs. Mobile phones, radios, TV sets, computers and smokeless jikos improve the livelihood of households. This is an inference that urban households are likely to accept introduction of new technologies that will improve their livelihoods.

3.2. Ranking of Fuels

The sample size was 313 households and six types of fuels were considered. These are firewood, charcoal, biogas, kerosene, LPG and electricity. The fuels were ranked by: (a) ignoring fuel cost and (b) in order of fuel cost. The fuels were ranked 1 to 6 with the most preferred fuel ranked 6 and the least preferred fuel ranked 1. The rest were ranked in between. The mean is used to rank the fuels for each category. For each category, the fuel with the highest mean is the most preferred and the one with the lowest mean is the least preferred.

3.2.1. Ignoring Fuel Cost

Ignoring the cost of fuels, the most preferred fuel is electricity followed by LPG, biogas, charcoal, kerosene and firewood in that order (see figure 2). Thus ignoring costs, majority of the households will prefer to use LPG and electricity than kerosene, charcoal or firewood.

3.2.2. In Order of Cost

In order of fuel cost, charcoal is the most preferred fuel, followed by LPG, biogas, kerosene, firewood and then electricity in that order (see figure 3). In urban areas there are no woodlots and this probably makes firewood a costly fuel. The use of diesel power plants for power generation increases the tariffs imposed on electricity making it a costly fuel.

3.3. Characteristics of Fuels

The characteristics of a fuel were sampled from households that use that particular fuel. It was assumed that households that do not use a particular fuel could not give the characteristics associated with the fuel. For the households sampled in this study, very few households use firewood and thus for this part of the study it can be ignored. For each fuel characteristic, mean was used to determine the proportion (see Table 1) of households that indicated that a fuel has that characteristic. This proportion was based on households that use the fuel. 84% indicated charcoal as an inexpensive fuel and less than 20% indicated kerosene, LPG and electricity to be inexpensive fuels. Over 90% indicated charcoal, kerosene and electricity as fuels with good availability and 52% indicated LPG as a fuel with good availability. 99% indicated LPG and electricity as clean fuels to work with and less than 50% indicated kerosene and charcoal as clean fuels to work with. Over 98% indicated LPG and electricity as fuels that produce no smoke with 45% and 3% indicating kerosene and charcoal respectively as fuels that produce no smoke. 99% indicated LPG and electricity as fuels that are fast with 40% indicating charcoal and kerosene in this respect. None of the fuels was indicated by more than 70% as safe.

3.4. Household Fuel Consumption

For each use, the proportion (see Table 2) of households using a particular fuel for a given purpose is determined from the mean. LPG is the fuel used for cooking by most households with charcoal, electricity and kerosene following in that order. For water heating, most households use electricity, with charcoal, kerosene and LPG following in that order. The fuel for lighting for most households is electricity, with very few households using kerosene and LPG. Substantial proportion of households (67%) use electricity for space heating.

Although most households indicated LPG and electricity as expensive, majority of households use LPG for cooking and electricity for lighting. This is because LPG and electricity are clean, fast, efficient and convenient to use. Bioethanol is a clean and convenient fuel and having similar characteristics as LPG. Thus bioethanol has potential to replace LPG as a household fuel. Bioethanol will be expected to have an additional advantage of being available and affordable as it will be produced domestically. LPG is imported and its supply is unreliable due to lack of storage facilities.

4. Bioethanol supply

4.1. Bioethanol Feedstocks

Kenya has suitable climatic conditions for growing bioethanol crops and is thus capable of developing its own supply of domestically produced bioethanol fuel. Bioethanol crops that can be grown in Kenya include potatoes, cassava, wheat, maize, sugarcane and sweet sorghum**.** Feedstocks such as potatoes, cassava, maize and wheat present a threat to food security. Therefore bioethanol crops selected for this study are sugarcane and sweet sorghum. The two are selected due to the history of production, climatic suitability, crop cycles per year and also they are not expected to compete with the food supply chain.

Sugarcane has a high potential for bioethanol production. Bioethanol is made from molasses at two plants i.e Spectre International and Agrochemical Food and Allied Company. Mumias Sugar Company is also producing bioethanol by utilizing its own molasses. Sweet sorghum, which is similar to grain sorghum with sugar rich stalks, is a water-use efficient crop with a very good potential for bioethanol production. Sweet sorghum is a crop similar to sugarcane but with a lower sugar-product yield and higher tolerance to warmer and drier conditions. International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT) considers sweet sorghum a smart crop as it produces food, feed, fodder and fuel, without significant tradeoffs in any of these uses in the production cycle. Sweet sorghum's growing period (about 4-5 months) and water requirement (8 000m^3 over two crops) are 4 times lower than those of sugarcane (12-16 months duration and 36 000m^3 of water per crop) (see Table 3).

4.2. The Availability of Bioethanol Feedstocks

Land availability, agricultural practices and demand from competing uses are the main factors that determine the supply and price of bioethanol feedstocks. This study reviewed a study conducted by GTZ and GoK in 2008 to establish that land availability and agricultural practices determine the supply of bioethanol feedstocks. The study considered three scenarios to determine potential availability of bioethanol feedstocks. The first scenario considered the status quo production of feedstocks and found that enough sugarcane was being produced for 49 million litres of bioethanol if only molasses was being used and 345 million litres if all sugarcane went to bioethanol instead of sugar (see Table 4).

The second scenario (see Table 5), considered potential production of feedstocks and calculated the amount of each crop that could be grown at current yields if half of all the suitable areas were planted. The production of each feedstock was based on suitability mapping done by Geographic Information Systems (GIS) experts at International Centre for Research in Agro forestry (ICRAF). Excluding land that was being used to grow other crops, enough sugarcane could be grown to produce 30 million litres of bioethanol depending on whether molasses or cane juice was used and over 8 billion litres of bioethanol could be produced from sweet sorghum. The third scenario (see Table 6), considered optimized production of feedstocks and calculated production if half of suitable lands were used at optimal yields for each crop. This scenario considered production using high yielding varieties under irrigation. Higher values were obtained than those in the second scenario. The "optimized scenario" show what difference higher yields would make in terms of bioethanol feedstocks.

From the above review, it can be established that both available land and increased yields are important factors in producing adequate supplies of bioethanol feedstock to support a domestic industry. High yielding varieties of both sugarcane and sweet sorghum have been developed through the efforts of Kenya Sugar Board and ICRISAT. Land is available in Kenya to grow enough sugarcane and sweet sorghum to produce enough bioethanol to be used as a fuel in urban households. The calculation in the two potential scenarios was based on 50% of the available suitable land and therefore it is possible to supply more of the feedstocks for bioethanol production. If Kenya embarks on an expansion plan to supply bioethanol feedstocks, enough bioethanol fuel for urban households will be available. The technical potential of bioethanol is therefore enormous.

There are other inputs such as electricity, labour, transport and chemicals (yeast and enzymes) required for bioethanol production. Electricity and transport are the most critical as these can drive up the cost of production. The cost of electricity can be brought down by the processing plants utilizing bagasse from both sugarcane and sweet sorghum to generate electricity. This is a lesson learned from Brazil which is a success story in bioethanol production. The transport cost can be lowered by ensuring that bioethanol plants are located where the feedstock is produced. The available lower labour costs and the potential to co-generate electricity from the bagasse can help to offset the added costs of the non-feedstock inputs.

4.3. Energy Balance

*T*he energy balance for the production of bioethanol is the ratio of the energy output (bioethanol, electricity and by-products value) to the input (fuel, water, fertilizers, chemicals, machinery and labour). Energy balances need to consider the entire fuel cycle from feedstock production to final consumption. Assessments should also include energy paybacks associated with co-products. Energy balances vary depending on the type of the feedstock, method of cultivation and the conversion technology. The energy balance also depends on the methodology used in assessment studies.

Brazilian sugarcane-based bioethanol is one of the most energy efficient forms of bioethanol. From an assessment study (Macedo et al, 2008) in the south region of Brazil, for each fossil energy unit used to produce sugarcane bioethanol, more than nine renewable energy units are produced in the form of bioethanol and surpluses of electric power and bagasse (see Table 7). Different studies in different countries give different energy balances for each crop (see Table 8). This indicates there are a variety of methods used to obtain the energy balance of bioethanol. Each of the approaches however indicates a positive energy balance of bioethanol and therefore more energy is produced than consumed.

4.5. Employment and Income

To produce adequate supplies of bioethanol feedstocks to meet domestic requirements will require expanded agricultural production of these feedstocks. This will provide farm jobs and opportunities for rural farmers to expand production into new cash crops. Sweet sorghum can grow in semi-arid areas, thus its introduction as a cash crop in such areas is an economic activity that will improve the livelihood of the rural population in these regions. An additional production of bioethanol will yield revenue to the national economy. The additional revenue could be used to invest in irrigation and better agriculture practices which will go a long way in increasing yields of all crops, even those grown for food. New jobs will also be created in the manufacturing and transport sectors by the planned bioethanol production.

Domestically produced bioethanol will reduce importation of petroleum products such as kerosene, LPG and fuel oil leading to saving in foreign currency. This can be reinvested in the economy and will go a long in creating new jobs and new opportunities especially for the underdeveloped rural areas. The potential reduction in GHG’s emissions from bioethanol will provide a revenue stream through carbon credits. These are the mandatory markets created through the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) and the market for voluntary credits. The former is more stringent and restrictive but yields higher price per tonne of carbon. The latter is more flexible and easier to gain compliance with, but fetches lower price. There will be carbon funding through the Clean Development Mechanisms (CDM) of the Kyoto Protocol. This enables countries to meet their emission obligations by funding projects that reduce emissions in other parts of the world, especially developing countries that are not bound to reduce emissions under the Climate Convention.

5. Conclusion and Recommendations

5.1. Conclusion

*Fr*om the study it was established that most households had the modern gadgets or equipments for communication and also for making them informed of new developments. Some households were also aware of a way to make savings in energy by using a smokeless jiko. Thus, this is an indication that urban households are likely to accept new technologies that impact positively on their way of livelihood. Introducing bioethanol as a household fuel is a completely new venture and from this study, it appears that there is a high likelihood of it being accepted. The cost of bioethanol as well as the bioethanol stove will be critical to its acceptance as a household fuel.

From the study it was observed that households were for modern, clean and convenient fuels i.e. LPG for cooking and electricity for lighting. Cooking and lighting are the two important uses of fuels for households in rural and urban areas. LPG and electricity were indicated as the most expensive fuels but they are clean, fast and produce no smoke. Bioethanol and LPG have almost similar characteristics and thus the former can replace the latter. The study also reviewed the potential of Kenya being a bioethanol producing country. Sugarcane and sweet sorghum were identified as the feedstocks for bioethanol production. Kenya has a suitable climate and available land for growing the two crops. The introduction of bioethanol production and use will be expected to have significant economic, social and environmental benefits.

5.2. Recommendations

Bioethanol feedstock production and hence its use as a household fuel requires various interventions to overcome the barriers and negative implications in order to stimulate progress while also addressing sustainability. The Kenya government through the Ministries of Energy, Agriculture and Finance need to make a number of interventions to back the bioethanol development. These interventions should control the initial stages of bioethanol development but later the prices of bioethanol should be determined by market prices. There is need of strong government commitment and bioethanol production should be given a priority development agenda so as to expand its production and use. The government should establish institutional frameworks with targets and defined tasks. These tasks will assist the creation of appropriate institutions.

The government should provide supportive policies such as tax incentives, low interest borrowing options and investment in research and development. These policies should focus on creating a predictable market through provision of economic incentives for bioethanol industry by offering loans with low interest rate and high productivity, hence making the bioethanol attractive by bringing its cost down. The government should determine the energy and fuel usage and expenditure at the household level. This will assist in evaluating energy subsidies and taxes. The subsidies and taxes are forms of government interventions in household markets to improve the availability of modern fuels at affordable prices (Alam M et al, 1998; Goldemberg, 2007).

An environment impact assessment (EIA) should be done so as to identify the social and environmental impacts associated with bioethanol development in the new areas where the bioethanol crops will be grown. This is a requirement whenever a major project is being undertaken and is enforced by the National Environment Management Authority (NEMA). Future research should be carried out to determine the Kenyan bioethanol energy balances, the net GHG emissions for sugarcane and sweet sorghum and on bioethanol equipment and machinery. These will ensure the bioethanol development is done in a sustainable way.

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Notes

Note 1- Acronyms and Abbreviations

BNDES - National Bank of Economic & Social Development
CGEE - Centre for Strategic Studies and Management in Science, Technology and Innovation
EPI - Earth Policy Institute
GoK - Government of Kenya
GTZ - German Technical Cooperation
RFA - Renewable Fuels Association
UNDP - United Nations Development Program

UNEP - United Nations Environment Program

UNF - United Nations Foundation

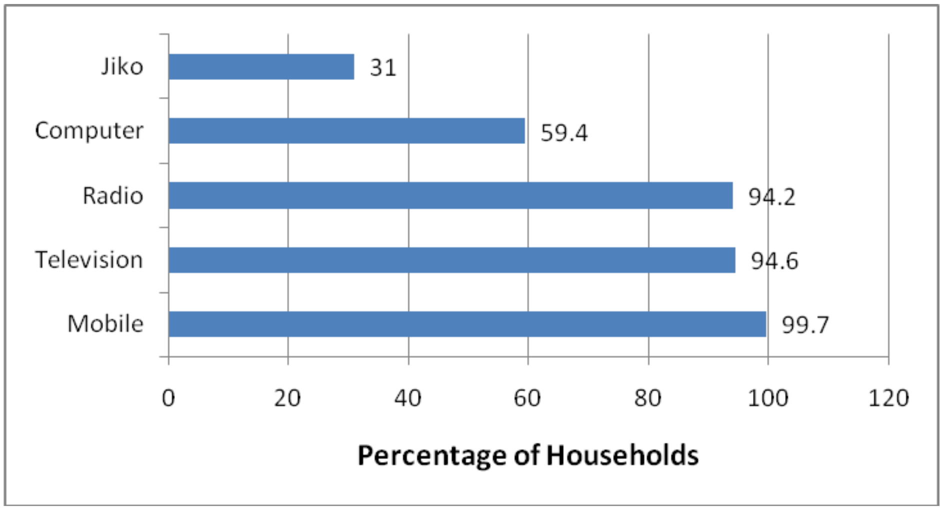

Figure 1: Barchart showing proportion of households possessing modern gadgets/equipments

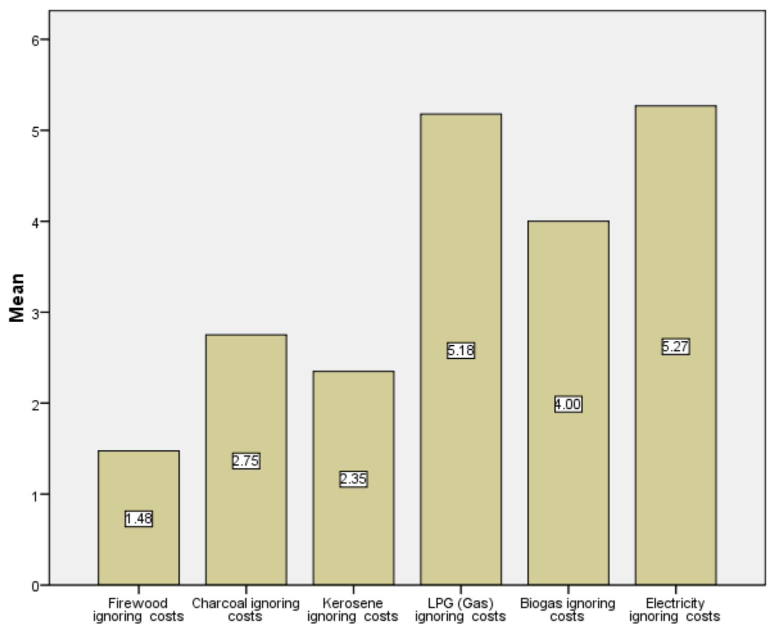

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Figure 2: Bar chart for the means of household fuels ignoring fuel cost
Source: From this study.

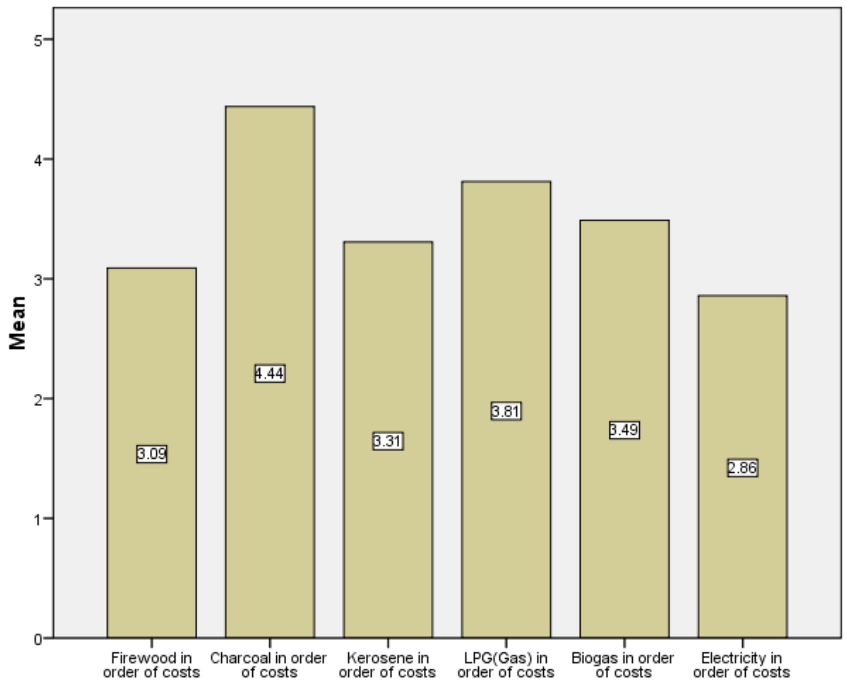

Figure 3: Bar chart for the means of household fuels in order of cost.
Source: From this study.

Table 1: Percentages of households indicating that a fuel has that characteristic
(Based on households that use the fuel)

	Firewood	Charcoal	Kerosene	LPG	Electricity
Fuel is inexpensive	74%	84%	19%	6%	4%
Good fuel availability	56%	96%	94%	52%	94%
Clean to work with	0%	23%	46%	99%	99%
No smoke	4%	3%	45%	98%	99%
Fast	36%	40%	41%	100%	99%
Safe	81%	53%	65%	50%	47%
Valid N (listwise)	23*	188*	135*	254*	294*
Sample % of households using the fuel	7.3%	60%	43%	81%	94%

*Number of households using a fuel.

Source: From this study.

Table 2: Percentages of households using a particular fuel for a given purpose

	Firewood	Charcoal	Kerosene	LPG	Electricity
Cooking	8%	59%	41%	81%	45%
Water heating	5%	36%	23%	17%	71%
Lighting	2%	2%	8%	3%	94%
Space heating	2%	5%	1%	1%	67%

Source: From this study.

Table 3: Characteristics of sweet sorghum and sugarcane

Parameter	Sweet sorghum	Sugarcane
Crop duration	4 months	12-16 months
Water requirement per crop	4 000 m^3	36 000 m^3
Grain yield (tonnes/Ha)	2.0	-
Bioethanol from grain (litres/Ha)	760	-
Green stalk cane yield (tonnes/Ha)	35	75
Bioethanol from stalk cane juice (litres/Ha)	1 400	5 600
Bioethanol from residue (litres/Ha)	1 000	3 325
Total bioethanol (litres/Ha)	3 160	8 925
Bioethanol cost per kilolitre (US$)	75.3	111.5

Source: ICRISAT (2006) cited from Kyritsis S. (2010).

Table 4: Status Quo Feedstock Production Scenario

			Non-food	Competing	Food	Competing
	Hectares ('000)	Yield (T/HA)	Production ('000 tons)	Bioethanol ('000 litres)	Production ('000 tons)	Bioethanol ('000 litres)
Sugarcane	147.7	33.4	4 933	49 330	4 933	345 310

Source: Adopted and modified from GTZ & GoK (2008).

Table 5: Potential Feedstock Production Scenario

		New	Farm	Lands	Existing	Farm	Lands
	Yield (T/Ha)	Land (MHa*)	Production (Mtons*)	Bioethanol (Mlitres*)	Land (MHa*)	Production (Mtons*)	Bioethanol (Mlitres*)
Sorghum	35	5.90	206.50	8 260	11.06	387.10	15 484
Sugarcane	33.4	0.09	3.01	30	0.83	27.72	277

*MHa refers to 10^6 Ha, Mtons refers to 10^6 tons and Mlitres refers to 10^6 litres.
Source: Adopted and modified from GTZ & GoK (2008).

Table 6: Optimised Potential Feedstock Production Scenario

		New	Farm	Lands	Existing	Farm	Lands
	Yield (T/Ha)	Land (MHa*)	Production (Mtons*)	Bioethanol (Mlitres*)	Land (MHa*)	Production (Mtons*)	Bioethanol (Mlitres*)
Sorghum	70.00	5.90	413	16 520	11.06	774	30 968
Sugarcane	68.84	0.09	6.15	61.5	0.83	56.72	567

*MHa refers to 10^6 Ha, Mtons refers to 10^6 tons and Mlitres refers to 10^6 litres

Source: Adopted and modified from GTZ and GoK (2008).

Table 7: Energy Balance of Sugarcane Bioethanol Production in Brazil

Energy balance component	2005/2006	2020 scenario
Sugarcane production and transport	210.2*	238.0*
Bioethanol production	23.6*	24.0*
Fossil input (total)	233.8*	262.0*
Bioethanol	1 926.0*	2 060.0*
Bagasse surplus	176.0*	0.0*
Electricity surplus	82.8*	972.0*
Renewable output (total)	2 148.8*	3 032.0*
Energy production/consumption		
Bioethanol + bagasse	9.0**	7.9**
Bioethanol + bagasse +electricity	9.3**	11.6**

*Units are Megajoules per ton of cane (MJ/tc)

**Energy balance = Energy Production/Energy Consumption

Source: Macedo et al (2008) cited from BNDES, CGEE (2008).

Table 8: Energy Balance for Bioethanol Production for different countries

Sugarcane	Sweet sorghum	Country (source)
21.3**	6.9**	Brazil (Da Silva, 1978)
1.9**		Zimbabwe (Rosenchein et al)
9.2-11.2**		Brazil (Macedo, 1996)
	3.4-6.1**	Spain (Fernandez, 1998)
	0.9-1.1**	USA/Europe (Santos, 1997)
	3.5-7.9**	USA (Worley et al, 1991)

** Energy balance = Energy Production/Energy Consumption

Source: Cited from Zuzarte F. (2007).

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