Ethanol for Cooking

Feasibility of small-scale ethanol supply and its demand as a cooking fuel: Tanzania Case study

FIONA ZUZARTE

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Abstract

Provision of modern energy services is essential to improving the well being of the developing world. Cooking represents a major share of energy consumption and is currently provided by traditional sources, which are highly gendered, present health hazards from exposure to smoke and particulates, and are inefficient. This paper reviews the health, social and developmental sectors benefits from the use of clean cooking fuels. It assesses how ethanol, when made from local feedstock, can address these issues and stimulate rural development, and provide renewable fuels. Understanding how the economics of clean fuels affect choices among existing cooking fuels is important for policy makers and investors.

The study addresses the production of ethanol fuel, and the economics associated with supply. In the case of ethanol for cooking in Tanzania, it can be provided through small-scale distilleries from sugarcane, sweet sorghum or cassava. The demand for ethanol is presented in the context of understanding consumer choice across the different fuels available. Fuel choice is modelled according to the price of the (cooking) appliance as well as operating (fuel) costs. Social and development objectives need to be addressed as well. Ethanol from sugarcane c-molasses presents the most economical option for this region in the short term, primarily for the urban Tanzania market. Policies are required to implement changes in social and economy infrastructure to encourage investment, development and incentives to create a market for cleaner fuels such as ethanol gel fuel.

ACKNOWLEDGEMENT

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NOMENCLATURE

CDM	Clean Development Mechanism
DDG	Dried Distiller Grain
EUR	Euro
GCCFI	Global Clean Cooking Fuel Initiative
GDP	Gross Domestic Product
HDI	Human Development Index
hh	household
MDG	Millennium Development Goals
Mfg	manufacturing
LPD	Litres per day
LPG	Liquefied Petroleum Gas
USD	US Dollars

1. INTRODUCTION

Studies have shown that measures of human development index (HDI) rises with energy consumption at a very rapid rate (Figure 1.1) for the first increments of modern energy services [Pasternak, 2000]. These first levels provide the basic needs such as cooking and lighting. Provision of these modern energy services is essential to improving the wellbeing of the developing community, especially with respect to women, children and public health issues.

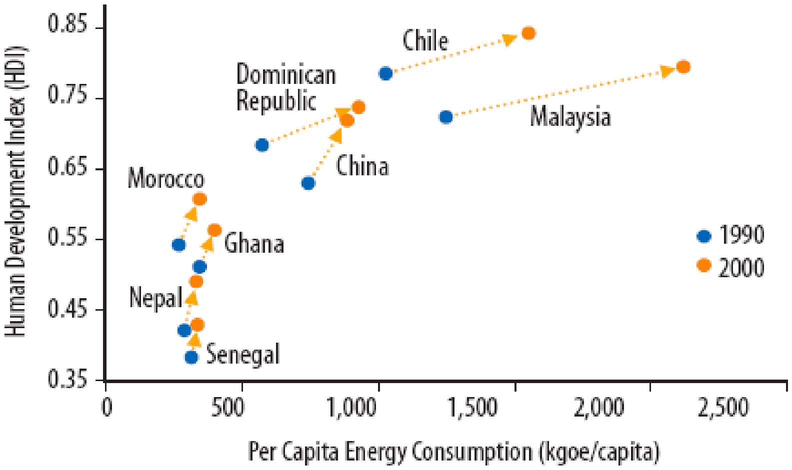


Figure 1.1:HDI vs energy consumption for selected countries

[Source: UNDP, 2005]

In most developing countries, cooking represents a major source of energy consumption, particularly in rural areas. The fuel of choice is primarily traditional, collected and prepared from local resources, such as wood and charcoal. These can be considered renewable when harvested sustainably; however traditional biomass is generally used inefficiently and presents environmental, health and welfare issues. Modern fuels are those that are controlled to provide consistent energy, and are efficient and clean when combusted, such as natural gas or electricity.

Health concerns are related to the indoor air pollution caused by burning biomass and coal in residences. Collection of firewood and related activities to food preparation is usually undertaken by women and children, which is not only a labour intensive activity that is not monetized, but results in limited time for children to attend school [Goldemberg et al, 2004]. Finally, unsustainable use of firewood or preparation of charcoal contributes to degradation of the local environment, although land clearing for large-scale agro-industry is generally a bigger contributor to deforestation.

By provision of clean cooking fuels, some of these concerns can be addressed. The World Health Organization has set the goal of “By 2015, to reduce the number of people without effective access to modern cooking fuels by 50%, and make improved cooking stoves widely available" [WHO, 2006].

As part of the Global Clean Cooking Fuel Initiative (GCCFI), clean cooking fuels are considered to be those that reduce indoor air pollution while addressing social and developmental issues as discussed above. [Goldemberg et al, 2004]. Modern clean cooking fuels include liquefied petroleum gas (LPG), natural gas, electricity and biofuels. Use of fossil fuels in some developing countries presents issues of import costs, limitation of future supplies due to diminishing resources of fossil fuels, and the problem of emission of greenhouse gases during combustion. The inclusion of sustainability in fuel selection must address global issues and renewable supplies. Biofuels have the potential to address both the health and sustainability aspects.

Ethanol (ethyl alcohol) has long been recognized as a fuel suitable for a variety of applications, including transportation and cooking. Ethanol can be produced from a variety of sugar, starch and grain crops. Brazil has developed an ethanol program unsurpassed in the rest of the world, using sugarcane as the primary feedstock. The advantage that several developing countries have is a fast growing cycle, due to favourable climatic conditions, as well as low labour and land costs. Ethanol presents the advantage of not only being a clean fuel, but also a sustainable one, in terms of reduction of greenhouse gases, use of renewable sources and contributing to rural development.

Small-scale business is a common platform for creating employment in rural regions of developing countries. If produced at a community-based facility, ethanol can provide rural economic and social empowerment of the poor, while minimizing the risks associated with large-scale production, such as environmental issues of extensive feedstock cultivation, conflicts with food production and competition with the energy needs of the transportation sector.

Among modern cooking fuels available in the developing world, there are several factors affecting both the supply and the demand. Each of these sides has been studied in detail, but for the case of ethanol gel fuel, there are few cases integrating both aspects. Understanding the impact of these variables on both sides of the market is a tool that policy-makers can use to determine how to implement changes in their regions to encourage use of clean fuels, thereby achieving development, health, economic and environmental goals.

1.1. Objectives

This paper will identify the opportunities for a selected region to produce ethanol for cooking purposes, using local resources and existing technology at a micro-distillery scale. Selection of a particular country will serve to apply actual data to an otherwise generic study.

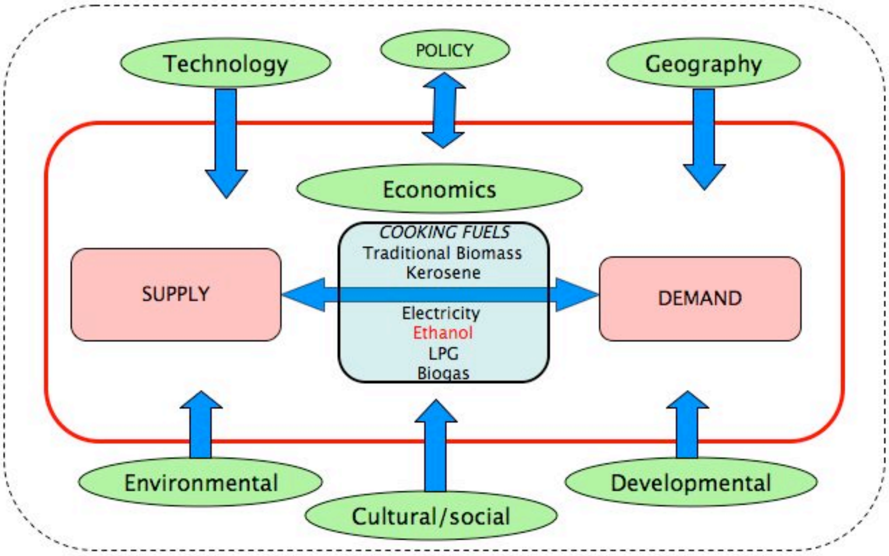


Figure 1.2: Factors in Evaluation of Feasibility of Ethanol

The study will examine the variables that influence the demand of modern cooking fuels. By identifying the barriers in implementing existing modern fuels (such as LPG, or natural gas), the supply side can be addressed by critically examining the economics, market distribution, fuel selection and equity implications of ethanol. The feasibility of ethanol will be evaluated amongst other fuel choices for the region, primarily focussing on the economics. Variables other than economics will be considered qualitatively. Finally, the appropriate time frame for implementation of such a biofuel scheme will be examined against the development objectives of the region.

1.2. Method of attack

This study will address the supply aspects of ethanol fuel and review the demand for cooking fuels in the region. Integration of the economics of both sides will be done to examine the feasibility of such a small-scale production facility for the cooking fuels market.

Supply aspects

- Review feedstock bio-resource potential for community based ethanol production plant for selected region. Focus on mini to micro-distilleries.
- Consider start-up aspects for the ethanol production by selecting technology that is small-scale, commercially available and reliable. Include maintenance and training aspects where possible.
- Evaluate key factors that influence the cost of production Determine the cost as a function of the scale of production.
- Assess by-products of ethanol processing that have social and economic value to the community.

Demand aspects

- For selected area, determine the demand for clean cooking fuels using available and suitable household survey data. The minimum data set requires a clearly displayed market share of cooking fuels, as well as the economics of fuel selection, operation and purchase cost of stoves, as required for the regression method of analysis chosen for this study.
- Measure and/or qualify present cooking fuel demand for the selected region's population. Compare alternative cooking fuel options based on a discrete choice model for consumers.
- Determine the relation of economic aspects, demonstrating operating cost and appliance cost on the demand for ethanol fuel. Compare economics of ethanol with other cooking fuels. Include stove efficiency, affordability and dissemination issues in comparison to biofuels.
- Examine qualitatively, the environmental and social impacts of household decisions to choose fuels (women working, convenience, income, education, cost, availability).

Feasibility Assessment

- Complete a technical-economic assessment of an ethanol distillery including system and feedstock costs, operating variables, scale-up costs, and integration into existing infrastructure.

- Complete an analysis of variables on consumer clean-cooking-fuel selection. Review existing datasets and factors from completed probability and market studies. Examine the economic aspects of fuel choice on demand.
- Evaluate supply of ethanol production from micro-distillery and consumer choice of this fuel to determine feasibility as a cooking fuel and other alternatives. Examine sensitivity studies with variations to both sides of the market, and evaluate the effect of subsidies on enhancing the uptake of ethanol as a cooking fuel.

This study will use a qualitative approach for the social and environmental aspects of cooking fuel choice via literature survey and reports from the selected region of Tanzania. The methodology used to determine the economic aspects of ethanol production and the demand for fuels will be done quantitatively, with a discrete choice model for consumers.

2. METHODOLOGY

2.1. Tanzania and energy situation

Tanzania is one of the biggest countries in Eastern Africa, and has diverse geography, from the rift valley, lake regions, highlands, and coastal plains. It has a total area of 945000 km^2 and a population of about 33 million people, of which 50% are living in poverty [Tanzania, 2006].

Figure 2.1: Map of Tanzania [Tanzania, 2006]

Major natural resources include minerals, wildlife and tourism, fisheries and forestry. A quarter of the population has no formal education. The economy of Tanzania is heavily dependent on agriculture, accounting for almost half of the GDP and providing employment to around 80% of the population [Tanzania, 2006].

For its commercial energy needs, the country relies on imported petroleum, hydropower from local power stations and coal, mined locally. The country has plans for connecting the grid with neighbouring countries to boost the supply [Tanzania, 2006]. About 10% of the households have electricity connections, of which it is mainly the urban areas that are grid-connected and the consumption continues to grow. As is the case for many African countries, Tanzania relies heavily on biomass for energy, in the form of wood, charcoal and residues, using over 90% of this resource in its total energy supply [Kaale, 2005] (Figure 2.2).

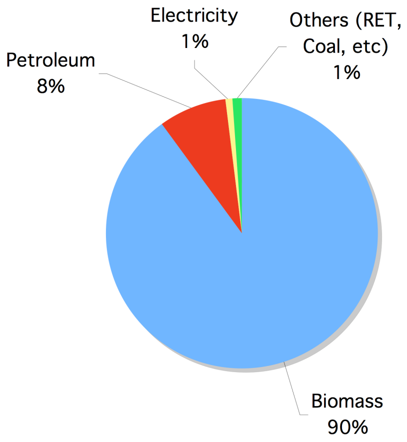


Figure 2.2: Share of energy in Tanzania [Kaale, 2005]

Subsidies to allow the poor to afford energy services were modified in the late 1990’s and removed for LPG and kerosene. Electricity continued to have a “life-line tariff” as a way of subsidizing the low income population.

Alternative sources are limited due to low development in the region, and low income of the majority of the population to afford commercial energy sources. Tanzania is selected as a case study due to some of the following driving policies:

- Tanzania has a National Strategy for Growth and Reduction of

Poverty (NSGRP) with an objective of providing 10% of the population with alternative energy options to wood-fuels for cooking by 2010 (related to biomass technology) [Tanzania, 2005].

- The global clean cooking fuel initiative (GCCFI) would like to bring a shift to clean fluid fuels for cooking with an objective to find ways to make them affordable and create or expand infrastructure for provision of clean fuels and appropriate stoves. [Goldemberg, 2004].

The country has recognized that the availability of energy to rural areas is important in reducing the burden on women, children, health hazards and exploitation of forestry resources. Lack of investment and affordable energy technology are constraints to alleviating this burden. With the aforementioned goal of reducing the reliance on biomass fuel by 10%, the government initiatives are in place for a transformation to alternatives such as ethanol.

2.2. Overview of traditional and modern cooking fuels

2.2.1. Traditional fuels

In Tanzania, as with most developing countries, firewood is a predominant energy source, as are other traditional fuels such as cow dung, and agricultural residues. These are usually free, multiple-purpose fuels, providing many services such as heating and lighting, hence their appeal. In terms of energy for cooking, over three quarters of the population on average relies on wood, with an even larger reliance in rural regions and less so in urban regions.

Charcoal is the fuel of choice in the urban household, and used to a lesser extent in rural areas. It is a favoured fuel with its high energy density and its ease of transport, use and storage. It is often the production process of charcoal that substantially reduces the efficiency of it as a fuel. However cooking with charcoal presents a higher efficiency (15-35%) than wood. Although the price varies from season to season and is location dependent (it is more expensive in the urban areas than rural), it presents the benefit of being available, with a low entry cost.

Both charcoal and firewood are highly gendered fuels, with the labour and responsibility primarily given to the females in the house. As it is usually used in enclosed spaces, it presents health hazards from exposure to smoke and particulates, contributing to respiratory illnesses. Greater awareness of efficient charcoal stoves, a result of workshops and demonstrations, is affecting an increase in the use of the improved stoves, especially in large cities like Dar es Salaam.

2.2.2. Kerosene

Kerosene is a liquid fuel distilled from petroleum. When burned, it produces soot and other particulates, and together with fire hazard risks, it is not an ideal cooking fuel. However, it is quite often used in developing countries where it is burned in wick stoves or fairly efficient pressurized stoves. While mainly used for lighting, kerosene has a market as a cooking fuel, especially in the urban regions of Tanzania, mainly due to its availability and relatively low cost. It is imported, and distributed at fuelling stations around the country.

2.2.3. LPG

LPG is considered a clean cooking fuel and on the ‘energy ladder’, is a more sophisticated energy carrier. Via government interventions, Senegal adopted LPG as a cooking fuel, increasing demand substantially. On the other hand, Tanzania has had little intervention in the adaptation of this fuel. Half of the LPG produced at the local refinery (TIPER) is flared, as it has no established market (Hosier et al, 1993). For many households, the up front costs of using LPG (cylinder purchase) as well as the high operating cost due to taxes and lack of subsidies, the inconsistency and/or unavailability of supply have prevented its demand from growing.

2.2.4. Electricity

Although an efficient and clean source of energy, electricity has difficulties in penetrating the cooking market in developing countries. There are many reasons for this, one of which is the grid or lack of it. Tanzania is no different, with less than 10% of the population having access to electricity, and in urban areas, this rises to only 32% [TNBS, 2002].

In Tanzania up to the 1990's, electricity was subsidized though a lifeline tariff, encouraging private consumers to use it for cooking, to the detriment of rural households without service. In the last decade, the government has switched to commercial pricing based on marginal cost [Ghanadan, 2004]. The transaction costs of using electricity for cooking are substantially higher than using other fuels, largely due to the connection fee and appliance cost. As a result, electricity is now less often used for cooking, even by the urban population with a high enough income to be able to afford the initial fee and have existing or readily available access to the grid.

2.2.5. Biogas

Biogas is gas derived from the fermentation of organic wastes. It is obtained by creating an environment for this to occur in an anaerobic digester, where organic residues, such as household, animal and human waste are decomposed to release methane and carbon dioxide. The scale of the digester is usually built for several households and animal waste is an important input.

There are benefits to a biogas plant built at the local community level. The fuel for the digester requires labour as the only input. The output is more or less constant and a clean burning fuel is obtained.

There are also limitations to this option. Since the output is more or less constant, this is not suitable for end-users who vary their output. This might be the case for multiple fuel users. The fact that labour is the only input to the digester operation might also be a disadvantage as the private cost (labour to operate digester) is higher than the private benefit (free cooking fuel), reducing likelihood of adaptation and maintenance required for the digester. Furthermore, the fuel cannot be traded or sold in small quantities, and requires bottling equipment should it be sold, increasing the investment cost. This option requires households to have manure available nearby, and this can vary depending on the cultural practices of the community (grazed versus household animals) and the density of the population. Currently, the use of biogas in Tanzania is limited to small scale, isolated cases.

2.2.6. Jatropha

Jatropha is tropical plant producing a fruit that has high oil content. It also has a high resistance to drought and pests, making it an attractive energy crop. Jatropha oil as a fuel for cooking is not suitable without specially adapted stoves.

2.3. Analysis of Supply of Ethanol

Ethanol is an alcohol that has been traditionally made for consumption as a beverage, and produced by fermentation of sugars of various crops. It is gaining importance as a fuel that can be locally produced using suitable feedstock. This makes it a renewable fuel that can help develop economically struggling regions with an agricultural stimulation to grow the crops and sell the feedstock to a processing plant. If community-based plants are used, further benefits are financial gains from sale of the fuel.

The supply of ethanol requires several areas to be studied. They can be divided into crop production, harvesting/delivery, processing and the products and by-products produced (Figure 2.3).

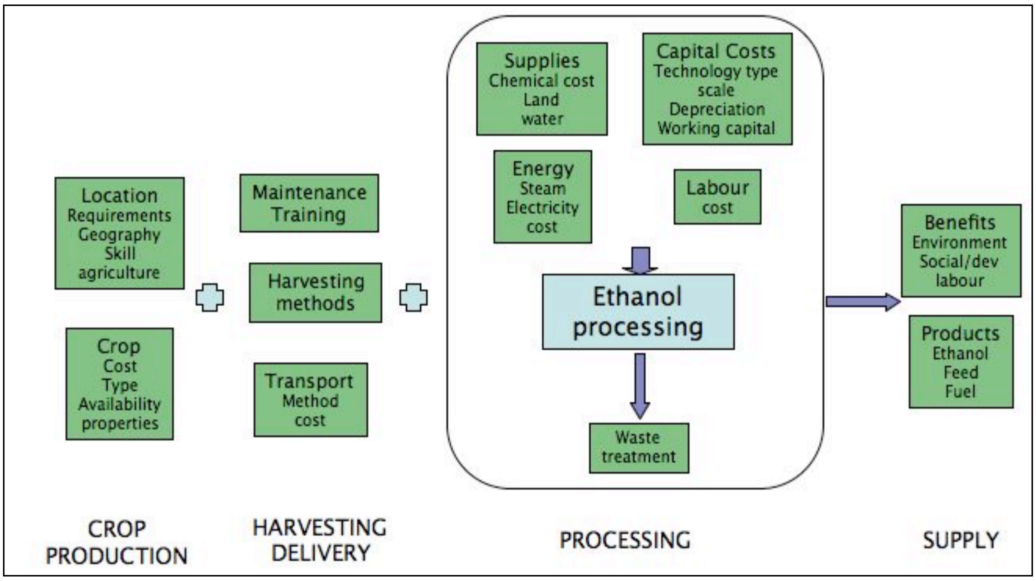


Figure 2.3: Supply Considerations

In crop production, the choice of the feedstock is affected by agricultural requirements for growth, the climate, geography and local practices. In addition, land use, fertilizers and good soil and land management, essential in any successful farming practice, affect productivity. In the harvesting and delivery processes, key parameters are the method of transport available and choice of harvesting technique. Good farming practices are essential to ensure that the feedstock is delivered consistently and farming these energy crops does not deplete the quality and nutrients of the soil. These considerations require extensive knowledge of the region and agro-economics of the feedstock. They are reviewed briefly, however, as details are beyond the scope of this study and must be considered when the site selection is complete for a feasible ethanol plant.

The last two considerations, processing and products of the ethanol supply chain, will be the focus of the supply of ethanol for cooking. Within these two aspects, energy input, labour, capital costs, supplies and waste produced are variables in the process. Maintenance and training are important for the selection and operation of the chosen technology but are secondary to the study. The benefits of the process as well as its products add value to the concept of ethanol production.

2.3.1. Feedstock

As with most ethanol plants, the feedstock represents the major cost input to the process. The criterion used for the selection of the feedstock for this region are: climate, previous experience, crop suitability for ethanol production with proven technology, crop cycles per year, and the importance of not competing with the food supply chain. Potential feed crops amongst the staples grown in Tanzania are: Maize, sorghum, wheat and cassava. For this study, the three crops selected for evaluation are sugarcane, cassava and sweet sorghum.

Sugarcane has a high potential for ethanol and is an established feedstock for the ethanol-producing giant, Brazil. Tanzania also grows sugarcane and the sugar produced is used primarily for local consumption, although not enough to meet local demand; the country had a supply deficit of almost half of its production of 271,000 tonnes in 2004 [GTZ, 2005], necessitating imports. However, there is still opportunity for production of fuel ethanol from sugarcane with expanded farming. Sugarcane molasses currently has a low economic value in Tanzania. Only about 30% of molasses from Tanzania factories is exported, the rest is treated as a waste product. The molasses can be further processed into ethanol fuel.

Cassava, as a starch crop, can be used for food production. However, given suitable land, it can be used as a feedstock for a distillery. Cassava has a high ethanol yield, making it attractive for use. It is also traditionally grown by small farmers using traditional farming methods and is tolerant of poor agricultural conditions. It can be left in the ground for up to 2 years and harvested as needed, but if used for food, it must be used up to a week after harvesting to preserve its food value [CIAT, 2006].

Unlike the grain sorghum grown for consumption, sweet sorghum is primarily used for its sugar-juice potential (brix) and is a crop similar to sugarcane but with a lower sugar-product yield and a higher tolerance to warmer and drier conditions. It can be used for forage, silage and sugar production, and in contrast to sugarcane, is propagated with seed, giving it the potential for mechanized planting. Due to its fast growing cycle, it can be harvested twice a year, compared to one cycle or less for sugarcane (see Table 2.1). Both Europe and USA have experimented with sweet sorghum and favourable productivity and yield rates were obtained. However, it is India that has made the most progress in developing a cultivation and ethanol production process at the International Crop Research Institute in the Semi-Arid Tropics (ICRISAT). Initial findings indicate that its cultivation is cheaper than that of sugarcane, requiring one-fourth the water and a shorter growing season [ICRISAT, 2006].

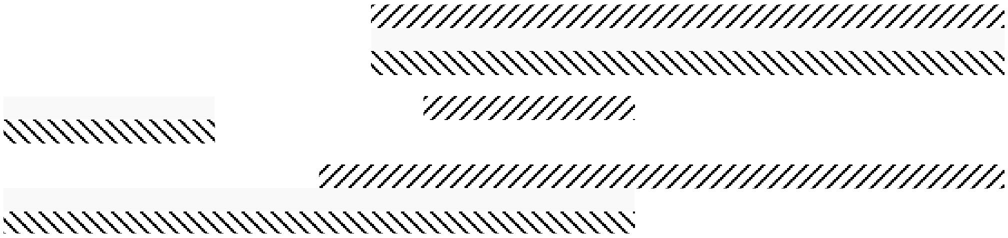
Table 2.1: Agricultural Characteristics of various feedstocks

	Sugarcane [a,c]	Cassava [c]	Sweet sorghum [b]
Seeds/cuttings required	4.500-6000 kg/ha	cuttings	~15 kg/ha
Plantation:		1-1.5 plants/m^2	6-25 plants/m^2
Length of growing cycle	365 days	120-365 days	90-150 days
Productivity: Sugar/starch	22.5 ton/ha/year	5 ton/ha/yr	5-14 ton/ha/year
Bagasse	21 ton/ha/year	--	12-40 ton/ha/year
Forage (leaves)	13.8 ton/ha/year	1.6-9.4 tons/ha/yr	1.9 ton/ha/year

[a] [Woods, 2000]
[b] [Grassi, 2004]
[c] [FAO, 2006]

The growing cycle of each crop determines the production rate of the ethanol facility. The start and length of the processing is dependent on site related factors, such as season (long rains, short rains, dry), species of feedstock, optimum yield in growth cycle of crop and deterioration with time, storage, and other agricultural considerations. An example of how each of the selected crops can be fit into a production cycle is shown in Table 2.2.

Table 2.2: Typical Growth cycles harvest and distillation of feedstock for ethanol



2.3.2. Conversion process

Ethanol (CH_3CH_2OH) is a clear liquid made of a group of compounds whose molecules are bonded to a hydroxyl –OH. From sugars (glucose compounds $C_6H_{12}O_6$) contained in biological feedstock, ethanol is produced as follows:

Equation 1

Ethanol can also be made from petrochemicals such as ethane following the reaction:

$$C_2H_4 + H_2 + \rightarrow CH_3CH_2OH \qquad \text{Equation 2}$$

Combustion of this compound follows the reaction:

$$CH_3CH_2OH + O_2 \rightarrow 2CO_2 + 3H_2O \qquad \text{Equation 3}$$

As the by-products are water and carbon dioxide, which is that absorbed through photosynthesis during the feedstock growth, fuel from bioenergy is considered to be neutral in terms of greenhouse gas emissions.

Ethanol is produced from a combination of physical processing and biological conversion of the feedstock, which involves several steps and is dependent on the type of process or crop selected [see Figure

2.4].

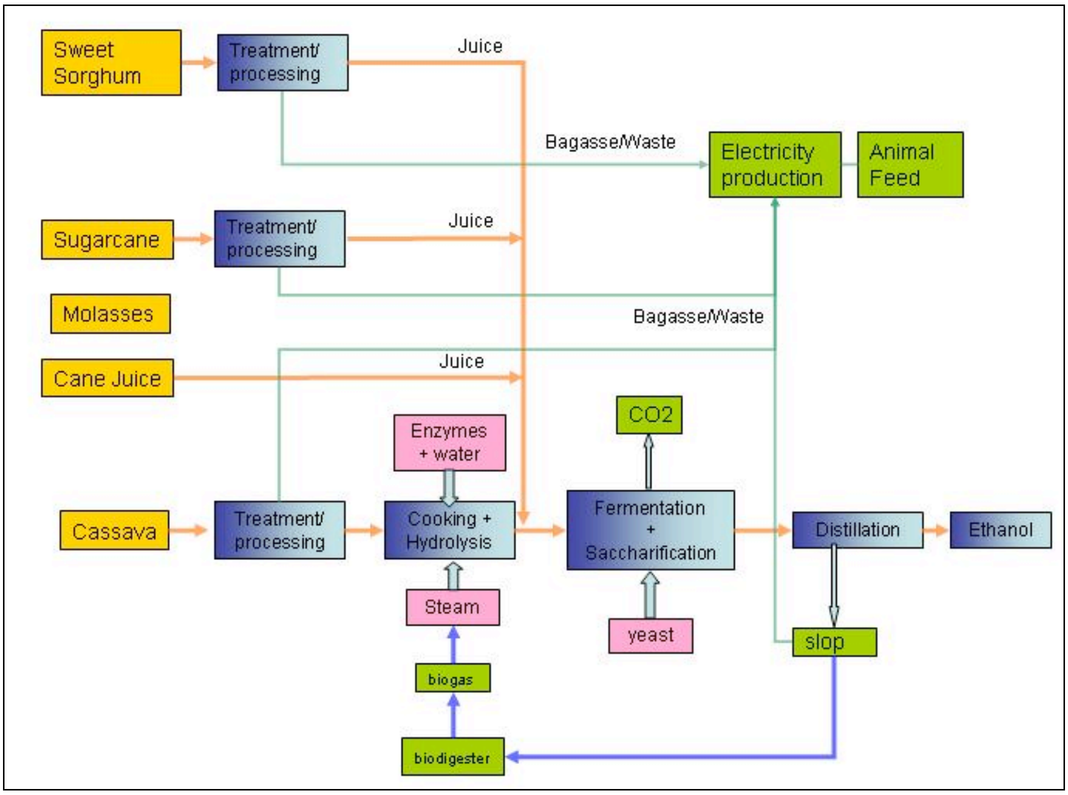


Figure 2.4: Ethanol Conversion Processes for different feedstock

The basic conversion of a sugar crop to ethanol begins with processing the feedstock. In the case of sugarcane and sweet sorghum, this consists of washing, crushing and filtering to separate the bagasse from the sugar. The sugar is sterilized, concentrated and then fermented, using yeast, to produce 8-10% alcohol solution, which is subsequently distilled to concentrate the alcohol to about 95%. Carbon dioxide is a by-product of the fermentation process as previously discussed. If the resultant alcohol is to be used as a fuel, a denaturant is added to the mixture to make it unsuitable for consumption. Dehydration is not necessary beyond 95% unless the derived ethanol is to be blended with gasoline.

Crops containing starch, such as cassava, are processed similarly to the basic sugar-to-ethanol process but require additional steps to convert the starch to sugar. An additional stage is to reduce the size of the tubers, and expose the starch to the enzymes that convert the starch to sugar in a chemical reaction called hydrolysis.

An important by-product of the process is the bagasse or agricultural residue from the initial treatment of sugarcane or sweet sorghum. This can be combusted in a boiler to subsequently be used to produce electricity. The slop resulting from the fermentation and following distillation also has value as animal feed or with further digestion by bacteria, creates biogas which can be then used for power in the process itself.

The capacity and conversion rate of ethanol for each type of feedstock is from operating facilities used as references for this study. For each conversion step, there are technical specifications to be considered in optimizing the process and ensuring that it is an efficient conversion method. The specifics of this optimization are beyond the scope of this study and are more suitably evaluated during technical selection of technology in the planning phase of an ethanol conversion facility.

Currently, most of the world’s ethanol-derived products are from starch or sugar-based crops. There exists an enormous potential to derive ethanol from the cellulose of crops, such as agricultural residues of harvesting corn, wheat, sugarcane bagasse, forestry waste and municipal solid waste. The residues are plentiful in every agricultural sector, and therefore this technology, could provide vast quantities of feedstock for ethanol. Like starches, the conversion requires a hydrolysis step to break down the polymers in these residues using a suitable micro-organism. The breakdown of this structure is complicated and is one of the major barriers to commercialization of this type of conversion process. Until proven technology is economically available, this application in an African context remains a potential, but not a fully realizable option, at present.

2.3.3. Economic scale

2.3.3.1. Methodology

The scale of production distilleries tends to be in the high range of annual production due to greater operating efficiency. Recent experiences in various countries around the world, including India and Thailand have shown that distilleries can be operated both effectively and economically, from mini-distillery (20 million-litres per year) to micro-distilleries (500,000 litres per year).

In order to determine a suitable scale of ethanol production for each type of feedstock, the method utilized is that outlined by Nguyen et al, 1996 for an Australian case study. The method allows the scaling of capital costs, feedstock, operating costs, discounting, labour and transport to find an optimum economic capacity. The method is applicable to analysing distilleries where the feedstock is to be transported from the areas surrounding the facility. With this method, scale dependent quantities are included in the production and transport costs.

The total cost (TC) of the factory operation is represented as:

$$\begin{aligned} TC &= A \times P^{m} + B \times P^{n} + k' \times P \\ &= A \times P^{1.5} + B \times P^{0.7} + k' \times P \end{aligned} \qquad \text{Equation 4}$$

A is the transport cost factor, m is the capacity exponent for transport (found as 1.5), *B* is the production cost factor, n is the capacity exponent for the production costs (generally 0.7), k’ is the constant costs of production (such as overhead) and P is the factory capacity (tons per year). Scaling of capital cost using a similar method has also applied by Murphy et al, 2005.

Other variables in the operation are utilities, chemicals and services, which are functions of the capacity. The production cost includes labour, maintenance and insurance, administration, depreciation, capital charges and working capital, all but the first being a function of capital cost [see Appendix 1].

2.3.3.2. Input for analysis

The study has been adapted to a developing world setting. Cost estimates for the plant setup are obtained from literature of actual distilleries in the developing world context [F.O.Licht, 2004]. A mini-distillery of 10 M-litres/year is selected as the baseline, since costs for this scale of facility are readily available. It is further assumed that the processing of the ethanol in all cases occurs near or at the feedstock plantation. The technology selected for producing ethanol is based on proven plants already in existence and operating worldwide [Appendix 1], except for sweet sorghum, whose development is underway. In the case of the cassava estimate, the manufacturer provides the training for the operating [cassavabiz, 2006].

Sugarcane derived ethanol is produced in numerous locations world-wide, but there are a limited number of distilleries operating at a small-scale. India has initiated the use of ethanol to be blended in gasoline as an octane enhancer thereby stimulating the set up of new distilleries and expansion of existing ones. The cost of producing ethanol from sugarcane and sugarcane molasses, at 30,000 LPD, is estimated at 3.39 M$ [Ethanol India, 2006] and used as the baseline.

Thailand has been producing ethanol from cassava for a number of years. Both fresh cassava and cassava chips are used, given that Thailand is the world's biggest exporter of cassava chips. The chips have lower water content, but higher starch content and higher ethanol output compared to the fresh variety. Although grinding makes chips more costly to process, the higher transportation of fresh roots can offset these costs. Operating costs, for cassava as a feedstock, are obtained from Thailand plants. Capital costs for setting up and operating a micro-distillery on a batch basis and producing 3000 litres per day at 96% alcohol (Cassavabiz, 2006) are scaled for the baseline of the study.

Sweet sorghum as a feedstock for ethanol is still in its infancy. Although it has a high sugar content, it has not been used as a sugar producing crop due to the low purity of the sugar extracted (ratio of the % wt of sucrose to the %wt of the solubles) compared to sugar cane or sugar beet [Gnansounou et al, 2005]. The juice must be extracted and processed immediately after harvesting if used for ethanol production only. If sugar is to be produced as well, the crystallization and centrifugation can be delayed, reducing capital costs for those stages. In this case, where the crop is assumed to be used for ethanol production only, processing would occur in the 3 months of harvesting, while heat and power generation can occur year round. The capital costs associated with such facilities are obtained from a pilot plant also set up in India [ICRISAT, 2007] and scaled to the baseline case.

Crop costs and crop yields are market prices for 2004 [FAO, 2006] except in the case of sweet sorghum, where there is currently no world market price for it. This instead was obtained from literature [Woods, 2000]. It should be noted that these are site-specific data, required for each country being evaluated. For example, for the case of cassava, this value is for the crop cost in Kenya, Tanzania's neighbouring country, as the price for Tanzania was not available. If compared to other markets in Asia, such as Thailand, this price is significantly higher (5 times). However, these are parameters that can be easily modified to the location of interest.

The methodology used directly relates transport to the production capacity such that transportation costs increase with scale due to the larger plantations required and thus increasing transportation costs. The assumed options used for this evaluation are in Appendix 1.

Table 2.3: Input data for feedstock

Crop potential	Crop yield from FAO 2005	Crop cost from FAO*	Ethanol potential	Conversion rate (calc)
	t/ha	USD/t	l/ha	l/t
Cassava	10.40	98.82	1702	163.65
Sweet Sorghum	23.00	14.31	1250	54.35
Sugar Cane (juice)	117.65	23.70	7561	64.27
Sugar Cane C-molasses	117.65	23.70	857	7.28

* Crop cost based on Kenya feedstock

Table 2.3 shows the input assumptions for the feedstock chosen for evaluation. The ethanol potential per ton of crop harvested is the highest for cassava, followed by the sugar crops. Sugar cane molasses, a by-product of sugar processing provides the lowest yield. Cassava has the highest crop cost as it is currently grown in the region for consumption, not for commercial sale.

2.3.4. Economics of supply

With the above input and evaluation of costs of operation of the facility [see Appendix 1 for basis of values], the total manufacturing cost is obtained. The cost per litre of ethanol is determined by dividing the cost by the capacity. This data is calculated using standard spreadsheet models and the relations for the operating and production costs as described above.

For each crop, data similar to that in Table 2.4 is produced, with the baseline of 10 ML/year used for scaling the facility. Table 2.4 shows the production costs for sugarcane as the feedstock for ethanol production. A profit margin of 10% is added to the production costs. Further processing to produce gel fuel, together with production and distribution costs associated with this additional step are estimated as 20% of the manufacturing cost. Although the price per litre is representative of the product of ethanol only, the benefits of any by-product available as a result will improve the profitability of the facility. This includes any sale of utilities generated from the bagasse disposal, animal feedstock and/or carbon dioxide gas produced and sold.

Table 2.4: Ethanol distillery cost (sugarcane) for varying capacity

The cost of the crops is obtained using prices for Kenya, as those for Tanzania were unavailable. Compared to other African countries such as South Africa, they are rather high. This is a conservative approach and the predicted price may well be lower, which would only improve the profit margin.

Table 2.5: Production costs for varying feedstock for baseline capacity (10 ML/year)

Table 2.5 shows the cost for the baseline scale of production (10 million litres per year) for each feedstock. From the analysis, the cost of production using sweet sorghum provides the cheapest cost per litre. The capital cost of a sweet sorghum plant is also the highest, likely due to a reference based on a pilot plant. These are expected to drop as experience and expansion of similar plants occur. The alcohol from sugarcane juice is provided at a slightly higher price, followed by cassava as a feedstock.

Several scales of operation are evaluated for each type of feedstock from mini-distillery to micro-distilleries, with scaling performed as discussed above. The details of various scales of production for each feedstock are available in Appendix 1.

The graphs presented below are for varying scales of operation. This compares the contribution of each major item to the total cost of the product, for each feedstock. The optimum scale occurs at a capacity with the ratio: $\frac{\text{Transport cost}}{\text{Processing cost}} = 0.6$ [Nguyen et al, 1996].

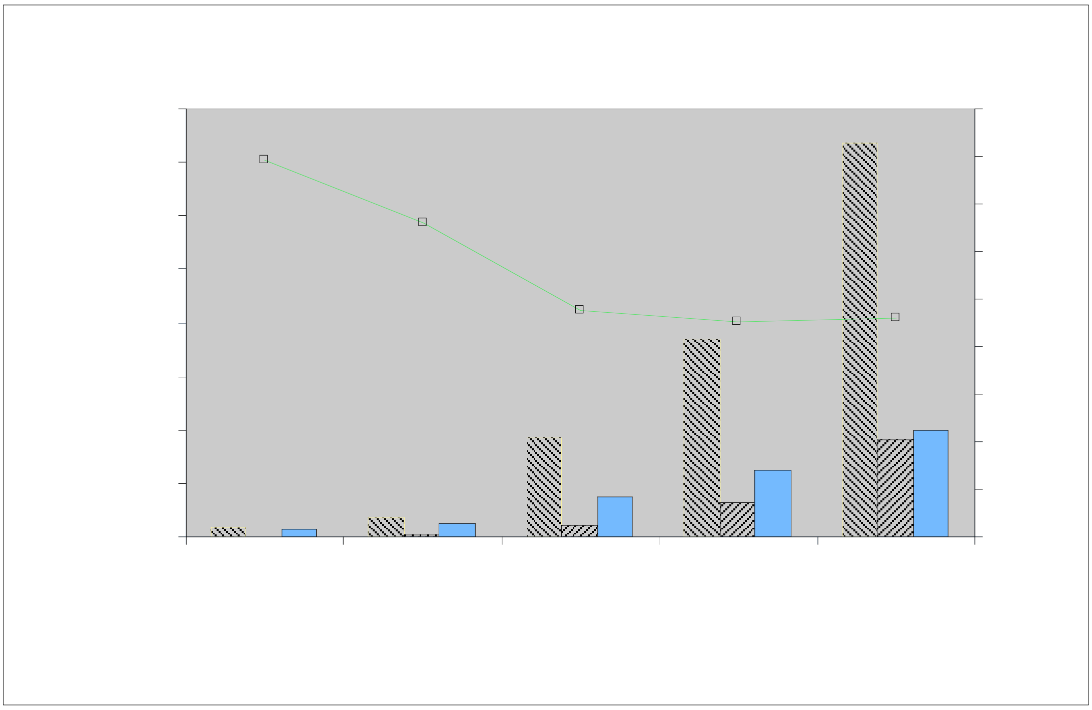


Figure 2.5: Cost of scale of production with Sugarcane

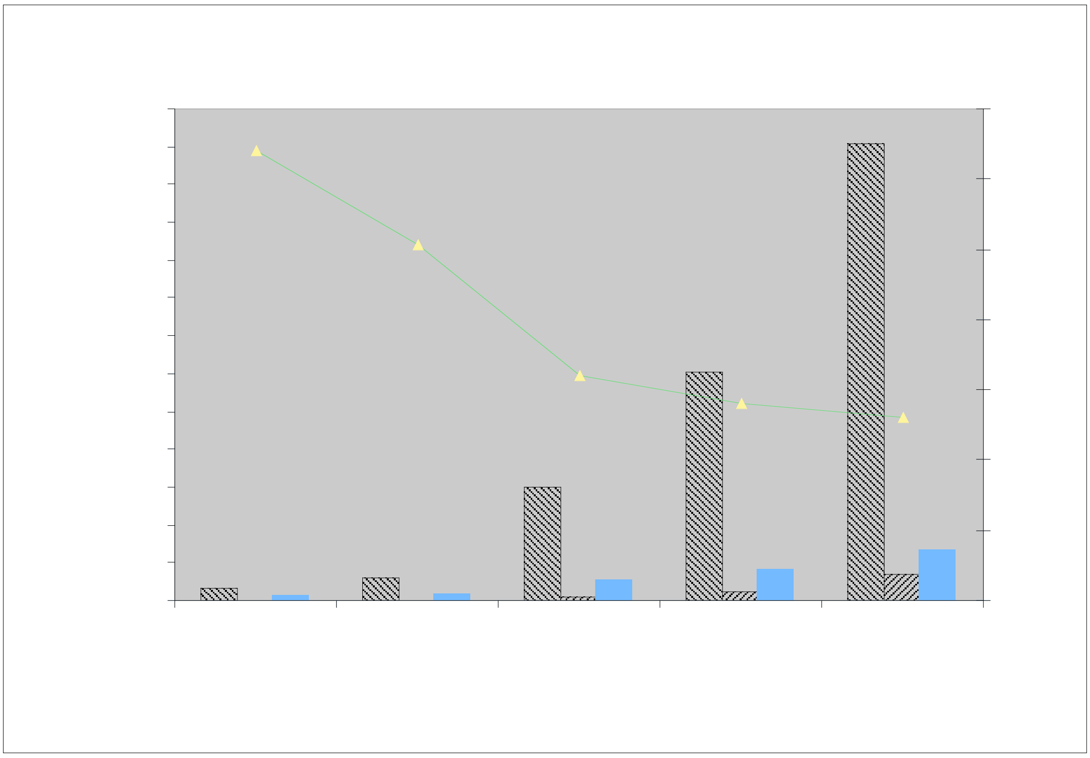


Figure 2.6: Cost of scale of production with Cassava

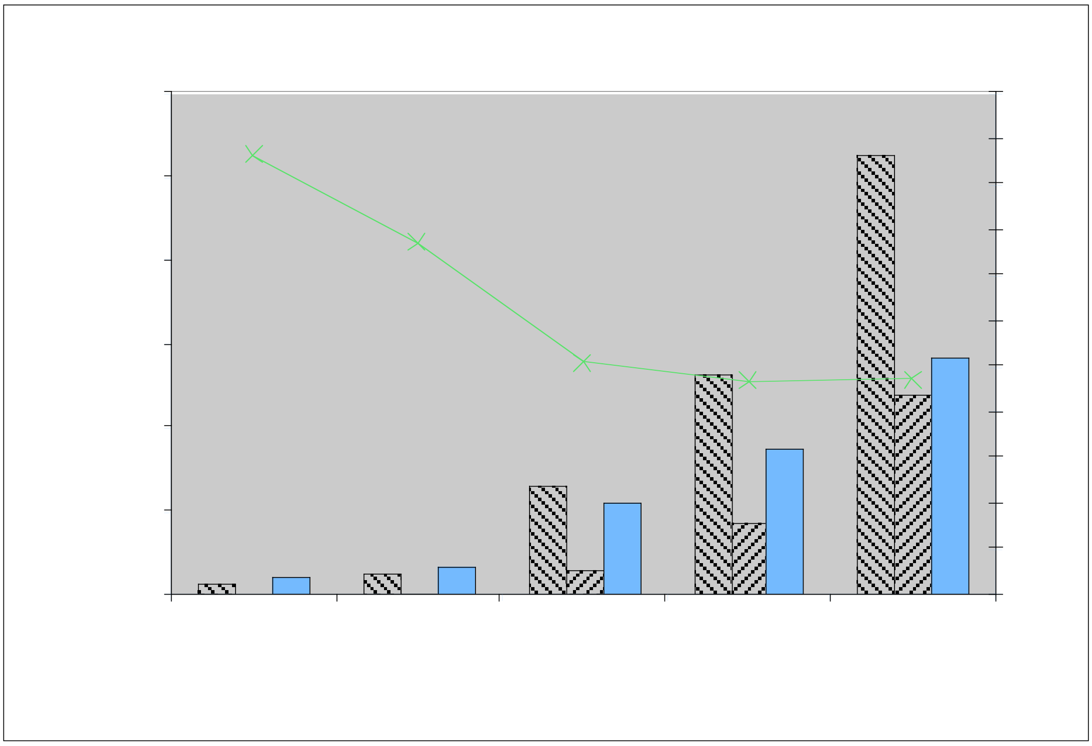


Figure 2.7: Cost of scale of production with Sweet Sorghum

These models provide a snapshot of the production of ethanol given the current market prices for feedstock and existing technology. It is expected that based on previous experiences of renewable energy technology, costs of hardware, installation, operational and learning to setup up and use of technology will decline as market sizes increase [Ahmed, 1994]. This will present a more favourable production price in the future.

Feedstock is the highest contributor to the cost of production, varying from as low as 44% for sweet sorghum to 79% for cassava [see Appendix 1]. Crop transportation to the facility is the second most significant parameter, contributing 3-15% of total production costs, followed by capital charges and utility costs.

The cost estimates for production of ethanol worldwide are lower, and range from 0.12-0.60 USD/l [F.O.Licht, 2004]. Feedstock costs play a significant role in these costs. In countries with low cost estimates, such as Brazil, sugarcane derived ethanol is produced with local industry and manufacturing infrastructure support and an experienced farming techniques. For this reason, as well as the immense scale of operation, Brazil affords the low capital and production costs in avoiding expenditure outside of the country.

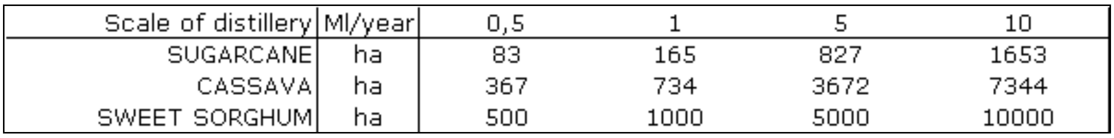
Small-scale of production provides benefits in terms of the reduced transportation costs, thus enhancing the case for micro-distilleries, since it varies with capacity to the power of 1.5 [Nguyen et al, 1996]. Feedstock costs have the biggest impact, regardless of the scale. Whereas little can be done to reduce the transport factor, feedstock costs can be decreased with improved agricultural economics, such as harvesting techniques, improved crop yields, farming practices, etc. As feedstock volumes are proportional to ethanol capacity and crop costs are proportional to volume, variation in feedstock prices is linearly related to both capacity and cost per litre of ethanol. Therefore, any change in feedstock cost will proportionally affect the price of the ethanol produced by its proportion in the cost estimate.

2.3.5. Land required

The productivity of the crop as described in Table 2.3 is determined by farming practices and the agro-ecological conditions and the land must be capable of supporting sufficiently high crop yields for economic production. Assessment of production of the land requires site-specific evaluation in the area of interest.

A recent study of the availability of land capable of producing crops but unused for agriculture is estimated at 55Mha [GTZ, 2005]. This is significant compared to that required by a micro-distillery as seen in Table 2.6. The growth of the market would require additional areas set aside for agriculture. On the level of micro-distilleries, the area to be set aside is trivial compared to the available potential for energy crop production.

Table 2.6: Plantation required for varying scale of distillery



Scale of distillery	Ml/year	0,5	1	5	10
SUGARCANE	ha	83	165	827	1653
CASSAVA	ha	367	734	3672	7344
SWEET SORGHUM	ha	500	1000	5000	10000

[based on 80% land use]

2.3.6. Energy Balance

The energy balance for the production of ethanol is the ratio of the energy output (ethanol, electricity and by-product value) to the energy input (water, machinery, fertilizers, labour, chemicals, fuel). These vary because of the different crops and related factors to their productivity and the treatment of the by-products and the inclusion of different externalities in the assessment. Studies for sugarcane and cassava are available from present agricultural production schemes; however sweet sorghum, as it has not been commercially established, must be estimated from similar crops or trials. The energy balance input to output ratio could have wide ranges. The values also differ depending variables such as the type of methodology used, the growth-cycle of crops, mechanized versus labour input, co-product credit and crop productivity.

A useful comparison is to apply the same methodology to all crops, thus determining the difference between the crops, rather than the absolute value for the energy balance. One such study (Table 2.7) compared the three chosen crops (sugarcane, sweet sorghum and cassava) in a Brazilian environment [Da Silva et Al, 1978]. Agricultural data is not available for sweet sorghum, thus the study uses energy consumption from ethanol processed with similar agriculture practices to sweet sorghum. For sugarcane and sweet sorghum, energy produced from the combustion of bagasse is used in the input. Assumptions of fertilizer, labour, harvesting method and machinery used are similar to those in an African context, however the sugarcane energy balance is optimistic compared to more recent studies.

Table 2.7: Energy balance for alcohol production

Sugarcane	Cassava	Sweet sorghu	Corn	Country of reference, [Source]
	1.55		1.34	China/USA [Du Dai et al, 2006]
21.3	1.8	6.9		Brazil, [Da Silva, 1978]
1.9				Zimbabwe [Rosenschein 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	4.5	USA, [Worley et al, 1991]
			1.34	USA, [Shapori et al, 2004]

The studies in Table 2.7 indicate that there are a variety of methods to address an energy balance for ethanol, the consequences of which are results that vary by country and study. However, each approach indicates a positive energy balance for ethanol, such that more energy is produced than consumed. With improvements to the processing and use of bagasse, by-products, recycling of nutrients, farming methods and so on, the ratio could be enhanced.

2.3.7. Products

Ethanol can be used in stoves adapted for its use. There is a risk that the alcohol produced for use as a fuel will be consumed as an alcohol beverage. Furthermore, if consumed accidentally in the home by children, become a poisonous substance. However, the process of denaturing makes ethanol unpalatable. It can be further processed to add a thickening agent, water and colouring to create a combustible ethanol gel that is safe, non-toxic, non-spill and potable. This gel has been successfully tried as a cooking fuel with private sector plants in various southern African countries [Utria, 2004]. There is an additional cost of processing the ethanol to a gel fuel, and is included as an additional factor in the manufacturing price.

2.3.8. By-products

The cost-effectiveness of ethanol can be improved through the co-products obtained during various production processes. Each feedstock provides similar output: crop residue, CO_2 and the residues from the fermentation and distillation columns. On a micro-distillery scale, CO_2 may not be generated in sufficient quantities to justify the capital cost of processing it into marketable products.

Use of the crop residue is beneficial to the operation expenses of the plant. It can be pelletised and subsequently used for co-generation, by combustion in boilers, creating steam for process use or electricity generation as previously mentioned. This is a common practice now in the distilleries in Brazil, which may be located in regions far from the grid. The plant demand for electricity is supplied by on-site treatment of the residues themselves. The crop residue can also be used for animal feed, particularly with the selection of sweet sorghum as a feedstock due to the high nutritional value of the sillage.

In the case of corn and other grains, other uses of the distillation and fermentation by-products (slop) are, by dehydration, producing DDG (Dried Distiller Grain), which is of value as an animal feedstock [Zhang et al, 2003]. Additional treatment of the remainder of the slop can provide valuable manure for use as a fertilizer, which can help farmers enhance the production of the feedstock.

The credits obtained from the sale of the co-products will help to offset the production costs of ethanol, however, their value is neither studied in detail in this analysis, nor applied to the production costs. Presented in Figure 2.8, Figure 2.9 and Figure 2.10 are production balances for the three different crops studied. It represents the ideal case of all by-products providing value to the overall production process. Some of this processing requires investment that needs to be included in a study of such benefits.

Cassava and sorghum also provide the additional benefit that they can be diverted for food, feed or forage. This can be useful in the case of surplus production or to reduce the dependency on imports.

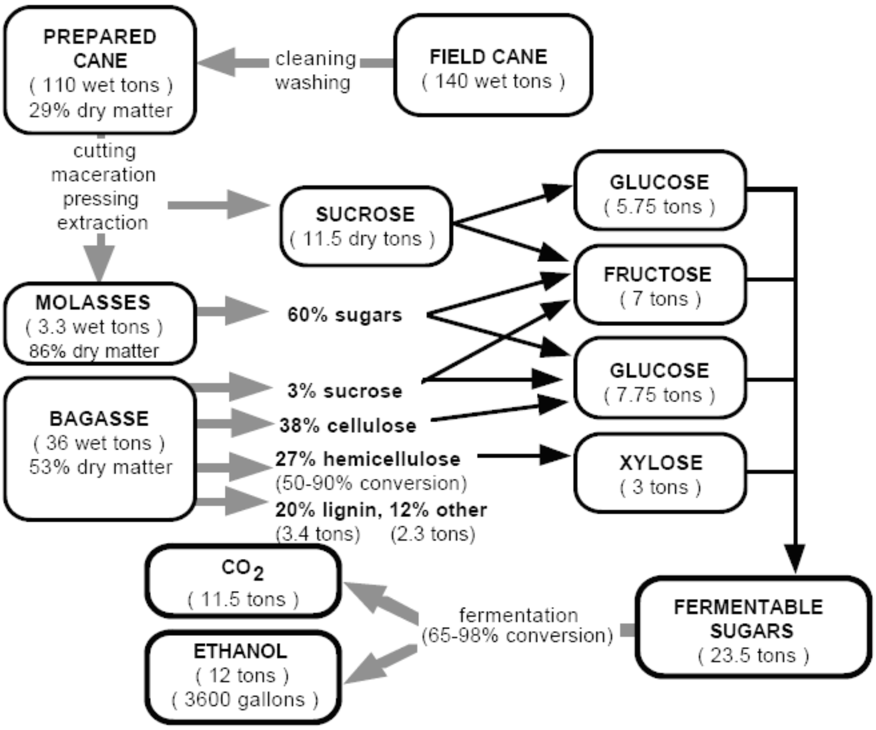


Figure 2.8: Production balance of sugarcane derived ethanol from 1 acre of harvested cane
[Source: Shleser, 1994]

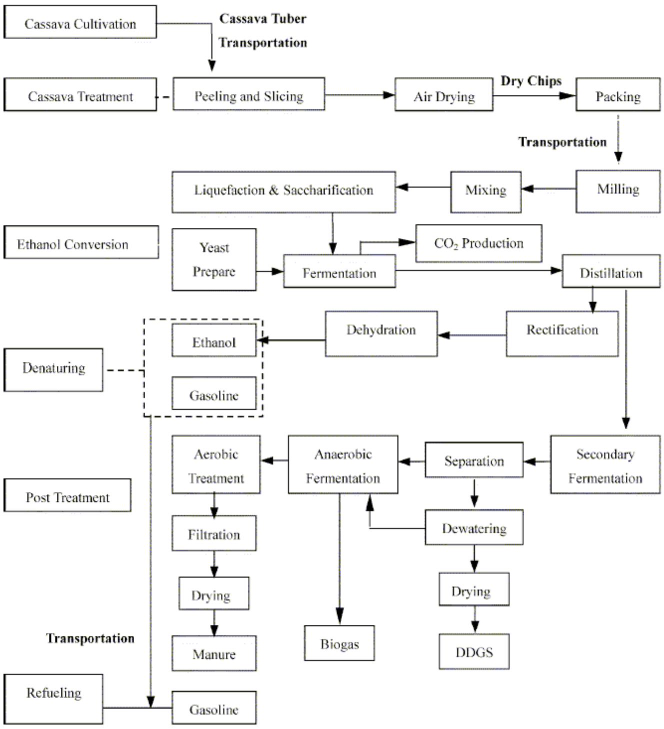


Figure 2.9: Production balance of cassava derived ethanol

[Source: Zhang et al, 2003]

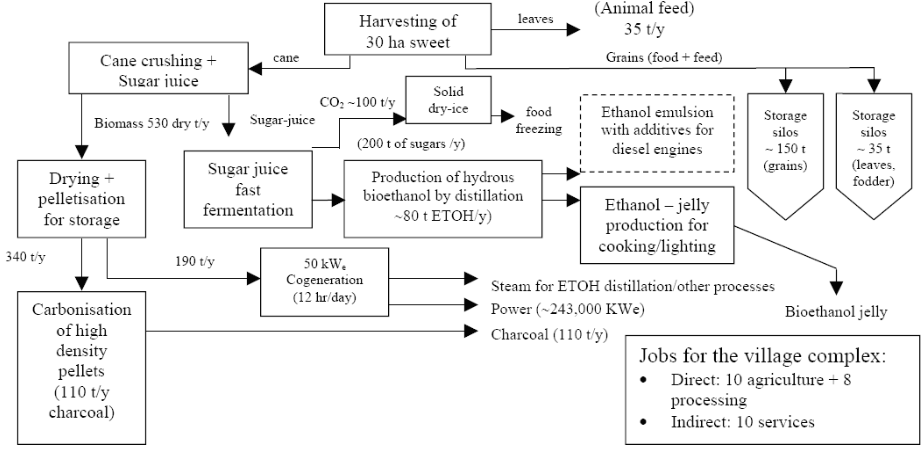


Figure 2.10: Production balance of sweet sorghum derived ethanol

[Source: Grassi et al, 2003]

2.3.9. The case for sugarcane C-molasses

Molasses is a by-product of crystal sugar processing. It still contains sugars that can be fermented to produce ethanol, and is economical if the distillery is located close to the sugar factory. In this case, the sugarcane feedstock becomes the input for the main product of sugar, while ethanol is a by-product of the residues. Thus the costs of processing have to be treated differently and the volume of ethanol that can be produced depends on the quantity of sugar produced.

With this in mind, the analysis of ethanol produced from sugarcane C-molasses is based on a facility whose scale is determined by a the primary product of sugar, i.e. a production complex for which sugar is the principal product while ethanol is made from the molasses by-product.

Table 2.8 shows the cost represented by this analysis with the plant size set by the sugarcane to be processed. The baseline costs are those for 10 million litres of ethanol a year (the last column). Details of the cost values are in Appendix 1.

Clearly the low ethanol price is affected by the absence of feedstock costs, making this an attractive option. The scale of the distillery operation is much smaller as the ethanol contained in molasses is far below that of sugarcane or other feedstock (see Table 2.3).

Table 2.8: Ethanol from as secondary product made from C-molasses

2.4. Analysis of Demand for fuels

In examining the choice of fuels and related appliances, there are many factors involved. Appliance selection is briefly addressed in this section. Fuel selection is addressed in greater detail, exploring the energy demand for cooking, outlining methodology to quantify the demand, data collection efforts and finally a discussion of the model predictions for the uptake of ethanol.

2.4.1. Stoves

For each type of fuel, there are many stoves available for use, each with different designs and costs. Some have improvements in the design to enhance efficiency and reduce fuel consumption. There have been many programs in developing countries to develop and disseminate improved cooking stoves for this reason.

Determining the fuel consumption of stoves is highly dependent on several factors such as; the type of stove used, the type of meal being prepared, the ingredients, cooking time and the user habits. Several international standards comparing stoves have been created [Visser, 2005]. There are many losses in the operation of a stove, such as efficiency of the combustion process, equipment conversion, transfer of heat from stove to the pot and from the pot to the food. The uncertainties of measurements make it difficult to accurately determine the fuel consumption in preparing a meal. Tests of preparing a meal in actual environment conditions are less ambiguous but require actual field studies in the area of interest, which was not feasible for this study.

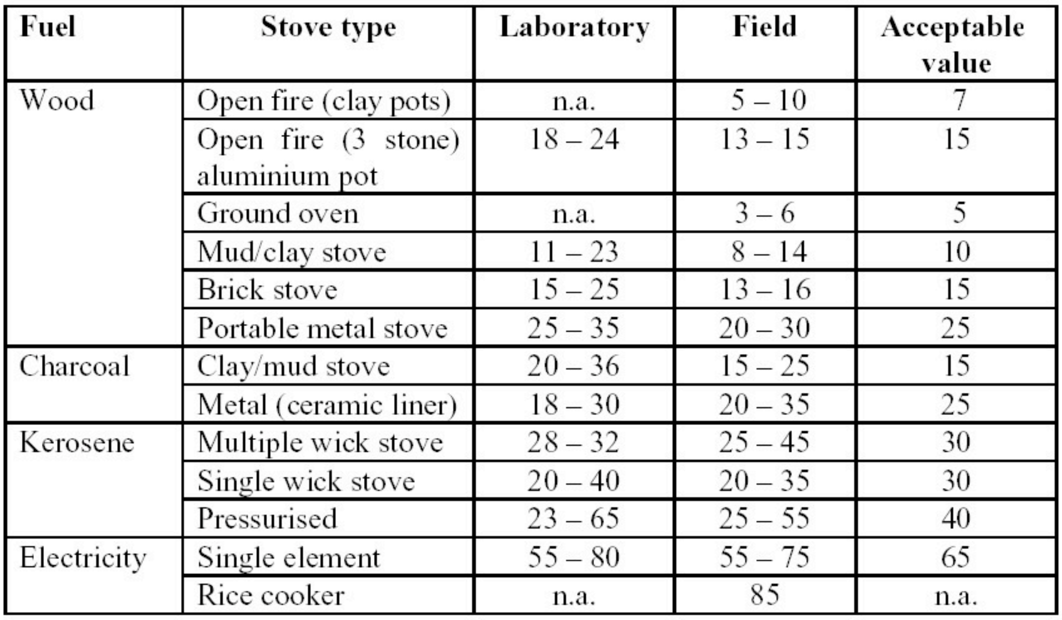
Ethanol gel has been subject to several field studies and tests of performance and acceptance by such organizations at Project Gaia in Ethiopia and regional programs in Africa [Bioenergy lists, 2006]. Field trials have been conducted and improvement to the stoves suggested. A simple ethanol fuelled stove tested is shown in Figure 2.11.

Figure 2.11: Ethanol gel stove

[Source, Mhazo, 2001]

The studies determined the fuel properties of the stove and the user's perception of its use. They demonstrate that gel fuel is a viable option as a replacement for paraffin among household users as well as caterers. It is at least as efficient, burns cleanly, and, as it is in a gel form, there is less risk of spillage. Improvements to reduce the production cost and yet still make a reliable and long lasting stove are recognized as some of the challenges still faced. The gel fuel, in the above case study, was produced in Zimbabwe by Greenheat Manufacturing (Pvt./Ltd) at a cost of US$ 0.67 per litre [Mhazo, 2001].

Table 2.9: Average cooking efficiency for various stoves and fuels (%)



Fuel	Stove type	Laboratory	Field	Acceptable value
Wood	Open fire (clay pots)	n.a.	5 – 10	7
	Open fire (3 stone) aluminium pot	18 – 24	13 – 15	15
	Ground oven	n.a.	3 – 6	5
	Mud/clay stove	11 – 23	8 – 14	10
	Brick stove	15 – 25	13 – 16	15
	Portable metal stove	25 – 35	20 – 30	25
Charcoal	Clay/mud stove	20 – 36	15 – 25	15
	Metal (ceramic liner)	18 – 30	20 – 35	25
Kerosene	Multiple wick stove	28 – 32	25 – 45	30
	Single wick stove	20 – 40	20 – 35	30
	Pressurised	23 – 65	25 – 55	40
Electricity	Single element	55 – 80	55 – 75	65
	Rice cooker	n.a.	85	n.a.

[Source: WEC, 1999]

The efficiency of stoves has an indirect influence on consumer behaviour in selecting a fuel. Improving efficiencies would increase consumer choice of ethanol. Although improvements are always a benefit, in this study focussing on fuels, the efficiency is taken to be a fixed value based on literature studies (Table 2.9).

2.4.2. Factors in selection of fuel

There are several issues that impact the energy patterns of consumption and the potential and restrictions to fuel switching, and their relationship can be complex. They include population density, rural and urban differences, income levels, proximity to energy resources, and other social and behavioural patterns. Understanding of the important factors is essential for a thorough analysis of demand of cooking fuels.

Multiple studies have been undertaken with extensive data sets to enable a better understanding of the importance of these variables. Households can have more than one option for fuel, so that fuel switching is never complete [Masera et al, 2000].

The traditional and simplified energy ladder describes a simple linear model suggesting that household decisions are based on families abandoning technologies that are inefficient, less costly and polluting as they move up in socio-economic status [Hosier et al, 1987 and Leach, 1992]. Implicit in the studies is the perceived status of improved appliances, but also the greater fuel efficiency and less pollution with the substitute. However, other research has also shown that modern fuels, when used, are not used alone. Rather, they are a partial substitute for traditional fuels [Masera et al, 2000]. Multiple fuel use, sometimes referred to as ‘fuel stacking’, appears to be a more representative picture of the current household patterns [Elias et al, 2005].

2.4.3. Analytical Methods

Partial equilibrium economics is an approach to study consumer demand and the cost of supplying the fuels. This theory focuses on only one sector or set of variables and assumes that other variables do not exert influence, i.e. the sector or set of variables does not interact with other aspects of industry/economy, or its effects are too small to have an impact. It measures utility using surplus of the consumer and producer actions. It is a relevant method to examine markets that are close to being perfectly competitive.

A statistical method in econometric analysis that is commonly used to study consumer behaviour is linear regression analysis. This type of analysis is used to model relationships between two variables. By determining the magnitude of the relationship between variables, the effect of one variable on another can be correlated. Multiple regression analysis introduces additional variables independently to assess each of their impacts on the variable of interest. Finally, the relationships must be verified with real data to determine the statistical confidence.

Models created using this type of analysis can be used to ascertain certain relationships amongst household cooking fuel choices, evaluating factors such as fuel price, education, income, gender of household head, household size, on the probability of choosing a particular fuel [Heltberg, 2005, Rao et al, 2006, Ouedraogo, 2005, Farsi, 2005]. Each of these models uses datasets collected for the particular location of interest. Using regression analysis, the relationship between consumer preferences for the fuel and the dependent variables is investigated. As a result, certain variables are found to be more predominant. They differ, depending on the region of study and the variables associated with each geographic and social pattern. However, there are common threads within these studies. For example, if only LPG is considered; economics (household expenditure and fuel price) and education of the household head are the main factors influencing the selection of modern cooking fuels (common influences found amongst each of the regions studied).

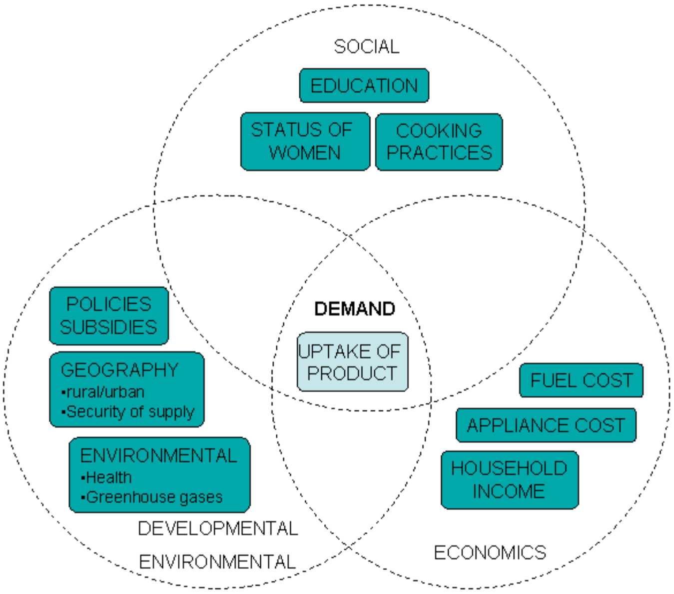


Figure 2.12: Demand Considerations for cooking fuels

Figure 2.12 shows important factors that must be accounted for in reviewing the demand for clean cooking fuels. In order to determine the intersection of the price of the supply side with the demand, the main focus of this study will be the economics of household fuel selection. The other considerations will be reviewed qualitatively.

2.5. Discrete Choice Analysis

2.5.1. Regression methodology

In simple linear regression, the relationship between two variables is evaluated by fitting a linear equation through the data:

$$U = \alpha + \beta x + \varepsilon \qquad \text{Equation 5}$$

Here, U is the dependent variable that is a function of the independent variable, x, and ε (error estimator), using parameters α (constant or intercept of line) and β (coefficient or slope of line). This method of fitting an equation to the data can provide a characterisation of the linear relationship between the dependent variable, U and the independent variable, x (observed). By minimizing the residuals (the distance between the observed value and the predicted value), the best fit to the data is obtained. A method commonly used to determine the best fit, as it is computationally simple to derive, is known as the least squares regression, where the sum of the squares of the residuals is minimized.

Multiple regression analysis includes the addition of more variables so that each of their effects on the dependent variable is evaluated. For n variables, instead of a 2-D scatter plot, the analysis is of a plane in n-space such that the sum of the square of errors is minimized. Logistic regression analysis uses a trial equation that is iteratively solved to determine the best fit. In this case however, the response variable is an indicator, rather than a quantitative variable as in linear or multiple regression analysis. The logistic equation predicts the log odds of the probability that an observation will occur to the probability that it will fail to occur. For this analysis, a discrete set of choices is used instead of a continuous set.

As discussed, there are many variables that influence the consumer choice of cooking fuel. In logit analysis, the analyst has to determine which variables should be considered [Bierlaire, 1997]. Knowledge of the data and the application are key factors in selecting the important variables. A multinomial logit model (MLM) is a model with more than one alternative.

As it is difficult to estimate a model that will successfully predict the individual alternatives, the concept of utility is used. Thus, the probability that a consumer will select an alternative becomes a choice based on maximising utility [Ben-Akiva et al, 1985]. This type of analysis is used in mathematical psychology and biometric applications. This is the least squares procedure as applied to choice models, defined by Berkson and applied in Ben-Akiva et al.

The probability (P) that a consumer will choose alternative i of a choice set j, given a linear utility function U with variables x, y and ε, of the form:

$$\log it(P\left(\frac{U=1}{U=0}\right)) = \beta_1 x_i + \beta_2 y_i + \varepsilon_i \qquad \text{Equation 6}$$

is:

$$P_i = \frac{e^{(U_i)}}{\sum_j e^{(U_j)}} \qquad \text{Equation 7}$$

Here, j is the set of all alternatives, β_1 and β_2 are coefficients to be solved for and ε is the error term. Logit probabilities always take the form of the exponential divided by the sum of the exponentials and is commonly used to assess choice, given certain measurable variables in consumer behaviour [Ben-Akiva et al, 1985, Train, 1993, Bierlaire, 1997].

A set of discrete choices, that is, finite alternatives that can be explicitly listed (ex. all types of cooking fuels), is used to determine a discrete choice model. A reduced choice set (ex. clean cooking fuels) is a subset of the universal discrete choices considered by an individual (ex. household). Each alternative is then characterized by an attribute (ex. operating cost, purchase price).

Considering the economics of the choice of cooking fuels, where the purchase price (pp) and operating cost (oc) and other factors (z) are the variables of the utility function for the j^{th} discrete fuel choice selection, the assumed logit utility function using the above equations can be written as:

$$U_j = \beta_1 pp_j + \beta_2 oc_j + \beta_3 z_j \qquad \text{Equation 8}$$

The form of the equation is:

$$\Pr ob\_of\_ownership_{pp,oc} = P_i = \frac{\exp(U_{pp,oc})}{\sum \exp(U_{pp',oc'})} \qquad \text{Equation 9}$$

The above function assumes certain behaviour: all probabilities sum to one, a graph of P_i vs U_i forms the logit curve and the probability is a non-linear function of the data. With this ownership model, there are four conditions that would result in a user choosing to buy an appliance: new household, replacement or upgrading, new user, and pre-failure replacement.

These parameters are determined from sample data at the household level. The model parameters are estimated using regression techniques and can be transformed using Berkson's method (described by Ben-Akiva et al, 1985) to:

$$— \qquad \text{Equation 10}$$

Here S_i is the share of option i, and option j is the one to which the other alternatives will be normalized. The parameters β_1 and β_2 are solved for using regression techniques described above, using the known shares S_i of each existing alternative (found in survey results). The probability of ownership is then obtained using Equation 9 for the solved logit utility parameters and known operating and purchase costs of the fuel.

Ideally, household-level (disaggregate) data is most suitable for obtaining the parameters. Use of aggregate data is possible, but has its limitations, the most significant being the loss of precision of the estimated variables from the model. Averaged, aggregate data can be used for the market share of each of the cooking fuels.

The dataset required should include market share, purchase price and operating costs, where:

$$\frac{(\qquad)(\qquad)}{\qquad}(\qquad) \qquad \text{Equation 11}$$

The annual operating cost can be determined in a number of ways, and use of measured fuel consumption is an alternative to the calculation above.

The discount rate is found using the following relationship:

$$\frac{\beta_1}{\beta_2}=\frac{r}{\left[1-\left(1+r\right)^{-T}\right]} \qquad \text{Equation 12}$$

Here r is the discount rate and T is the expected lifetime. For an infinite lifetime, the discount ratio is the ratio of the cost coefficients, β_1 and β_2. For the case of simplifying this analysis and understanding the trends of consumer behaviour, it is assumed that the lifetime is infinite. This can be justified for the case of the consumer with a limited income who would perceive the economics based purely on purchase and operating cost. It also assumes a certain quality of appliance so that frequent breakdown of the appliance in the future would not affect market share. Typically, in evaluation of projects, a discount rate is assumed as that offered by banking institutions. However, the rate is known to vary across countries and sectors. This method does not assume a discount rate, but rather obtains it from the economics of the situation. The discount rate in this analysis is an interpretation of the logit parameters, and is not a parameter that can be used for other engineering-economic studies such as life-cycle cost models.

This method is most useful under the following conditions for groups with non-zero shares [Ben-Akiva et al, 1985]:

- The available sample is extremely large
- The data are only available in aggregated form
- The model structure uses only a small number of categorized variables, reducing the number of cells
- The respondents to the survey are observed making a large number of repeated decisions, allowing choices to be grouped.

Using standard spreadsheet techniques available in Excel, the data above is used as input for the model described. Regression analysis is run on the data to determine the coefficients of the utility function, β_1 and β_2. These results are subsequently used in the utility function of the form in Equation 10.

An ethanol cook stove as a discrete choice is now included with the above coefficients. The calculation of the probability of ownership is repeated, and hence the market share of each fuel, including the hypothetical choice of ethanol, is determined. The cost of ethanol is the price determined in the supply analysis of this study. By using samples of actual consumer choice, this model can be used as a forecasting tool for the introduction of a new alternative.

2.5.2. Economics of Demand

2.5.2.1. Input data challenges

In order to determine the demand for various cooking fuels, data is required from the selected region as input into the methodology above. The household data is preferably household-level responses to questions of fuel choice, operating costs and appliance cost for each of the households and fuel used. In developing countries, especially those in Africa, the household budget surveys collect this type of data, the quality of which is increasing with the year of completion of the survey. Although there have been studies carried out with this framework, such as those available at World Bank-Living Standard Measurement Survey (LSMS) and individual country census and statistical data departments, actually obtaining the data for use in this context has been a major hurdle.

A household budget survey conducted in Tanzania in 2002, for example, provides the aggregate data for the main cooking fuels used but did not provide the household expenditure on the fuel used specifically for cooking (i.e. specifically excluding lighting and heating). A similar survey conducted is outlined in the Malawi Integrated Household survey, 2004 and provides questionnaires for the individual main source of cooking fuel, and general expenditure for charcoal, paraffin and wood. Manipulation and assumptions are necessary for the datasets to determine the expenditure for cooking alone (as kerosene, for example can be used for both lighting and cooking, charcoal for both heating and cooking, etc). A local LSMS survey (2004) conducted in the region of Kagera, Tanzania provided similar findings and similar obstacles. The challenge of obtaining a relevant data set applied not only to Tanzania, but also to other countries in the region that were investigated as potential case studies.

A significant amount of time was spent in seeking appropriate surveys and studying findings for suitable data. Obtaining the data in a form that is appropriate and applicable was difficult. Interpretation of relevant datasets and then applying appropriate methodology to ensure the suitability of the data is another challenge. One way of realizing this data is through field work, by actually going to conduct an on-site survey itself or visiting the site to obtain the already gathered relevant information in person. These are time consuming efforts and given the time frame and scope, is not the focus of this thesis. A decision was made instead that aggregate data be used since survey summaries are more readily available in this form. The conditions for using aggregate data in this form are met for this method as described in the previous section.

The prices for fuels in the region and the operating cost also presented challenges since the data was not available in a single document. As a result, various combinations of sources are used for the appropriate fuel prices, while the operating costs are calculated from the prices and the efficiencies of the stoves presented later in Table 2.11. This is an approach that has been used for choice of heating/cooling equipment and appliances, and the application is described in Hwang et al, 1994.

This are issues that will hopefully be resolved with the increasing practice of both public and private organizations placing the background of their surveys on the Internet, along with access possibilities for the datasets.

2.5.2.2. Datasets

The 2002 Tanzania population and housing census lists the distribution of private households by main source of energy for cooking (Table 2.10). It does not differentiate between households that use more than one fuel for cooking.

Table 2.10: Market share of cooking fuel [TNBS, 2002]

	Urban Tanzania	Rural Tanzania	Total Tanzania
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1.6	0.1	0.6
[illegible]	[illegible]	[illegible]	[illegible]

As mentioned, the aggregate data provides the market share for each of the cooking fuels, however obtaining the operating cost requires a different set of data. Typically the estimates for monthly cooking costs are calculated, based on the fuel price, an assumption of stove efficiency and number of meals cooked per day. There are a limited number of publications of actual fuel consumption used in preparing a meal. The actual energy consumption varies from region to region, with type of stove used, with the quality of the fuel used and the social practices, such as use of wood or charcoal for multiple purposes of heating, cooking, lighting, or food preparation techniques. It also differs if multiple fuels are used in a given household.

In order to study the relative costs of cooking, a snapshot is required. A common method used is to estimate the energy delivered to the stove during cooking, a function of the energy of the fuel and the efficiency of the stove, as described in 2.4.1 above. This will be applied in this study of energy consumption per household.

A recent study of the energy access in Tanzania was used as a reference for the equipment price and fuel price for several options, as in Table 2.11. The lifetime cost is not factored into the operating cost of the appliance, as this would negate the discount rate obtained, as discussed above. Instead, the operating cost is solely a function of energy used in a typical household in the preparation of a meal, and is estimated to be 320 MJ/month [Hosier et al, 1993]. The energy use per standard meal preparation is correlated to field tests as described above, for 2 ½ meals per day or 75 meals per month [Vissier, 2003, Utria, 2004].

Table 2.11: Cost of cooking for various fuels

[Source: Ghanadan, 2004, Sanga et al, 2005]
++ Ethanol energy content, with a cost basis of 0.65 $/l

The urban price is given in the reference above for Dar es Salaam, and the rural costs are taken from a study of rural energy options [Bioquest, 1998] that determined the cost of kerosene to be higher in rural regions, by 22%, likely due to the transportation and/or distribution factor. The same assumption is made for the price of LPG. However, for the traditional fuels, the rural areas have the price advantage. The study compared the charcoal prices in rural areas and found them to be about one third of that in the urban areas. The averages of the rural and urban prices are taken in the case of the average Tanzania costs. The data correlates with the range of estimates for Kenya [Bailis, 2004], except for the price for charcoal, which is much lower than the costs in a similar urban city of Nairobi.

For ethanol, the input for the operating cost and efficiency are obtained from Visser, 2005 and Visser, 2003 for cook stove tests with comparisons completed for the combustion of gel fuel and other fuels with respect to boiling water tests, food preparation and field studies. There is some deviation between the energy required using other fuels (of 20-30% per year).

Another consideration is that the discrete choice model presumes choices based on a set of mutually exclusive alternatives. Thus for this case, the consumer is faced with a selection of stoves and the choices for each are available. The consumer is assumed to choose one of them and one only, as a new user, or as a replacement, or upgrade of an existing stove. It is also assumed that there is a 100% replacement for the appliance.

2.5.2.3. Results for Analysis on Demand for Fuels

With the input as above in a spreadsheet regression model, the data is normalized to LPG (equation 10, parameter S_j). LPG has similar characteristics to ethanol, in that it is a modern fuel, provided in discrete quantities and requires a distribution network. Comparison of normalization to other fuels in the study is discussed in 3.2.1. The results are manipulated as per the method described previously the demand for fuel in the urban Tanzania produces the following results (Table 2.12).

Table 2.12: Urban predicted ownership and discount rate for various fuels and appliances

	INPUT			RESULTS		
Urban Tanzania	Market share	PP USD/Item	OC USD/year	Prob of ownership	ownership incl ethanol	Regression results
Fuelwood	27%	1.00	195.67	2.9%	2.8%	B1
Charcoal	54%	3.52	62.75	76.8%	76.2%	-0.016
Kerosene	15%	5.53	116.44	19.4%	19.2%	B2
LPG	0%	90.54	240.71	0.2%	0.2%	-0.025
Electricity	3%	143.77	162.02	0.7%	0.7%	Discount rate
Ethanol		35.00	226.39		0.8%	64%
						R Square
						0.640
Normalized to LPG		Cost basis of ethanol $/l= 0.65				

The results of the regression analysis are reported in the right column. The coefficients for the results are presented in the table as B1 and B2. The R square reports the square of the correlation between the observed and the predicted values. The discount rate is high for the urban market, implying that the purchase cost of the appliance is a driver for selection of use of a particular fuel. Consumers who are unaware of the operating costs of a particular selection of fuel and appliance are likely to operate at a high discount rate. This trend is observed in the results for the urban Tanzania case study and rural case studies (see 3.2).

The estimated probability of selection of charcoal is higher than the actual market share, due to the low operating costs associated with this fuel. LPG and electricity predictions are in line with the actual market share. Ethanol operating costs are similar to that of LPG but with a lower purchase price, thus its uptake is higher than the other clean fuels.

Similar analysis can be done for the rural population and Tanzania on average and are discussed more appropriately in the sensitivity studies in 3.2.

2.5.3. Boundaries of the model

Aggregation of data has limitations in that there is a loss of precision in the model and the error can be significant. Furthermore, there is also a forecasting error due to the fact that the market shares used in the input are subject to sampling errors and contribute to the total error.

A verification of the internal consistency of the model is to determine whether the signs of the coefficients are the same. This result is the discount rate of the analysis (the ratios of the coefficients). With negative values for β_1 and β_2, this implies that an increase in capital cost or fuel cost would result in a decrease in the probability of the alternative being chosen.

The R square, also called the coefficient of determination, provides an indication of how closely the assumed linear model describes the variability of the data, but does not evaluate the validity of the model.

Other factors can be added to increase the accuracy of the model, such as the level of income, the availability of fuel, etc. These would result in several other coefficients in the model that can improve the fit of the model to the data. The model in this application is kept simple, and has only the price and operating cost of the fuel. The estimated parameters determine an implied discount rate. Use of the discount rate is an intuitive, simple interpretation of the internal consistency of the model. To accurately determine the consumer behaviour, such as including the income effects and substitution of fuel effects, creates a complicated econometric problem. This model presents a scenario based on the assumptions made and a relative comparison of varying costs and its effect on the market share.

As mentioned previously, the discount rate obtained in the demand analysis is derived from the regression analysis, and is not an assumed value. The discount rate is thus very different from one that might be used on the supply side, such as the interest rate on loans that might be offered by financial institutions.

3. DISCUSSION

3.1. Demand/supply

The model above provides an indication of the probability of choosing ethanol amongst other choices, given the economics of fuel price and appliance cost. With this in mind, the supply of ethanol is integrated to determine what scale of plant and what production price is a best fit to the demand situation.

To determine the proportion of the population served by a particularly sized ethanol production facility, the following relation is used:

$$\%\ \text{population served} = \frac{\text{ethanol produced}\,[\text{l/yr}]}{\#\ \text{hh\_region} \times \text{hh\_annual demand}\,[\text{l/yr}]} \quad \textbf{Equation 13}$$

The annual household demand is assumed to be fixed as predetermined from the amount of ethanol a typical household would use if that were its only fuel and is estimated at 350 l/year [Utria, 2004]. The number of households is determined from the most recent Tanzania statistical report [TNBS, 2002] shown in Table 3.1.

Table 3.1: Tanzania's Regional population distribution

	pop distn by area	area (km^2)	population	hh(people per hh)	# HH's	hh/km^2
urban	22.6%		7,554,838	4.2	1,798,771	28.57
rural	77.4%		25,907,011	4.9	5,287,145	7.14
total	100%	881,289	33,461,849	4.7	7,119,542	8.08

The results are independent of the type of feedstock used (Table 3.2). A small proportion of the population served in the rural areas, but a bigger area is covered, due to higher numbers of people in this region.

Table 3.2: Regional population served with varying scale of ethanol production

[illegible]	0.5	1	5	10
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Adjusting the costs of ethanol as a function of the feedstock and scale, (described in 2.3.3), the various predictions of market share can be obtained using Equation 10. The supply of ethanol at various scales and costs (based on the chosen feedstock) are measured against the population served by the scale of a chosen facility (Figure 3.1).

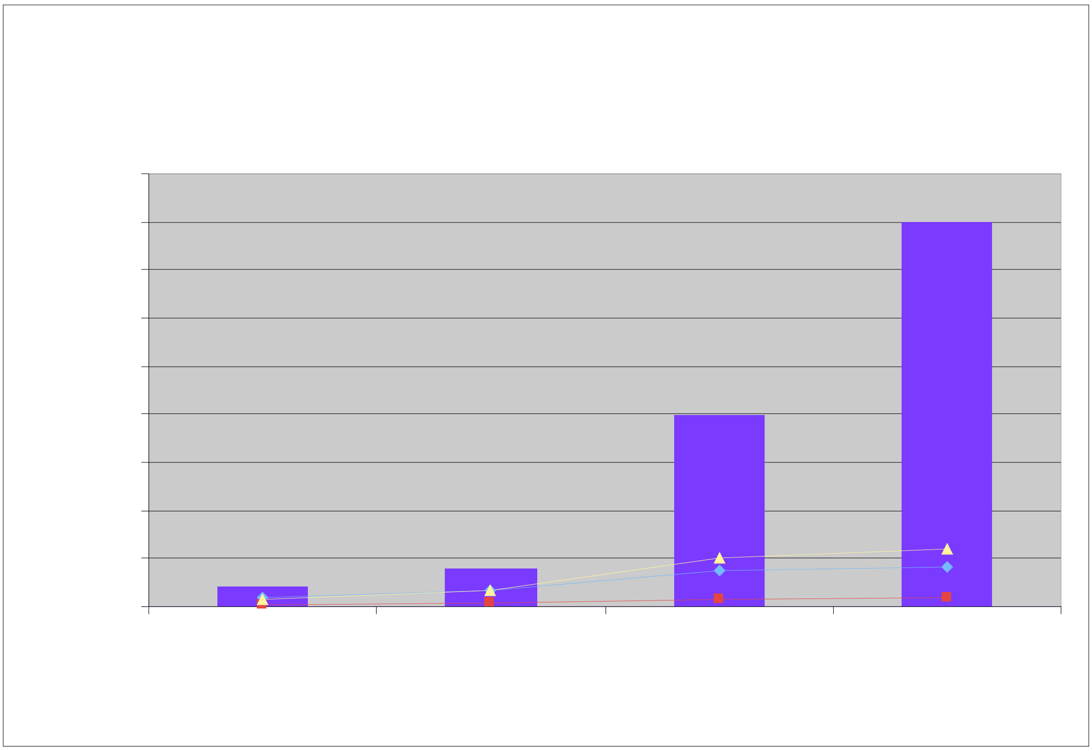


Figure 3.1: Urban Tanzania market share of fuels based on scale and feedstock

For the scale of 500,000 LPD to 10 MLPD, the supply exceeds the demand for all the crop-derived ethanol to varying degrees, with cassava having the lowest demand and the lower cost of sugarcane and sweet sorghum having a higher demand. Sugarcane C-molasses is not shown in this graph, but its low cost creates a demand that far exceeds the supply for all studied scales of operation (Appendix 1).

3.2. Sensitivity Analysis

3.2.1. Normalization of regression study

The results presented above are with shares normalized to LPG, as per Equation 10. However, the data can be normalized to the other fuels in the study. This will result in a different line being fitted through the linear regression analysis, and in different discount rates and R-square values.

Table 3.3: Regression results with varying normalization (Urban Tanzania case)

As noted in Table 3.3, the discount rate changes substantially with the fuel selected for normalization, as does the share of ethanol. Increasing the number of observations will improve the variation in the results. The range in values provides an indication of the extent uncertainty in the regression results.

3.2.2. Rural demand

The rural Tanzania market shares of fuels present quite a different scenario of fuel choice. As shown in Table 3.4, a significant portion of the population uses firewood as the main source of cooking. The regression model shows a distribution based on a more or less split between charcoal and firewood and a very high discount rate. This implies that the population behaviour in this region may operate on the up front cost of the appliance.

Table 3.4: Rural Tanzania Regression results of cooking fuel choice

Firewood is the logical choice as it involves little or no upfront or operating costs. The other fuels might also be unavailable in the rural regions of Tanzania, their absences making them trivial choices. There is no real distribution in choice of cooking fuel, as the overwhelming preference is firewood, it is difficult to draw any conclusions on the probability of other choices.

3.2.3. Effect of subsidies

A measure to favour the consumption of ethanol or any other fuel has commonly been promoted with the use of subsidies. They serve to lower the price of either the fuel or the appliance to improve consumer use via economic methods as has been applied in the case of LPG in Senegal.

To examine the effect of subsidies, one approach is to look at the production volume and determine with the regression results, what would be the price at which the uptake of the fuel would meet the quantity produced.

Table 3.5: Subsidies required to equate the consumption to the supply

Table 3.5 also indicates the price per litre of subsidy required to enhance uptake of ethanol as a cooking fuel based on the discrete choice analysis method used. Sugarcane and sweet sorghum require the least subsidies, compared to cassava. For sugarcane C-molasses, the uptake exceeds the supply, making subsidies unnecessary

3.3. Other factors affecting fuel choice

Economics is one of many factors influencing the decisions of households to adapt type of fuel or stove, which may be important but are not considered in this quantitative model. In the many regression studies completed (Figure 2.12), economics is by far the dominant factor, as determined by income, discount rate, availability of equipment and information on choices. Clearly, economics determines the household's ability to afford modern fuels and can also reflect a level of education and social status, engaging the individual to improve their living standard. Rural and low-income households are therefore more likely to use traditional fuels, especially firewood, as in Table

2.10.

A higher level of income also allows the individual to be able to afford the increased cost of appliances associated with modern fuels (Table 2.11). A recent study indicated that the increasing tariffs in electricity prices reduce the share of households using it as a cooking fuel [Ghanadan, 2004]. A more significant example of this is Senegal as previously indicated. Here extensive subsidies by the government on LPG fuel prices and appliances reduced the level of entry of most households to LPG as a cooking fuel, spreading its exclusive use from the rich, urban households to the poorer households, initially in the urban areas but increasingly to the rural areas. The effect of the subsidized fuel was to increase the demand beyond the domestic refinery capability, creating increasing imports of LPG. Although economics is an important factor, it is one of many in a complex structure affecting the energy transition. Some of the other influences should be considered.

The geography of the population is an important driver to fuel switching, including the rural-urban split and security of supply. The urban-rural distribution has important implications. Often the urban areas have access to the grid, providing the opportunity to use electricity as well as other fuels, which are primarily marketed in urban areas (LPG, Kerosene). Furthermore, urban areas provide employment and attract the wealthy, higher-income earners, with a higher level of education, improving the probability of uptake of clean fuels. In rural settings, the low-income earners are more likely to rely on gathered firewood, which has no opportunity cost for their labour. They are also located closer to agricultural areas with access to gathered firewood, and farm residues, often used as cooking fuels. The firewood market in this context serves the rural poor who rely on it as a buyer or seller. The distance from major supply centres is found to have the effect of increasing the cost of fuels to rural regions [Bioquest, 1998], the result of which these modern fuels are used less often. The production of ethanol in a rural setting can be appropriate, as the transportation and distribution costs for the regional rural market are lower than for the overall market.

In the rural-urban setting, fuel choice is also a reflection of fuel security. Access to modern fuels in important in understanding how and why consumers select fuels. There have been many studies undertaken that have found that consumers are unlikely to select a fuel if its availability is poor. Therefore in Tanzania, uptake LPG has been limited due to the unavailability of the fuel and equipment as well as its unreliability of fuel supply.

Education is also a parameter of choice models, and is evidenced by the higher income earners selecting cleaner, more expensive fuels. Health benefits from clean burning fuels and a reduction in greenhouse gas emissions are benefits already mentioned and implicit in the use of modern energy sources, and those aware of the benefits and able to afford them are more likely to use these fuels. Education and awareness contribute to this.

As traditional fuels have impacts on the livelihoods of women and children in developing countries, who are the most involved in its gathering or preparation, a transition to modern, efficient ethanol provides opportunities and empowerment. This is more likely, however, if women are involved in the decision making of the type of energy used or if the utility is provided at low costs (that is, within their decision making power). The gender-biased domestic activity and decision making are social research issues for trying to establish a market for clean fuels in the absence of economic intervention.

Customs and cooking practices can sometimes affect the household's decision to accept or reject a fuel. This is from the perception that the food tastes different, or that the ease of use of the fuel, handling and lighting are not familiar. Awareness, education and demonstrations can influence these choices.

3.4. Transition

Management of the demand of clean cooking fuels and alternatives is best handled with the urban market in mind, as this is the sector of the population best able to afford the appliances and fuels in Tanzania. Transportation from the rural region where the feedstock is grown and the distillery located to the urban areas has to be considered in the distribution costs. For the short term, the uptake of ethanol in the urban areas will be low, unless a lower cost can be achieved, such as fuel obtained from sugarcane molasses. In the situation using other feedstock, the fuel price appears to be too high for the consumption to match the supply. In this case, subsides can enhance the use of ethanol as a cooking fuel. However, alternative uses for the fuel besides cooking can also be sought, such as industry or transportation.

Rural household cooking patterns include complex social behaviour, such as the status of women, the position of women in the decision makers in terms of fuel/appliance purchase, cultural practices related to fuel used for food preparation, the un-quantifiable cost of time for collection of fuel and finally the income which is the strongest variable for energy (Figure 1.1). Poverty in rural Tanzania limits the population's ability to afford this fuel. Interventions such as subsidised stoves, aid programs and rural development can aid in raising the economic status of the region. This places any clean cooking fuel initiatives in this area in the medium to long-term time scale.

As discussed, energy stacking involves using more than one fuel as the household moves up and down the energy ladder. Displacing traditional fuels completely would then appear to be an inappropriate policy. The study presented here does not seek to displace one fuel or another, but to understand how ethanol can fit into the existing choice. Influencing displacement requires government intervention such as subsidies but cannot rely on economics alone. Policies are required to implement changes in social and economic infrastructure, encouraging both private and public investment. Provision of guaranteed market prices for the local farmers, tax incentives for use of cleaner fuels and higher taxes for fossil based fuels are some methods that can be applied.

3.5. Food Security

There is a debate on the development of biofuels and the resulting deficit created for food available for consumption. The suggestions on one side are that the demand for fuel would tip the market balance in favour of growing and selling crops exclusively for this need, leaving in its wake malnourished people, reduction of forests and natural reserves and land potential for food production [Partners for Africa, 2005]. On the other hand, if properly implemented, small scale production can provide value to the local community, while generating agricultural stimulation as farmers have a market for their product. Brazil has been able to produce enough biofuel for its own consumption without compromising its food market. Growing of the feedstock provides, employment, rural development, and as a low-value crop that can be produced on land that doesn't compete for food. In fact, the available land for agriculture far exceeds that required for a micro-distillery (Table 2.6).

The energy crops selected in this study do not compete with food demands in Tanzania; they are produced on land area that is small compared to what is available. Thus, small-scale production of ethanol mitigates the competition of land for food, and has reduced implications to water availability and hydrology.

3.6. Environmental Issues

Tanzania, as most other countries in Africa, has a diverse bio system. In order to ensure that any bioenergy system implemented is sustainable, protection of this diversity is essential. The criterion for sustainability must include the monitoring of land use, soil management, use of genetically modified organisms and fertilizer, guidelines for irrigation and crop protection, environmental impact assessment of the ethanol plant and its emissions, and the overall greenhouse gas emissions of the system.

3.7. Benefits

There are other benefits to small-scale production. The reduced cost of transport decreases costs for the players involved and local entrepreneurs benefit from the secondary industry created. This generates local employment while reducing the reliance on imports and realizing savings from the foreign exchange. The biofuel production sustains economic growth, by stimulating the agricultural sector and local jobs at the facilities for both the ethanol and stove production. The environmental benefits include reduction of greenhouse gas emissions by use of biofuels, but more importantly have a direct impact on the users of the fuel. The clean burning fuel reduces health problems.

Although not discussed in detail, ethanol in transportation is a gaining interest worldwide and large scale production is required to provide adequate fuel for the immense market. Tanzania has the potential to contribute significantly to this sector [GTZ, 2005]. If the supply of ethanol is constrained on the level of a micro-distillery, it is likely that the ethanol produced would be used for cooking than if produced on a large-scale basis, where it may compete with the energy needs of the transportation sector.

The Clean Development Mechanism (CDM) is a mechanism under the Kyoto Protocol that allows industrialized countries to meet their emission targets for carbon dioxide emissions by investing in clean technology and projects in developing countries. Small scale biofuel production provides this opportunity.

In the near term, small-scale applications are suitable to progress with initial investments and learning curves of the production process. It is less capital intensive and less resource intensive, which is preferable to avoid disruption of the food supply. It also has a lower requirement for infrastructure for water supply systems, transportation, pollution control and electricity.

3.8. Experiences elsewhere

In Africa, there have been some experiences with ethanol gel for cooking fuel. As previously discussed, Greenheat manufacturing was involved with a gel fuel initiative in Zimbabwe and continues be involved in both the gel and appliances in South Africa for both local use and export.

In Ethiopia, Project Gaia has initiated alternatives to household cooking with ethanol fuels from the countries sugar industry [Bioenergy lists, 2006], with the objectives of rural economic and social development, and environmental issues. Pilot studies were conducted using European stoves in rural Ethiopia to assess the issues related to public use and acceptance and commercialisation using small-scale distilleries and possible future local manufacturing of stoves. The study is on going and initial findings have proven positive as interventions are received with enthusiasm in the region.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

The economics of the supply of ethanol from three feedstocks from micro-distilleries have been determined for the case of Tanzania. Feedstock has the biggest impact on the price, so that using the by-product of sugarcane c-molasses for ethanol production provides the most attractive economic option for ethanol, as it has no feedstock costs associated with it.

Discrete choice analysis using linear regression methods of household survey data provides a method of evaluating fuel selection probabilities assuming consumer choice is based on the operating and purchase costs of an appliance. A high discount rate found is indicative of consumer behaviour is driven by primarily the price of the appliance. Due to regional poverty in Tanzania this indicates that the economics is an important driver in fuel selection.

Although economics is an important influence on the uptake of ethanol or any other alternative fuel, it is one of many in a complex structure affecting the consumer behaviour, including poverty, education, gender bias, customs and security of supply. Tanzania's high level of poverty and low development creates challenges for establishment of the alternative of ethanol gel for cooking without subsidies in the fuel price to improve the uptake of the fuel locally.

Experiences in other regions in Africa have shown that small-scale ethanol production may be feasible. With the concern in achieving the millennium development goals on improving health, environment and economic conditions in developing countries, small-scale production of ethanol for cooking fuels can fit into the scheme for medium to long term goals in Tanzania. Successful schemes can be brought forward with government intervention and private investment, both locally and internationally.

4.2. Recommendations for future work

The survey data available for this region was limited, and aggregated national surveys were used as input for the linear regression analysis. It would be useful to repeat the regression analysis with individual household surveys. This would improve the accuracy of the predictions and better reflect household choice.

It would also be valuable to study the relation of fuel and/or equipment choice to social characteristics such as income, education, status, family size, age and sex of household head. This would provide further insight into the consumer fuel/appliance selection process. Another option is to study consumer two or more fuels selected simultaneously, such as ethanol gel and wood, modelling how clean fuels fit in with existing fuels.

Applying this method in the case of a rural setting with a better diversity of fuel and distribution of income would be interesting to see if a more obvious distribution in fuel choice affects the probability of ownership predictions. It would also offer ethanol as a valid choice in a larger market share with other clean cooking and traditional fuels. Examples of such countries would be Botswana, Senegal or South Africa.

Another aspect to study could be the benefits and drawbacks of using mixed crops to extend the processing season and diversify feedstock. In this way, there is more agricultural diversity and security of supply should there be any unpredictable or changes in growing conditions. It also spreads the capital charges of setting up a distillery over a longer period and greater production scales.

Other options for sensitivity studies using regression techniques that may be of interest in future research are: Restrictions on firewood and/or charcoal sales (increased price); including value of by products; and improving stove efficiency.

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APPENDIX 1

Supply of ethanol

Input data

Sugarcane

Cassava

Sweet Sorghum

Sugar Cane C-Molasses

Demand for Ethanol

Demand for Sugarcane C-Molasses

Region served by scale of supply and demand as a result of price of ethanol with C-molasses as a feedstock