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An Exploration of the Potential of Producing Biofuels and the Prospective Influence of Biofuels Production on Poverty Alleviation among Small-Scale Farmers in Tanzania

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ABSTRACT

Tanzania is among the countries which depend entirely on imports for their oil needs. Consequently, the recent increases in world oil prices have led to rapid increases in the country's expenditure on petrol and diesel imports. It is with this concern in mind that, just recently, the Tanzanian government started to think about the possibility of displacing fossil fuels with liquid biofuels. Unfortunately, however, the government has not yet backed its interest on biofuels with detailed economic analyses on the feasibility of producing biofuels in the country. Thus, the present study is an attempt to contribute towards the knowledge base regarding the feasibility of producing ethanol and biodiesel in the country. The general objective of the present study is to explore the potential of producing biofuels and the prospective influence of biofuels production on poverty alleviation among small-scale farmers in Tanzania. To achieve its objective, the present study estimates the costs of producing biofuels from various feedstocks. The estimates of the costs of producing biofuels are then compared with the prevailing petrol and diesel prices to find out whether biofuels produced in the country can compete with the traditional fossil fuels. Furthermore, the present study uses a linear programming model to determine the quantities of various crops which could be produced for use as feedstocks for producing biofuels. The results show that the costs of producing ethanol are 351, 570, 676 and 584 TZS/l for sugarcane, maize, sorghum and cassava respectively. At the same time the threshold ethanol production cost has been estimated to be 597 TZS/l. A quick comparison of the ethanol production cost figures and the threshold production cost shows that ethanol can be produced profitably in the country by using sugarcane, maize and/or cassava as feedstocks. Also the results show that ethanol can be produced competitively by using sugarcane even if world oil prices would fall to as low as US$ 40 a barrel. Moreover, the results show that the costs of producing biodiesel are 601 and 648 TZS/l for palm oil and jatropha respectively. Furthermore, the results show that the country can produce about 4010.10 and 1726.80 million litres of ethanol and biodiesel respectively. The annual demands for petrol and diesel in Tanzania are 375 and 789 million litres respectively. Thus it is clear that the country can produce enough biofuels to meet the local demand (for those fuels). The results also show that the use of sugarcane and jatropha for producing biofuels would increase the net returns for the producers of those crops by 28 and 53% respectively. In addition to increasing net returns for small-scale farmers, the results show that the production of biofuels would create about 1.8 million employment opportunities for the rural poor. Furthermore, the results show that the production of biofuels, by using sugarcane and jatropha as feedstocks, would reduce rural poverty by about 31%. Given the high potential of producing biofuels in Tanzania and their likely impact on poverty alleviation among small-scale farmers, the present study recommends deliberate efforts to attract investments in biofuels production in the country.

ZUSAMMENFASSUNG

Tansania gehört zu den Ländern, die vollständig vom Ölimport abhängig sind. Deshalb haben die jüngsten Anstiege der Weltölpreise in Tansania zu raschen Anstiegen der Geldausgaben für Benzin- und Dieselimporte geführt. Aufgrund dieser Angelegenheit begann die tansanische Regierung kürzlich über die Möglichkeit nachzudenken, fossile Brennstoffe durch flüssige Biobrennstoffe zu ersetzen. Bedauerlicherweise hat die Regierung ihr Interesse an Biobrennstoffen noch nicht durch detaillierte ökonomische Analysen über die Durchführbarkeit der Produktion von Biobrennstoffen im Land unterstrichen. So ist die vorliegende Studie ein Versuch, zur Grundlagenkenntnis hinsichtlich der Durchführbarkeit der Produktion von Äthanol und Biodiesel im Land beizutragen. Das generelle Ziel der vorliegenden Studie ist es, das Potential der Produktion von Biobrennstoffen und den voraussichtlichen Einfluss der Biobrennstoffproduktion auf die Verminderung der Armut unter den Kleinbauern in Tansania zu untersuchen. Um ihr Ziel zu erreichen, schätzt die vorliegende Studie die Produktionskosten von aus verschiedenen Rohstoffen gewonnenen Biobrennstoffen. Die Kostenschätzungen der Produktion von Biobrennstoffen werden anschließend mit den aktuellen Preisen von Benzin und Diesel verglichen, um herauszufinden, ob die im Land produzierten Biobrennstoffe mit den herkömmlichen fossilen Brennstoffen in Wettbewerb treten können. Darüber hinaus benutzt die vorliegende Studie ein lineare Programmierung Modell, um die Mengen verschiedener Feldfrüchte, die als Rohstoffe für die Produktion von Biobrennstoffen erzeugt werden könnten, zu bestimmen. Aus der Untersuchung ergibt sich, dass sich die Kosten der Äthanolproduktion für Zuckerrohr, Mais, Hirse und Maniok jeweils auf 351, 570, 676 und 584 TZS/l belaufen. Gleichzeitig wurde der Einstandspreis für Benzin auf 597 TZS/l geschätzt. Ein kurzer Vergleich der Äthanolproduktionskosten mit dem Benzineinstandspreis zeigt, dass Äthanol durch den Gebrauch von Zuckerrohr, Mais und/oder Maniok als Rohstoffe gewinnbringend im Land produziert werden kann. Außerdem zeigen die Ergebnisse, dass Äthanol wettbewerbsfähig durch den Gebrauch von Zuckerrohr produziert werden kann, sogar wenn die Weltölpreise auf 40 US$/Barrel fielen. Weiterhin wird aus den Ergebnissen ersichtlich, dass sich die Kosten der Produktion von Biodiesel für Palmöl und Jatropha jeweils auf 601 und 648 TZS/l belaufen. Zusätzlich kann man den Ergebnissen entnehmen, dass das Land jeweils ca. 4010,10 und 1726,80 Millionen Liter Äthanol und Biodiesel produzieren kann. Der jährliche Bedarf an Benzin und Diesel entspricht in Tansania jeweils 375 und 789 Millionen Litern. Folglich kann das Land genug Biobrennstoffe produzieren, um den lokalen Bedarf zu decken. Außerdem zeigen die Ergebnisse, dass sich durch den Gebrauch von Zuckerrohr und Jatropha für die Produktion von Biobrennstoffen der Nettogewinn für die Erzeuger der Feldfrüchte um jeweils 28 und 53% steigern ließe. Zusätzlich zu den ansteigenden Nettogewinnen lässt sich aus den Ergebnissen entnehmen, dass die Produktion von Biobrennstoffen ca. 1,8 Millionen neue Beschäftigungsmöglichkeiten für die arme ländliche Bevölkerung erschüfe. Weiterhin wird aus den Ergebnissen ersichtlich, dass die Produktion von Biobrennstoffen durch den Gebrauch von Zuckerrohr und Jatropha als Rohstoffen die Armut der ländlichen Bevölkerung um ca. 31% reduzieren würde. In Anbetracht des hohen Potentials der Produktion von Biobrennstoffen im Land und ihrem wahrscheinlichen Einfluss auf die Verminderung der Armut unter den Kleinbauern empfiehlt die vorliegende Studie bewusste Bemühungen, um Investitionen in die Produktion von Biobrennstoffen im Land attraktiv zu gestalten.

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LIST OF ACRONYMS AND ABBREVIATIONS

A$:	Australian Dollar
€:	Euro
BMZ:	*Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung* [Federal (German) Ministry for Economic Cooperation and Development]
BoT:	Central Bank of the United Republic of Tanzania
CRFA:	Canadian Renewable Fuels Association
CRS:	Constant Returns to Scale
DAAD:	*Deutscher Akademischer Austausch Diesnt* (German Academic Exchange Service)
DDGS:	Distiller's Dried Grains with Solubles
DEA:	Data Envelopment Analysis
DMU:	Decision Making Unit
FAO:	Food and Agriculture Organisation of the United Nations
GTZ:	*Deutsche Gessellschaft für Technische Zusammenarbeit* (The German Agency for Technical Cooperation)
ha:	Hectare
IFPRI:	International Food Policy Research Institute
IPCC:	Intergovernmental Panel on Climate Change
IRA:	University of Dar es Salaam's Institute for Resource Assessment
KAKUTE:	*Kampuni ya Kusambaza Teknolojia* [Technology Dissemination Company]
KSC:	Kilombero Sugar Company Ltd
KSCL:	Kagera Sugar Company Ltd
l:	Litre
LP:	Linear Programming
LRAC:	Long Run Average Cost Curve

M:	Million (10^6)
MoACFS:	Ministry of Agriculture Co-operatives and Food Security (Tanzania)
MSE:	Mtibwa Sugar Estates Ltd
MTBE:	Methyl tertiary-butyl ether
NBS:	National (Tanzania) Bureau of Statistics
NGOs:	Non-Governmental Organisations
OECD:	Organisation for Economic Co-operation and Development
OPEC:	Organisation of the Petroleum Exporting Countries
SFA:	Stochastic Frontier Analysis
SUA:	Sokoine University of Agriculture
T:	Metric Tonne
TaTeDo:	Tanzania Traditional Energy Development and Environment Organisation
TE:	Technical Efficiency
TFP:	Total Factor Productivity
TPC:	Tanganyika Plantation Company Ltd
TPDC:	Tanzania Petroleum Development Corporation
TZS:	Tanzanian Shilling
URT:	United Republic of Tanzania
US$:	American (United States) Dollar
USDA:	United States Department of Agriculture
VAT:	Value Added Tax
VRS:	Variable Returns to Scale

1.0 Introduction

1.1 Background and Motivation of the Study

The use of biofuels has long been promoted as a feasible substitute for conventional fossil petrol and diesel fuels. Historical records indicate that Rudolph Diesel, the inventor of the diesel engine, used vegetable oil in his engine as early as 1900 (Prakash, 1998, Shumaker *et al.,* 2003; CRFA, 2006). The use of biofuels to power engines was not only practised in Europe but also in other parts of the world; for instance, castor oil was used in the first diesel engine in Argentina in 1916 (Shumaker *et al.,* 2003). Interests in biofuels continued in various parts of the world during the second world war, but later on the arrival of peace, and the relative abundance of inexpensive fossil fuels made research into substitutes for conventional petrol and diesel unnecessary. However, the organisation of petroleum exporting countries (OPEC) embargo of the 1970's, the subsequent rise of oil prices[1], and the fear of fuel shortages revived the interest in alternative fuels, including ethanol and biodiesel, for petrol and diesel engines (Prakash, 1998).

Moreover, recent environmental and economic concerns have prompted resurgence in the use of biofuels throughout the world; for instance, the total production of fuel ethanol in the world increased by 9.5% in 2005 (CRFA, 2006; Licht, 2006). Among the most threatening environmental effects of the increasing use of fossil fuels is global warming. According to the report of the Intergovernmental Panel on Climate Change (IPCC)[2], if governments would continue to allow unfettered use of fossil fuels, temperatures are estimated to rise by at least 2.4^{o}C in the next one hundred years. Thus increasing the production and use of biofuels is important for reducing the rate of global warming. Unfortunately, however, in some countries like Tanzania there has been very little effort to produce and use biofuels. Although there is a general interest in the subject of ethanol and biodiesel production in Tanzania, yet there is neither commercial biofuels production nor detailed economic analyses on the feasibility of producing ethanol and biodiesel in the country.

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[1] The world oil prices have increased from around US$ 20 a barrel in 2002 to about US$ 70 a barrel in May, 2007.

[2] This refers to the report on the physical science basis of climate change which was released in Paris on 2nd February 2007.

As pointed out in the previous paragraph, the recent increases in world oil prices have led to increases in the production and use of biofuels in many parts of the world. This is mainly because increases in world oil prices have hit hard the economies of countries which depend on imports for their oil requirements. Tanzania is among the countries which depend entirely on imports for their oil needs. Consequently, the recent increases in world oil prices have led to rapid increases in the country's expenditure on oil imports. For instance, the value of the country's oil imports increased from US$ 400.3 million in 2003 to US$ 1.1 billion in 2005 (BoT, 2006). The expenditure on oil imports in 2005 was almost equal to 50% of the total foreign exchange reserves of the country. Therefore, it is clear that the country is spending a significant proportion of its meagre foreign exchange reserves on oil imports. To address this problem, it is important to look for alternatives to the traditional fossil fuels. The most appealing alternatives are ethanol and biodiesel. The present study, amongst others, is an attempt to determine the feasibility of producing biofuels in Tanzania.

The term biofuels generally refers to fuels derived from biological sources (Von Lampe, 2006). Biofuels come in various forms. They can be in liquid form, such as fuel ethanol and biodiesel, or gaseous form, for example biogas and hydrogen. The present study focuses on liquid biofuels, *i.e.* ethanol and biodiesel. Biofuels can be produced from a variety of feedstocks. The feedstock required for biofuel production depends on the type of biofuel being produced. For instance, ethanol can be produced from starchy and sugar crops. Starchy crops which can be used as feedstocks for producing ethanol include maize, rice, millet, sorghum and cassava, to mention a few. The main sugar crops which are commonly used in the production of ethanol are sugarcane and sugarbeet. On the other hand, the most common feedstocks for producing biodiesel are generally vegetable oils derived from oilseed crops such as oil palm, jatropha, sunflower and rape seed (CRFA, 2006).

The feasibility of biofuels production and use depend on a number of factors specific to the local situation. These factors include: (i) the cost of feedstocks, which varies among countries, depending on land availability and quality, agricultural productivity, and labour costs; (ii) processing costs, which depend on plant size and location; and (iii) the costs of fossil petrol and diesel, which depend on world oil prices. Thus the present study undertook detailed analyses for each of the three determinants of the feasibility of producing biofuels. Regarding the productivity of potential feedstocks for producing ethanol and biodiesel, the present study focuses on sugarcane, maize, cassava, sorghum, jatropha and oil palm. After conducting a general analysis of the feasibility of producing biofuels, sugarcane was selected for a detailed analysis of the viability of producing ethanol in the country. The selection of sugarcane was based on the fact that it had a higher production potential than other crops which were considered to be suitable for use as feedstocks for producing biofuels. Moreover, this crop has been found to be the cheapest feedstock for ethanol production in the country.

As pointed out in the previous paragraph, land availability and labour costs, which determine the availability and costs of feedstocks for producing biofuels, are among the key determinants of the feasibility of producing ethanol and biodiesel. Consequently, countries like Tanzania which have abundant arable land and cheap labour are well placed to produce biofuels at lower costs than developed countries where in most cases land is scarce and labour is relatively more expensive. This means that it would be more economical for developed countries to import biofuels from countries such as Tanzania. The export of biofuels would help to ease the problem of declining world prices for the traditional exports of the country (Tanzania), such as cotton and coffee. Moreover, the production of biofuels would help to reduce the country's expenditure on oil imports.

In addition to easing the country's expenditure on oil imports, the production of biofuels would provide a reliable market for farmers who would be producing crops which would be used as feedstocks for biofuels production. Since unreliable markets[3] is among the main problems facing small-scale farmers in Tanzania, then the reliable markets provided by the introduction of biofuels production would go a long way in improving the incomes of small-scale farmers in the country. The potential contribution of biofuels production to the improvement of the performance of the agriculture sector in the country is significant because improving agriculture productivity is among the key ways for alleviating poverty for agriculture based economies like Tanzania. For instance, in South East Asia, rapid agricultural productivity gains lifted millions of small-scale farmers out of poverty and provided a platform for diversified economic growth.

[3] The term 'unreliable markets' as used here refers to the situation whereby farmers are not assured whether they will find buyers for their crops.

Elsewhere, this has not happened; agriculture has performed badly when it needed to do well. This is particularly true in sub-Saharan Africa where agricultural production declined by 5% between 1980 and 2001, and as a result the absolute number of people going hungry increased by 50% during the same period (Maxwell, 2004). The poor performance of the agriculture sector has led to widespread poverty in Sub-Saharan Africa. Eighty percent of all Africans live on a daily income of less than US$ 2; nearly half struggle to survive on US$ 1 a day or less (IFPRI, 2002)[4].

Despite the projected increases in mortality resulting from infectious diseases, African population growth rates remain among the highest in the world[5]. The situation is not any better in Tanzania. Although the country is trying to invigorate the performance of the agricultural sector so as to alleviate poverty, yet 50% of all Tanzanians are considered to be basically poor and approximately one-third lives in abject poverty (URT, 2006). The majority of the poor are engaged in agriculture which is the mainstay of the country's economy[6].

The deteriorating conditions in Sub-Saharan Africa are thought to be caused by inappropriate social and economic policies, natural disasters, and civil strife. Fortunately, Tanzania has been spared from severe natural disasters and civil strife. Therefore, inappropriate social and economic policies is the most likely reason for the poor performance of the country's agricultural sector. The formulation of appropriate policies requires reliable information on the potential and limitations of the target sector, such as agriculture. Unfortunately, however, the economic difficulties experienced by the country make it difficulty for it to fund demand driven research projects which would have provided the information required by policy makers. Thus the present study, which explores the potential of producing biofuels and the prospective influence of biofuels production on poverty alleviation among small-scale farmers in Tanzania is, amongst others, an attempt to contribute towards the knowledge base regarding the appropriate approach for invigorating the agriculture sector in the country.

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[4] The situation is not any different in Tanzania where almost 36% of the country's population struggle to survive on less than US$ 1 a day.

[5] The population growth rate for Tanzania (2006 estimate) is 1.83%.

[6] The agriculture sector accounts for about half of the national income and provides employment opportunities to about 80% of Tanzanians.

Invigorating the agriculture sector is crucial for alleviating poverty in the country. This is because the performance of the overall Tanzanian economy has been driven by the agriculture sector. The sector employs the majority of the poor, and has strong consumption linkages with other sectors. In 2004, agriculture contributed approximately 51% of foreign exchange, 80% of total employment and 47% of the Gross Domestic Product (GDP) (URT, 2006). Smallholder subsistence farming dominates agricultural production in the country. It is important to note that poverty in Tanzania is predominantly a rural phenomenon. For instance, the average urban household income is estimated to be more than three times that of a similar household in rural areas (URT, 2006). Since poverty is predominantly a rural phenomenon, and agriculture is a major economic activity for the rural population, it follows that success in poverty reduction will largely depend on the performance of the agriculture sector.

According to a study undertaken by the World Bank (2000), the agriculture sector in Tanzania has to grow by at least 11% in order to have a significant contribution to economic growth and hence hasten poverty alleviation in the country. Unfortunately, however, in recent years the agriculture sector has been growing at a rate which is no where near the target required for it to have a significant contribution to the overall economic growth and poverty reduction. The relationship between the trend of growth in the agriculture sector (from 1990 to 2002) and the overall GDP growth is provided in figure 1.1.

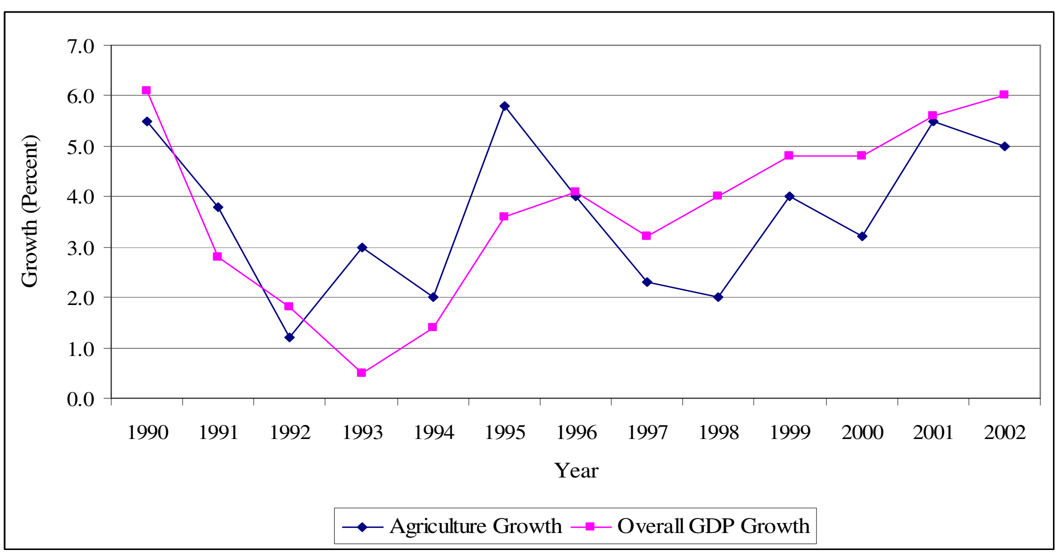

Figure 1.1: Trends of Real GDP and Annual Agriculture Growth in Tanzania

Source: Produced by using data from NBS (2006)

Figure 1.1 shows that there is a very close relationship between the overall GDP growth and the performance of the agriculture sector. This association can be attributed to the large contribution of the agriculture sector to the total GDP. As pointed out in the previous section, the sector accounts for about 47% of the country's GDP. Therefore, it is plausible to argue that efforts to invigorate the Tanzanian economy should, amongst others, focus on the improvement of the performance of the agriculture sector. Thus the findings of the present study, which examines the potential of producing biofuels and the prospective influence of biofuels production on poverty alleviation among small-scale farmers in Tanzania, are likely to have a significant contribution to the country's efforts to formulate appropriate strategies for alleviating poverty.

1.2 Problem Statement and Justification

Tanzania depends exclusively on imports for its oil requirements. Due to the country's dependency on oil imports, the recent increases in world oil prices and local oil demand have led to rapid increases in the country's expenditure on oil imports. For instance, the value of the country's oil imports rose from US$ 400.3 million in 2003 to US$ 1.1 billion in 2005 (BoT, 2006). The expenditure on oil imports in 2005 was almost equal to 50% of the total foreign exchange reserves of the country. Thus it is clear that the country is spending a significant proportion of its meagre foreign exchange reserves on oil imports. Therefore, it could be rightly argued that the high oil prices are a heavy burden for the country's economy. It is with this concern in mind that, just recently, the Tanzanian government started to think about the possibility of displacing petrol and diesel fuels with liquid biofuels (URT, 2006). Unfortunately, the government has not yet backed its interest on ethanol and biodiesel with detailed economic analyses on the feasibility of producing them (biofuels) in the country. Though there are several studies which provide an overview of the country's potential in producing biofuels, there is not any study which has conducted a detailed empirical analysis of the feasibility of producing ethanol and biodiesel in Tanzania. Thus the present study is, amongst others, an attempt to contribute towards the knowledge base regarding the feasibility of producing biofuels in the country.

Ethanol and biodiesel have a good potential as transport fuels because they can be produced from locally grown sugar/starchy and oil crops thereby saving foreign currency for other imports. Moreover, producing ethanol from crops such as sugarcane is likely to have a direct impact on the livelihoods of smallholder sugarcane growers in the country[7]. The country has a large area of land that can be used to grow sugarcane for the production of ethanol[8]. Growing conditions in some parts of the country are very well suited to the production of sugarcane. The average sugarcane yield in the country is significantly higher than the world average[9]. This is likely to put the country in a good position to produce ethanol at low cost[10]. Sugarcane is not the only crop which has a high potential for supplying feedstocks for producing ethanol. Other crops which have been considered in assessing the feasibility of producing ethanol are maize, rice, cassava and sorghum. The present study also tries to determine the viability of producing biodiesel in the country. The assessment of the feasibility of producing biodiesel focuses on the use of jatropha and oil palm as feedstocks. This is because these crops have higher production potential than other crops which could also be used to produce biodiesel.

The need to look for alternatives to fossil fuels does not only arise from their increasing prices but also other factors such as their finiteness and their negative environmental impacts. For instance, the use of fossil fuels produces green house gases which contribute significantly to global warming. According to the IPCC, if the current trend of using fossil fuels continues then temperatures are estimated to rise by at least 2.4^{o}C in the next one hundred years. Proponents of the use of biofuels argue that their use would help to reduce global warming because, amongst others, the feedstocks used to produce them have the capacity to absorb some greenhouse gases such as carbon dioxide. Moreover, their relatively lower amounts of sulphur and aromatic compounds offers promise to reduce particulate and toxic emissions which are common for engines

[7] The use of sugarcane for producing ethanol is likely to increase the incomes of small-scale farmers through the increased net returns for sugarcane that is likely to be associated with the use of the crop as a feedstock for producing ethanol. Moreover, the production of ethanol by using sugarcane as a feedstock would create employment opportunities for the rural poor. Therefore, the production of ethanol would contribute significantly towards the efforts to alleviate poverty in the country.

[8] The area suitable for sugarcane production in Tanzania is estimated to be 0.57 million hectares.

[9] The average sugarcane yield in Tanzania is 99.2 tonnes/ha. This is significantly higher than the world average yield for the crop which is 65.1 tonnes/ha.

[10] Feedstock costs constitute the main cost component in producing ethanol.

running on conventional fossil fuels (CRFA, 2006). In addition to the absorption of carbon dioxide, a study by Shumaker *et al.,* (2003), have reported that the use of biofuels, such as biodiesel, would decrease the emission of carbon dioxide by about 78%. The study also found that the use of biodiesel would reduce the emission of carbon monoxide, by 43.2%; hydrocarbons, by 56.3%, toxic emissions, by about 75%, and particulates, by 55.4%. Thus the burgeoning danger of global warming, caused by the emission of greenhouse gases, such as carbon dioxide, and the lower emissions of such gases (compared to fossil fuels) when using biofuels, is likely to lead to a rapid increase in global biofuels demand. Therefore, Tanzania would benefit significantly from biofuels production because of their high export potential. Their (biofuels) export would help to ease the economic problems caused by the decline of the prices of its traditional exports such as cotton and coffee.

The feasibility of producing biofuels is largely dependent on the availability and costs of feedstocks. Thus the present study also assesses the performance of the producers of crops which can be used for producing biofuels. The assessment of the performance of the producers of potential feedstocks for producing biofuels is not only helpful in determining the availability and costs of feedstocks for ethanol and biodiesel production, but also in providing suggestions on what should be done to improve their productivity. The assessment of the key determinants of farm performance focuses on farm size, amongst others. The decision to focus on the size-performance relationship is based on the lack of absolute truth regarding the existence of economies of scale in agriculture in developing countries. Although, several studies have shown that agricultural productivity decreases with farm size in developing countries, there are quite a few studies which found non-monotonic relationships between productivity and farm size, with productivity decreasing with size up to a certain size, and increasing beyond that point (Kimhi, 2003, Kevane, 1996; Dorward, 1999; Eswaran and Kotwal, 1986; Benjamin, 1995; Carter and Wieber, 1990). Thus, the present study tries, amongst others, to determine the relationship between farm size and farm profitability in the study area. The knowledge of the variations of profitability with farm size, and other key determinants of farm performance would provide an important input towards the process of formulating appropriate agriculture sector improvement strategies and hence hasten the pace of alleviating poverty in the country.

1.3 Study Objectives and Hypotheses

1.3.1 Study Objectives

The general objective of the present study is to explore the potential of producing biofuels and the prospective influence of biofuels production on poverty alleviation among small-scale farmers in Tanzania. Encompassed under this general objective are five specific objectives. These include:

1. To explore the potential of producing biofuels in Tanzania.
2. To determine the potential contribution of biofuels production towards the efforts to pull small-scale farmers out of poverty.
3. To examine the relationship between profitability and farm size among producers of potential feedstocks for biofuels production.
4. To identify the main problems encountered by producers of potential feedstocks for producing biofuels.
5. To determine the efficiency of the producers of potential feedstocks for producing biofuels.

1.3.2 Study Hypotheses

The present study explores the potential of producing biofuels and the prospective influence of biofuels production on poverty alleviation among small-scale farmers in Tanzania. As pointed out in the previous sections, the availability and costs of feedstocks are among the key determinants of the viability of producing biofuels. This is partly because the ability of ethanol and biodiesel to compete with the traditional fossil petrol and diesel fuels, to a large extent, depends on the costs of their respective feedstocks. Thus the present study also assesses the performance of the producers of crops which can be used for producing biofuels. The present study is guided by three main hypotheses.

The first hypothesis is: *"there is a large potential of producing biofuels in Tanzania"*. This hypothesis was divided into two specific hypotheses which could be easily tested. The specific hypotheses, which were tested during the analysis, are:

i) The country has a large potential of producing various crops which could be used as feedstocks for biofuels production.
ii) Biofuels could be produced competitively[11] in Tanzania.

The second hypothesis is: *the production of biofuels would contribute significantly towards the efforts to alleviate poverty among small-scale sugarcane and jatropha farmers in Tanzania.* To be able to test this hypothesis the present study assessed the potential impacts of ethanol and biodiesel production on the profitability of sugarcane and jatropha farming among small-scale producers of those crops.

The third hypothesis is: *"the performance of the producers of potential feedstocks for biofuels production could be improved significantly if the resources at their disposal are used efficiently"*. This hypothesis was subdivided into two specific hypotheses which could be easily tested. These specific hypotheses are:

i) Most producers of crops which can be used as feedstocks for producing biofuels are inefficient.

ii) Farm size has a negative effect on profitability among producers of potential feedstocks for biofuels production.

1.4 Organisation of the Study

The present study has seven chapters. The first chapter provides a general background to the study, where amongst other things; it presents the problem statement, study objectives and hypotheses. The second chapter presents a critical review of literature relevant to the study. The third chapter presents a detailed description of the study area and the data. A detailed description of the methodology employed by the present study is provided in chapter four. The fifth chapter presents results and discussion. Main policy recommendations emanating from the present study are provided in chapter six. The last section of the study contains a list of appendices and the literature cited in this study.

[11] The term "competitive" as used here refers to the ability of the country to produce ethanol and biodiesel at costs which are equal to or lower than the landed costs for fossil petrol and diesel respectively.

2.0 Literature Review and Theoretical Background

2.1 An Overview of Biofuels Production in the World

The term biofuels generally refers to fuels derived from biological sources. If the focus is the transport sector, then biofuels can be defined as "transportation fuels derived from biological sources" (Von Lampe, 2006). Biofuels come in various forms. They can be in liquid form such as fuel ethanol and biodiesel, or gaseous form such as biogas or hydrogen. Biofuels can be produced from a variety of feedstocks. Ethanol can be produced from starchy and sugar crops. Starchy crops which can be used as feedstocks for producing ethanol include: maize, rice, millet, sorghum and cassava, to mention a few. On the other hand, the main sugar crops which are commonly used as feedstocks for producing ethanol are sugarcane and sugarbeet. The most common feedstocks for biodiesel production are generally vegetable oils derived from oilseed crops such as oil palm, jatropha, sunflower and rape seed (CRFA, 2006).

2.1.1 Ethanol Production

2.1.1.1 An Overview of World Ethanol Production

Ethanol is a high-octane fuel which is used primarily as a gasoline additive and extender. The only economically feasible fuel oxygenates currently available are ethanol and methyl tertiary butyl ether (MTBE). MTBE has been used since 1979 to replace lead in gasoline as an octane enhancer. Ethanol is replacing the use of MTBE as a fuel additive due to groundwater contamination that is associated with MTBE use in gasoline (Adam and Schwarz, 2006). Though ethanol's energy content is relatively lower than that of fossil petrol [according to Von Lampe (2006), the amount of energy contained in a litre of ethanol is equal to 66% of that contained in a litre of fossil petrol], yet ethanol can be used to power engines. It can be used on its own or as a blend with conventional petrol fuel. Recent increases in prices of petroleum based fuels and the global warming problem which is associated with the increase in the use of fossil fuels are expanding the demand for ethanol as an energy source. As a result of the unlikely significant decline in world oil prices and the burgeoning threat of global warming that is caused by excessive use of fossil fuels, the demand for ethanol in the world is projected to increase substantially over the next ten to twenty years (Annual Energy Outlook, 2006).

Ethanol can be produced from carbohydrates such as sugar, starch, and cellulose by fermentation using yeast or other organisms. World production of ethanol in 2005 was about 45.424 billion litres (Licht, 2006). Although many countries produce ethanol from a variety of feedstocks, Brazil and the United States are the major producers of ethanol in the world, each accounting for approximately 35 percent of the total global production. In 2005, Brazil produced 15.898 billion litres of ethanol, up from 15.141 billion litres produced in 2004. The major feedstocks for ethanol production in Brazil are sugar and molasses from sugarcane. In addition to Brazil, production of ethanol from sugarcane is currently underway in several other countries including Australia, Columbia, India, Peru, Cuba, Ethiopia, Vietnam, and Zimbabwe (Shapour *et al.*, 2006).

The proportion of sugarcane used as feedstock for ethanol production in Brazil has increased considerably in the last three decades. In 1970, about 80 percent of the Brazilian sugarcane crop was used to produce sugar for food, while only 20 percent was used to produce ethanol. Ethanol production in Brazil started to increase in the late 1970s and early 1980s. For the 2005/06 sugarcane crop year, it was projected that Brazil would use 53 percent of the crop to produce ethanol, the highest proportion since 2000/01 when almost 55 percent was converted into fuel (Licht, 2006). In addition to Brazil and USA, there are several other countries which are producing ethanol. A detailed description of world ethanol production for 2004 and 2005 is provided in table 2.1.

Table 2.1: World Ethanol Production in 2004 and 2005

2004			2005		
Country	M., Litres	Percent	Country	M., Litres	Percent
Brazil	15,100.008	37.00	Brazil	16,000.937	35.80
United States	12,870.401	32.80	United States	14,778.248	33.10
China	3,649.137	9.00	China	3,800.554	8.50
India	1,748.860	4.30	India	1,699.650	3.80
France	829.005	2.00	France	908.499	2.00
Russia	749.512	1.80	Russia	749.512	1.70
South Africa	416.395	1.00	Germany	431.537	1.00
United Kingdom	401.254	1.00	South Africa	389.897	0.90
Saudi Arabia	299.048	0.70	Spain	352.043	0.80
Spain	299.048	0.70	United Kingdom	348.258	0.80
Others	3,895.189	9.60	Others	5,170.873	11.60
Total	40,768.887	100.00	Total	44,630.007	100.00

Source: F. O. Licht (2006)

It can be noted from table 2.1 that the United States produced 14.763 billion litres of ethanol in 2005, up from 12.870 billion litres produced in 2004. Unlike Brazil where sugarcane is the main feedstock for ethanol production, maize-based ethanol accounts for around 97 percent of the total ethanol produced in the United States (Licht, 2005; Shapour *et al*., 2006). Most ethanol in the United States is produced by either a wet milling or dry milling process utilising shelled maize as the principal feedstock. The table shows that Brazil and USA accounted for more than two thirds of the world's total ethanol production in 2004 and 2005. The large amount of ethanol produced in the USA could be attributed to the strong support in form of government incentives such as motor fuel excise tax credits, small ethanol producers tax credits and import duties on fuel ethanol imports (Shapour *et al*., 2006).

2.1.1.2 Review of Feedstocks for Ethanol Production

As pointed out in the previous sections, ethanol can be produced from a wide range of feedstocks. It can be produced from crops which contain starch, such as grains, like maize, sorghum, rice and millet. Furthermore, ethanol can be produced from root crops, such as cassava. Crops containing sugar, for example sugarcane and sugarbeet can also be used as feedstocks for ethanol production. Other feedstocks which can be used for producing ethanol include: food processing by-products, such as molasses and cellulosic materials which include grass and wood, as well as agricultural and forestry residues (Shapour *et al*., 2006).

Potential Sugar Based Feedstocks for Ethanol Production in Tanzania

Sugarcane is among the crops which have a high potential for use as feedstocks for ethanol production in Tanzania[12]. This is because, there is a long history of growing sugarcane as a cash crop in Tanzania, and of even more importance, is the fact that there is a great potential for expanding the production of this crop in the country. Growing conditions in some parts of Tanzania are very well suited for the production of sugarcane, and the average yield for sugarcane in the country is significantly higher than the world average. Sugarcane can be processed into ethanol through either the

[12] Sugarcane is one of the few crops whose production per unit area in Tanzania is higher than the world average. The average sugarcane yield in Tanzania, which is 99.2 tonnes/ha, is higher than the world average yield for the crop which is 65.1 tonnes/ha.

sugarcane-sugar route or through the sugarcane-sugar-molasses route. A description of the production of sugar and molasses from the main sugar factories in Tanzania is provided in table 2.2.

Table 2.2: Sugar and Molasses Production in Tanzania

Company	MSE		KSC		TPC		KSCL		Total	
Year	Molasses	Sugar	Molasses	Sugar	Molasses	Sugar	Molasses	Sugar	Molasses	Sugar
	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2000/1	13,407	31,829	23,091	61,688	16,489	42,018	0	0	52,987	135,535
2001/2	17,283	41,151	24,108	72,499	19,496	49,681	0	0	60,887	163,331
2002/3	15,477	36,850	30,683	98,420	22,682	54,850	0	0	68,842	190,120
2003/4	14,501	34,526	44,210	126,743	27,273	62,519	0	0	85,984	223,788
2004/5	14,734	35,081	42,944	126,516	24,354	52,755	6,883	15,511	88,915	229,863

Source: Tanzania Sugar Board (2005)

Potential Starch Based Feedstocks for Ethanol Production in Tanzania

The production of alcohol by using starch requires the conversion of starch into sugar in addition to the fermentation and distillation processes. The amount of ethanol that can be produced from a given quantity of feedstock varies from one crop to another. For instance, whereas about 275 litres of ethanol can be produced from one metric tonne of maize, a tonne of rice can produce more than 300 litres of ethanol (Shapour *et al.*, 2006). With an estimated productivity of 1.6 metric tonnes per hectare in Tanzania, 440 litres of ethanol can be produced from one hectare of a maize farm (FAO, 2004). Given the current market price[13] for maize, and the fact that maize is a staple food for the majority of Tanzanians, its use for ethanol production is likely to face stiff competition from its food use. The same can be said for millet, sorghum and wheat. This leaves sugarcane as the only realistic feedstock for ethanol production in Tanzania for the foreseeable future[14]. A comparative presentation of Tanzania's and world average yields for various sugar and starchy crops is provided in figure 2.1.

[13] The average price for maize in the local market (2003-2005) was TZS 225/kg. This means that the cost of maize that can be used to produce 440 litres of ethanol is TZS 360000; within the same period the average gasoline price was TZS 1100/litre.

[14] This is by considering the prevailing production structure, the productivities of the crops considered and the returns from their major uses.

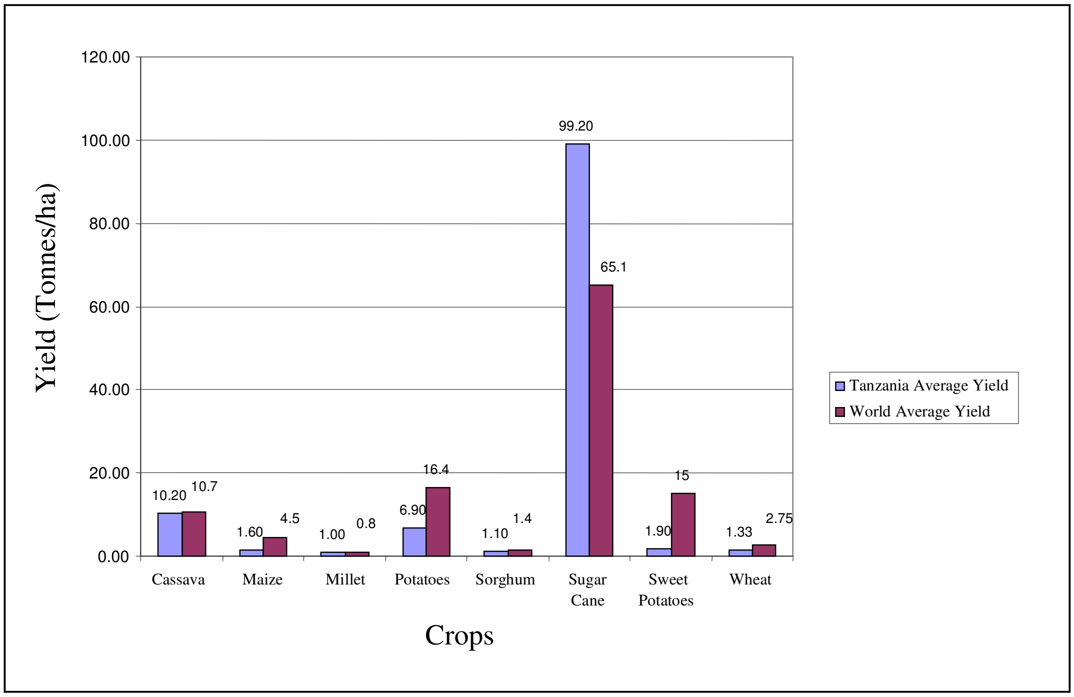

Figure 2.1: Tanzania and World Yields for Sugar and Starchy Crops

Source: FAO (2004)

There are several factors which determine the amount of biofuel that can be produced from a given area under production for a particular feedstock. Among the main determinants are the productivity of the crop and the amount of biofuel that can be produced from a given amount of the feedstock. Figure 2.2 provides estimates of quantities of ethanol that can be produced from one hectare of each of the crops which have been considered as potential feedstocks for ethanol production in Tanzania. The figure shows that sugarcane and cassava have the highest estimates of ethanol production per hectare. It is important to note that the estimates have not included the amount of ethanol that can be produced from lignocellulosic parts of the crops. A review of the quantities of residues from various crops which can be used as lignocellulosic feedstocks for ethanol production, and the corresponding quantities of ethanol that can be produced from those residues is provided in the next section.

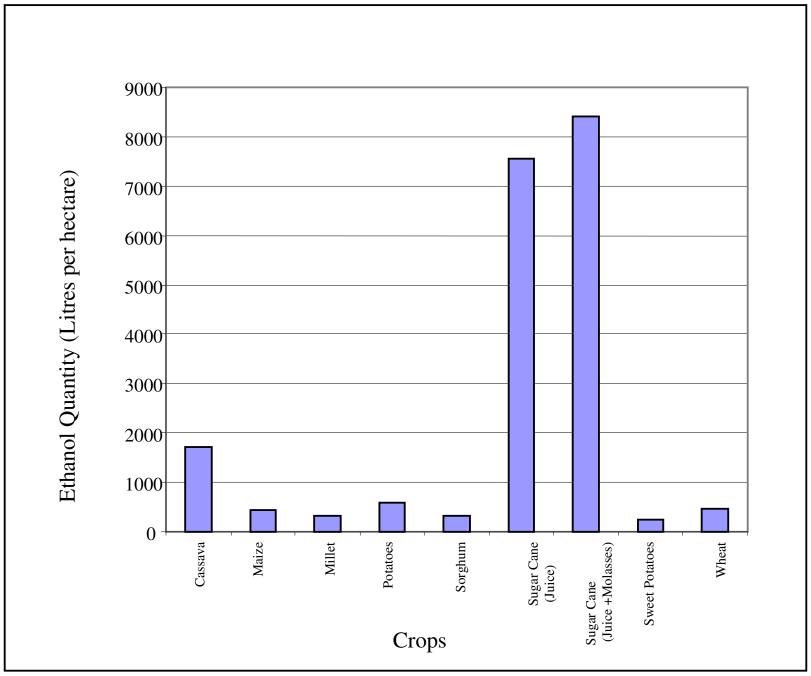

Figure 2.2: Ethanol Production Potential for Selected Crops in Tanzania

Source: Computed using data from FAO (http://faostat.fao.org)

Potential Lignocellulosic Feedstocks for Producing Ethanol in Tanzania

Tanzania has a vast amount of lignocellulosic feedstocks which could be used to produce ethanol. Studies in the USA have shown that on average a tonne of lignocellulosic materials, such as maize stover can produce up to 236.26 litres of ethanol (Mosier, 2006). The use of such materials is important since they constitute a large proportion of the biomass. Furthermore, their use will increase the range of suitable feedstocks for ethanol production. Moreover, the use of lignocellulosic materials is likely to lower the cost of feedstocks as they are readily available in the country. The assumption that lignocellulosic feedstocks would be cheaper is based on the fact that they have limited alternative uses. Thus the opportunity cost of using them for producing ethanol is expected to be low. Unfortunately, however, the technology for producing ethanol from lignocellulosic feedstocks is still in its infancy stage. Moreover, the current processing cost for lignocellulosic ethanol is relatively higher than the cost of producing ethanol from the traditional sugar and starchy feedstocks. Thus there is a possibility that the benefits of the low opportunity costs for those feedstocks would be offset by their high processing costs (Lindstedt, 2003). Nonetheless, the present study explored the potential of using them for ethanol production in Tanzania.

Lindstedt (2003) reported an estimated cost of 40-60€ cents per litre of ethanol produced from lignocellulosic materials. A study undertaken by the USDA (2005) showed that the cost of producing ethanol by using those feedstocks was almost twice the cost of ethanol produced by using grains such as maize (for a detailed review of biofuels production costs for various feedstocks see section 2.1.3). Due to the high costs of producing ethanol from lignocellulosic feedstocks, the two studies suggested co-locating the plants using the traditional feedstocks and those using lignocellulosic feedstocks for ethanol production as a way of reducing the cost of ethanol produced from lignocellulosic materials. A detailed description of how the two processes could be integrated is provided in figure 2.3.

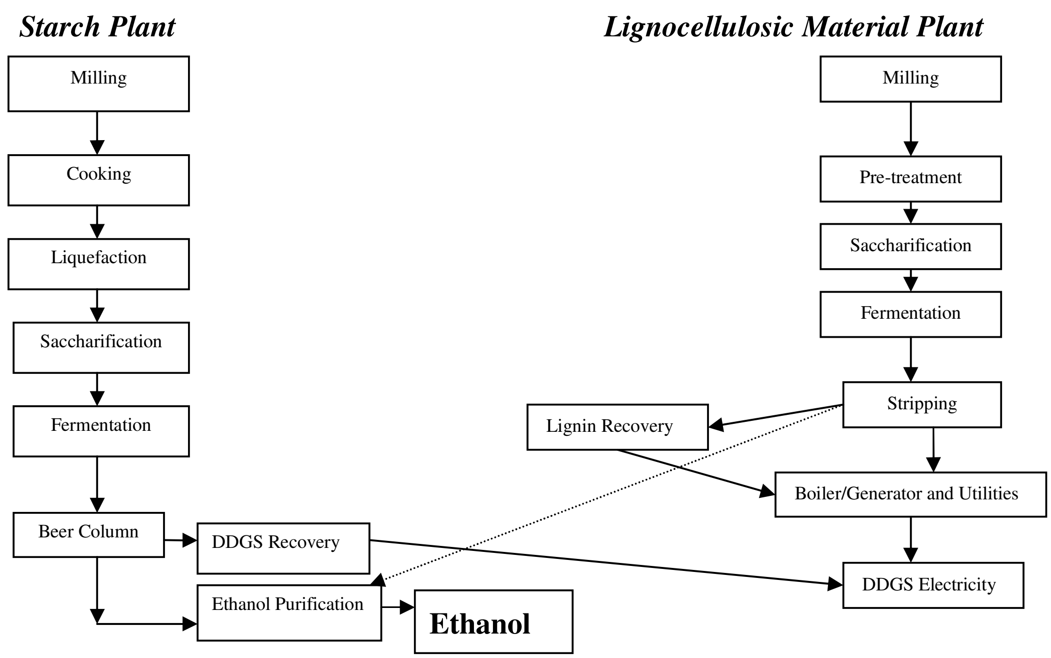

Figure 2.3: Combined (Starch/Lignocellulosic) Ethanol Purification Plant
(DDGS: Distiller's Dried Grains with Solubles)

In the case of Tanzania, where sugarcane and cassava are among the most promising feedstocks for ethanol production, residues from those crops and other crops which are normally grown in close proximity to sugarcane and cassava farms would provide a good source of lignocellulosic ethanol plant feedstocks. The crops which have large quantities of residues which could be used as lignocellulosic feedstocks for producing ethanol include sugarcane, rice, maize, coconut, sisal and sorghum.

2.1.1.3 Review of Various Issues on Ethanol Production Plants

A) Capital Expenditure and Plant Size for Ethanol Plants

This section provides a review of the key determinants of capital expenditure for ethanol plants. The construction costs for any type of processing facility are dependent upon the circumstances involved with constructing a particular plant in a given location. Moreover, economies of scale have been shown to exist in construction costs for ethanol plants. Therefore, the construction costs, for ethanol plants, depend on both the size and location of the plant. The average construction costs for plants of a given size at different locations are highly variable due to costs associated with unique circumstances, such as utility access and environmental compliance issues (Prakash, 1998).

Studies in the USA have shown that the average construction cost for ethanol plants using maize as feedstock is US$ 0.41 per litre of annual capacity. On the other hand, the average construction cost for ethanol plants utilising molasses as feedstock has been estimated to be US$ 0.34 per litre of annual capacity. According to data from Brazil, where sugarcane is the main feedstock for producing ethanol, the average construction cost for ethanol plants is US$ 0.35 per litre of annual capacity (Coelho, 2005; Shapour *et al*., 2006).

A study in India has shown that the construction costs for ethanol plants (expressed in US$ per litre of annual capacity) decrease significantly with increasing plant size. For example, the construction costs, per litre of annual capacity, for ethanol plants with annual capacities of 75.7 and 151.4 million litres respectively, utilising maize as feedstock, have been estimated to be US$ 0.40 and US$ 0.34 respectively (Shapour *et al*., 2006). In addition to plant size, construction costs are influenced by the type of feedstock used. For instance, the cost is likely to be higher when using sugarcane or sugarbeet than when using maize as feedstock. This is due to the extra preparation costs when using the former as feedstocks. According to Shapour *et al.,* (2006), while the construction costs for ethanol plants which can produce 75.7 million litres per year by using sugarcane or sugarbeet as feedstock is US$ 0.57 per litre of annual capacity, the cost for a similar plant using maize as feedstock is US$ 0.40 per litre of annual capacity. Furthermore, they [(Shapour *et al.,* (2006)] reported that a new ethanol plant using sugarcane/sugarbeet juice or sugarcane/sugarbeet molasses would require capital expenditure similar to that needed when using maize as feedstock. Construction costs for the two plant sizes, *i.e.* 75.7 and 151.4 million litres per year, utilising sugarcane/sugarbeet juice as feedstock have been estimated at US$ 0.37 and US$ 0.29 per litre of annual capacity respectively. This shows that doubling the ethanol plant capacity, *i.e.* from 75.7 to 151.4 million litres per year, decreases the construction cost per litre of annual capacity by 21.6 percent. Moreover, they found that, when using sugarcane/sugarbeet molasses as feedstock, the construction costs were US$ 0.36 and US$ 0.27 per litre of annual capacity respectively. A detailed description of the estimates of construction costs for various feedstocks and plant sizes is provided in table 2.3.

Table 2.3: Estimates of Construction Costs for Various Feedstocks

	Construction Costs (US$ per litre of annual capacity)			
Feedstock	Brazil	India		USA
		75.7 million l/year	151.4 million l/ year	
Maize		0.40	0.34	0.41
Sugarcane	0.35	0.57	0.44	
Sugarbeet		0.57	0.44	
Cane/beet juice		0.37	0.29	0.41
Cane/beet molasses		0.36	0.27	0.34

Source: Shapour *et al*., (2006)

Another important factor to consider, which is directly linked to the construction costs described previously and presented in table 2.3, is the capital expenditure[15] per litre of annual capacity for ethanol plants using alternative feedstocks for the entire economic life of the ethanol plant. This essentially distributes the construction cost[16]. over the entire productive life of the plant. The reviewed studies have made use of a twenty year period and assumed a seven percent interest rate. Distributing capital expenditure over the entire economic life of the plant is important because it provides an estimate of the construction cost's contribution towards the ethanol processing costs for every litre that would be produced during the entire life of the plant. This, *i.e.* the estimate of capital

[15] We use the terms 'capital expenditure', 'capital cost' and 'construction costs' as synonyms.

[16] Construction costs for ethanol plants utilising sugar crops as feedstocks can vary significantly based on several factors. The main determinants (of the construction costs per litre of annual capacity) are: the technology used, plant size and location. It is important to point out that the construction costs would be lower for the addition of an ethanol facility adjacent to an existing sugar factory than for a standalone facility.

expenditure per litre, is useful in estimating the total cost of producing ethanol. The average capital expenditure values for various feedstocks and plant sizes are provided in table 2.4.

Table 2.4: Capital Expenditure per Litre of Ethanol

Feedstock	Capital Expenditure (US$/l)	
	75.7 million l/year	151.4 million l/ year
Maize	0.04	0.03
Sugarcane	0.05	0.04
Sugarbeet	0.05	0.04
Cane/beet juice	0.03	0.03
Cane/beet molasses	0.03	0.03

Source: Shapour *et al*., (2006) and Own compilation

B) Considerations for Ethanol Plant Size and Location

This section provides a brief review of the determinants of the appropriate size and location for ethanol plants. Due to the bulkiness of most of the feedstocks commonly used for producing ethanol, then the most important factor to consider when deciding where the plant should be located is the availability of feedstocks. Ideally, regardless of which feedstock would be utilised, the ethanol production facility should be in close proximity to its source of feedstock. Other factors which are important in considering where to locate the ethanol production plant are market access, availability of energy to power the plant and flexibility for future expansion (Shapour *et al*., 2006).

Just like the selection of the optimal location, the process of determining the appropriate plant size should take into account the availability of feedstocks required for producing ethanol. The optimal ethanol plant capacity should ensure availability of the feedstocks within a reasonable distance. This (minimising transport distance for feedstocks) is even more important for countries such as Tanzania where the transport infrastructure is not well developed and the transport costs are quite high. It is important to point out that the feedstock transport distance is largely dependent on the productivity and land share of the crops which would be used for producing ethanol. Consequently, the process of determining the optimal plant size should consider those factors. Other issues that need to be taken into account include: market availability (for ethanol), capital availability and the possibility of exploiting economies of scale (Joe *et al*., 2003).

2.1.2 Biodiesel Production

2.1.2.1 General Introduction to Biodiesel

Biodiesel is a name that is used for a variety of ester-based fuels (fatty esters). These are generally defined as monoalkyl esters. Biodiesel is normally produced by using vegetable oils, such as soybean oil, sunflower oil, palm oil, jatropha, canola or hemp oil, or sometimes from animal fats through a simple transesterification process (Prakash, 1998; CRFA, 2006). This renewable energy source is almost as efficient as petroleum diesel in powering unmodified diesel engines[17]. It can be used on in its own or as a blend with conventional diesel fuel. Since biodiesel can be produced from renewable, domestically grown feedstocks, it can reduce the use of petroleum based fuels and thus lower the dependency on diesel imports which are draining a large portion of the foreign exchange reserves of Tanzania. Furthermore, due to its biodegradable nature and its relatively lower sulphur and aromatic compounds contents, biodiesel offers promise to reduce particulate and toxic emissions which are common for engines running on conventional petroleum diesel. Moreover, biodiesel when mixed with conventional diesel fuel, in small quantities, also seems to improve the fuel lubricity, extends engine life, and reduces fuel consumption (CRFA, 2006).

2.1.2.2 Historical Background of Biodiesel Production

The use of vegetable oils has long been promoted as a feasible substitute for the traditional diesel fuel. Historical records indicate that Rudolph Diesel, the inventor of the diesel engine, used vegetable oil in his engine as early as 1900 (Prakash, 1998; Shumaker *et al.,* 2003; CRFA, 2006). Castor oil was used in the first diesel engine in Argentina in 1916. Gauthier, a French engineer, published a paper in 1928 discussing the use of vegetable oils in diesel engines. Interest in vegetable oils continued in various parts of the world during the second world war, but later on the arrival of peace and the relative abundance of inexpensive fossil fuels made research into diesel substitutes unnecessary. However, the organisation of petroleum exporting countries (OPEC) embargo of the 1970's and the subsequent rise of fuel prices and the fear of fuel

[17]The amount of energy contained in a litre of biodiesel is equal to 89% of the amount of energy contained in a litre of conventional petroleum diesel. This figure (the biodiesel-fossil diesel energy content ratio) has been extracted from a study by Von Lampe, (2006).

shortages revived the interest in alternative fuels, including vegetable oils as energy sources for diesel engines. However, the high viscosity of vegetable oils, which results in poor fuel atomisation and fuel injector blockage, makes them best used after conversion to vegetable oil esters which are commonly known as biodiesel (Prakash, 1998).

In addition to the increasing world oil prices, the recent environmental concerns have prompted resurgence in the use of biodiesel throughout the world. Having recognised the importance of biodiesel, several countries have decided to use various incentives to encourage its production. For instance, in 1991, the European Community (EC) proposed a 90% tax reduction in order to promote the use of biodiesel. As a result of the incentives, biodiesel manufacturing plants, with annual capacities of about 5.0 million litres, have been built by several companies in Europe (Gustafson, 2003). The interest in biodiesel is also growing in the United States (USA) and Canada. Several demonstration programs in North America are using biodiesel to fuel many vehicles, including buses, trucks, construction and mining equipment, and motor boats. Research on using biodiesel to enhance the lubricity of diesel fuel is also underway (Prakash, 1998). Unfortunately, however, in some countries like Tanzania there has been very little efforts to produce and use biodiesel. Although there has been some general interest in the subject of biodiesel production in Tanzania, yet there is neither commercial biodiesel production nor detailed economic analyses of the feasibility of producing biodiesel in the country.

2.1.2.3 An Overview of World Biodiesel Production Trend

As the price of oil increases, it becomes increasingly profitable to convert farm products into automotive fuels, such as biodiesel. In effect, the price of oil becomes the support price for food commodities. Consequently, the increasing world oil prices are likely to lead to increases in biodiesel production. It is important to point out that there are other factors which might also influence biodiesel production. These include: the need to reduce expenditure on oil imports and ensuring energy security for countries which depend on imports for their oil needs, and the worldwide efforts to reduce the emission of greenhouse gases which causes global warming. To get a clear picture of the relationship between world oil prices and biodiesel production, the present study compared the amount of biodiesel produced and the world oil price from 1991 to 2005. The world oil prices used in the review were obtained from Statistics Norway (2006). A detailed description of the relationship between world oil prices and biodiesel production is provided in figure 2.4.

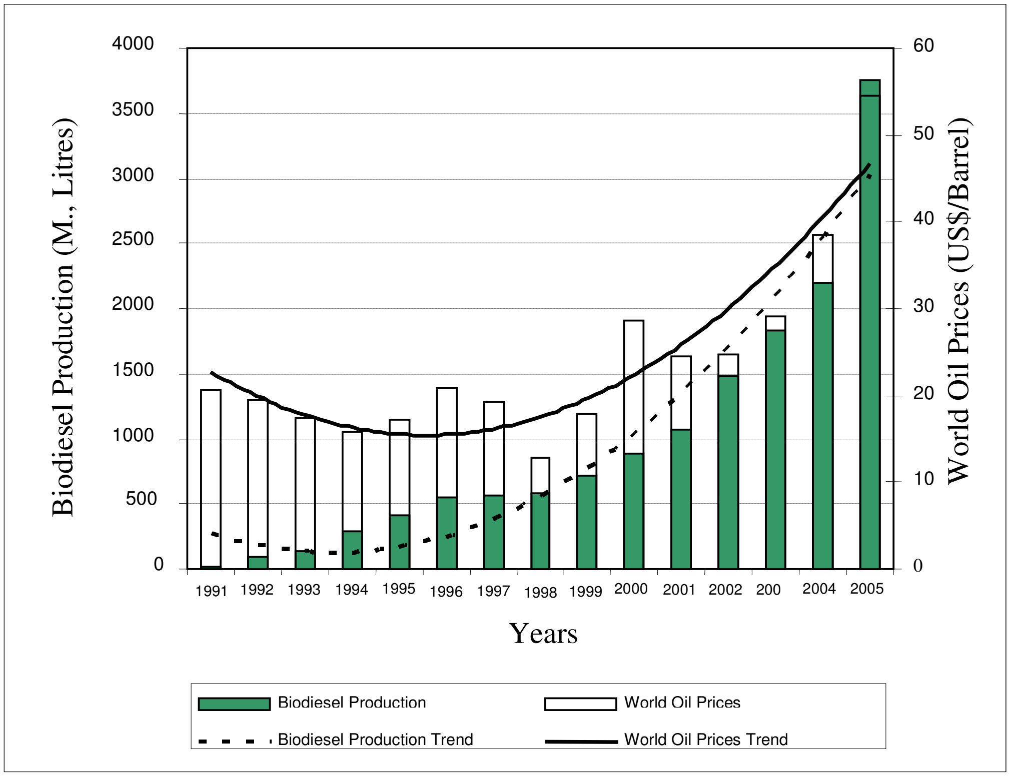

Figure 2.4: World Biodiesel Production Trend

Source: Data from Earth Policy Institute and Statistics Norway (2006)

Figure 2.4 shows that there is a close relationship between world oil prices and biodiesel production. This close association could be attributed to the fact that while increasing world oil prices make biodiesel production more profitable, a decrease in world oil prices reduces the profitability of biodiesel production. Thus increasing world oil prices will prompt increases in biodiesel production and decreasing world oil prices are likely to lead to a decrease in biodiesel production[18]. It is important to point out that the recent concerns of the negative environmental impacts of the use of fossil fuels would also increase the production of biofuels in the world. For instance, just recently, in an

[18] This argument is based on the assumption that biodiesel prices would increase with increasing world oil prices.

attempt to reduce the emission of greenhouse gases[19] which are blamed for causing global warming, the European Union's energy ministers agreed to increase the share of biofuels used in the transport sector to 10% by 2020.

The production of biodiesel is currently concentrated in Germany, France, United States, Italy, Czech Republic, Austria, Spain, Denmark, Poland, United Kingdom, Brazil, Australia and Sweden. In the year 2005, Germany and France produced 1,921 and 557 million litres of biodiesel respectively. The amount of biodiesel produced in Germany and France accounted for more than two thirds of the total world production in 2005 (Licht, 2006). Thus, just like the case of ethanol where Brazil and USA were the main production centres, biodiesel production is also concentrated in few countries. The large quantities of biodiesel produced in Germany and France could be attributed to the high tax reductions for biodiesel producers in those countries. According to Frondel and Peters (2005), the tax reductions for various European countries in 2005 were as follows: Germany (0.47€/l), France (0.33€/l), Italy (0.29€/l), Czech Republic (0.10€/l), Spain (0.29€/l) and United Kingdom (0.28€/l).

2.1.2.4 Potential Feedstocks for Biodiesel Production in Tanzania

Tanzania has a wide range of crops which can be used as feedstocks for producing biodiesel. The most promising crops are oil palm and jatropha. Oil palm comes first in the list of potential sources of feedstocks for biodiesel production. This is because the crop has a high oil yield per hectare compared with other oilseed crops currently grown in Tanzania. It is important to point out that despite its relatively high productivity, there might be some problems in using palm oil for producing biodiesel. This is because palm oil is also used as food. Thus its use as a fuel is not likely to be popular with policy makers in a country which imports thousands of tonnes of palm oil every year for food use. Jatropha, on the other hand, is not a food crop and its use for biodiesel production is not likely to face the problems related to the competition between food

[19] The use of biofuels, such as ethanol and biodiesel reduces the amount of greenhouse gases in two ways. (i) the crops which are normally used as feedstocks for producing biofuels absorb carbon dioxide from the atmosphere. (ii) In addition to the absorption of carbon dioxide, a study by Shumaker *et al.,* (2003), have reported that the use of biofuels, such as biodiesel, would decrease the emission of carbon dioxide by about 78%. The study also found that the use of biodiesel would reduce the emission of carbon monoxide, by 43.2%; hydrocarbons, by 56.3%, toxic emissions, by about 75%, and particulates, by 55.4%.

and fuel uses. A detailed description of the estimates of potential biodiesel production per hectare for various oil seed crops in the country is provided in figure 2.5.

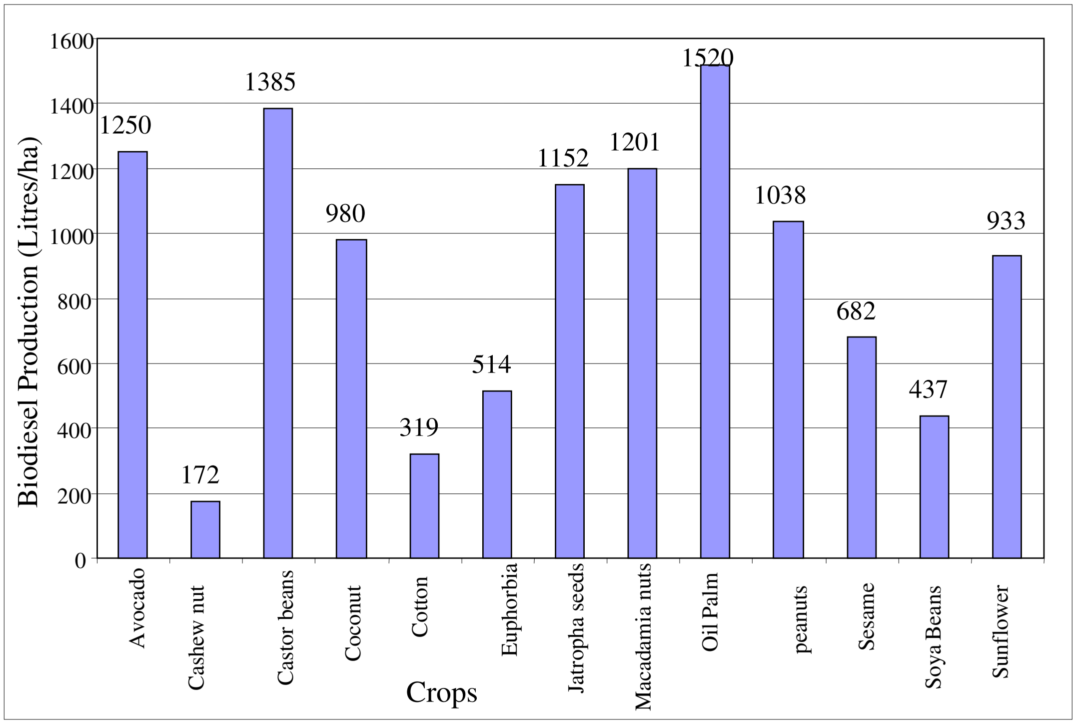

Figure 2.5: Potential Biodiesel Production From Various Crops in Tanzania

Source: URT, 2003 and own computations

It can be easily noted in figure 2.5 that oil palm has the highest potential biodiesel production per hectare. The potential biodiesel production for most of the other oilseed crops is well below 1,000l/ha. The other crop which has a high potential for biodiesel production is Jatropha. Although its biodiesel output is lower than that of oil palm, still it is a good return for a crop which requires very low inputs. Moreover, its ability to grow on marginal lands, where other crops cannot be produced, means that it could be grown in a larger area of the country than oil palm. Other crops which have high potential biodiesel production per hectare are avocado, castor beans, macadamia nuts, groundnuts, and sunflower. Though these crops have high potential biodiesel production per hectare, the higher returns from their alternative uses means that the opportunity costs of using them for producing biodiesel will be very high. The high opportunity costs means that biodiesel produced by using those crops as feedstocks would have a very little possibility of competing with the conventional diesel.

Production and Consumption of Palm Oil in Tanzania

Despite its high potential biodiesel output per hectare, the production of palm oil in Tanzania is well below the quantity demanded for its use as food. A detailed description of the production and consumption trends for palm oil in Tanzania is provided in figure 2.6.

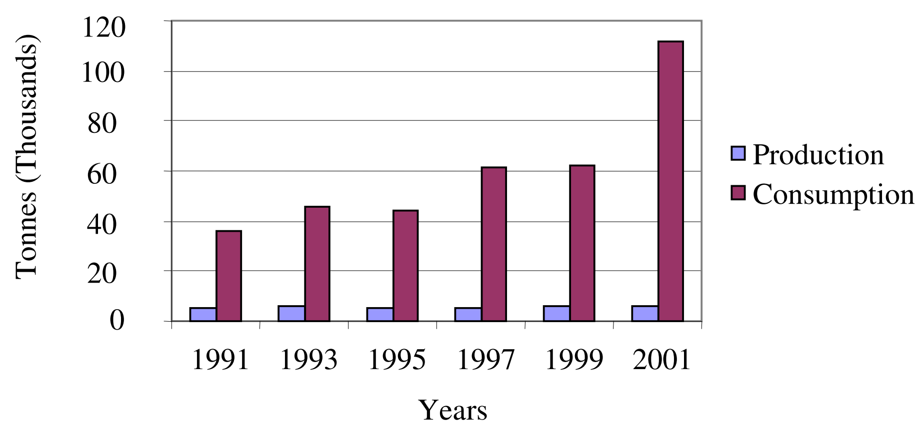

Figure 2.6: Production and Consumption of Palm Oil in Tanzania
Source: URT (2003)

Figure 2.6 shows that palm oil consumption in Tanzania has been increasing steadily. Unfortunately, however, the increase in consumption has not been accompanied by a comparable increase in production. This has led to a continuously widening gap between production and consumption. The wide gap between consumption and production means that the use of palm oil for producing biodiesel is likely to face stiff competition from its food use. Moreover, the large difference between consumption and production has led to high local prices for the crop. The high prices means that biodiesel produced by using palm oil as feedstock will have a hard time to compete with fossil diesel[20]. Nonetheless the present study tried to determine the feasibility of using the crop as a feedstock for producing biodiesel. This decision is based on the assumption that if

[20] Since feedstock costs constitute a large proportion of the total biodiesel production cost, then higher feedstock prices would inevitably lead to higher biodiesel production cost. High production costs reduce the ability of biodiesel to compete with the traditional fossil diesel.

using the crop for biodiesel production would bring higher returns than using it as food then it would be economical to continue importing palm oil for use as food.

Jatropha Production in Tanzania

This is the second most promising crop for use as a feedstock for producing biodiesel in Tanzania. There is Jatropha cultivation experience in the country for small-scale oil production, and this has been particularly promising in its demonstration of the potential for aiding rural poverty alleviation. The oil currently produced from jatropha seeds is mainly used for soap production. Cultivation of jatropha around the world has tended to be on a small scale, and production and yield data for plantation-scale cultivation is limited. The oil yield from jatropha plantations is reported to be about 1600 kg per hectare from the fifth year onwards (KAKUTE, 2006; URT, 2006).

The yield of jatropha in Tanzania is significantly less than 1600 kg/ha (TaTeDo, 2005; URT, 2006, KAKUTE, 2006). The low productivity of the crop has led to relatively high prices for jatropha seeds in the country (KAKUTE, 2006). Despite its low productivity, the lack of significant alternative uses for the crop means that the opportunity cost of using it as a feedstock for producing biodiesel is likely to be low. Thus it is reasonable to argue that there is a high potential of producing biodiesel by using jatropha as a feedstock.

2.1.2.5 Review of Various Issues on Biodiesel Production Plants

A) Capital Expenditure and Plant Size for Biodiesel Plants

Just like in the case of ethanol, construction costs for biodiesel plants are dependent on the circumstances involved in constructing them. Economies of scale have been shown to exist in construction costs for biodiesel plants. However, as pointed out in the case of ethanol, average capital expenditure for plants of a given size at a particular location are still highly variable due to location specific costs. Variations in location specific costs arise from differences in utility prices and environmental compliance issues, to mention a few. The construction costs for biodiesel production plants are relatively lower than those of ethanol plants (Shumaker *et al.,* 2003). In addition to size and location, the capital expenditure for biodiesel plants are also determined by the type of feedstock that is used. Gustafson (2003) reported an average capital expenditure of US$ 0.26 per litre of annual biodiesel production capacity.

Just like in the case of ethanol, construction costs decline sharply at lower biodiesel plant capacities. Shumaker *et al.,* (2003) in their study on the feasibility of biodiesel production in Georgia found that the investment costs for biodiesel plants decreases continuously up to a capacity of 56.78 million litres per year from where there is no significant decline in capital expenditure per litre of biodiesel produced with increasing plant size. They found that the capital costs decrease from about US$ 0.51/l for a biodiesel plant with annual capacity of 1.89 million litres to US$ 0.28/l for a plant with annual capacity of 56.78 million litres or more. This is about 45 percent decrease. A detailed description of the variation of the construction costs per litre of annual biodiesel plant capacity with increasing plant size is provided in figure 2.7.

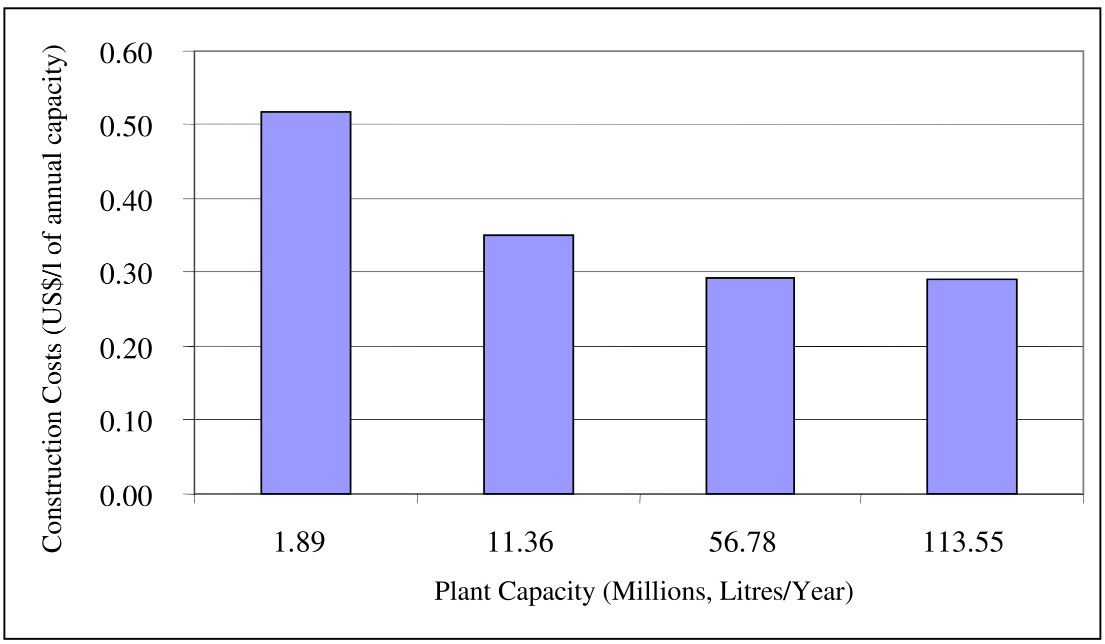

Figure 2.7: Variations of Construction Costs with Biodiesel Plant Size
Source: Produced by using data from Shumaker *et. al.*, (2003)

Having reviewed the initial capital costs for various plant sizes, then it is important to look at another aspect of the cost which is useful in computing biodiesel processing cost. This other aspect focuses on the nature of the distribution of the construction costs over the entire economic life of the plant. This is in essence an attempt to estimate the average capital expenditure for every litre of biodiesel that would be produced during the entire economic life of the plant. The reviewed studies have made use of a twenty year period and assumed a seven percent interest rate. A detailed description of the average capital cost values for various plant sizes is provided in figure 2.8.

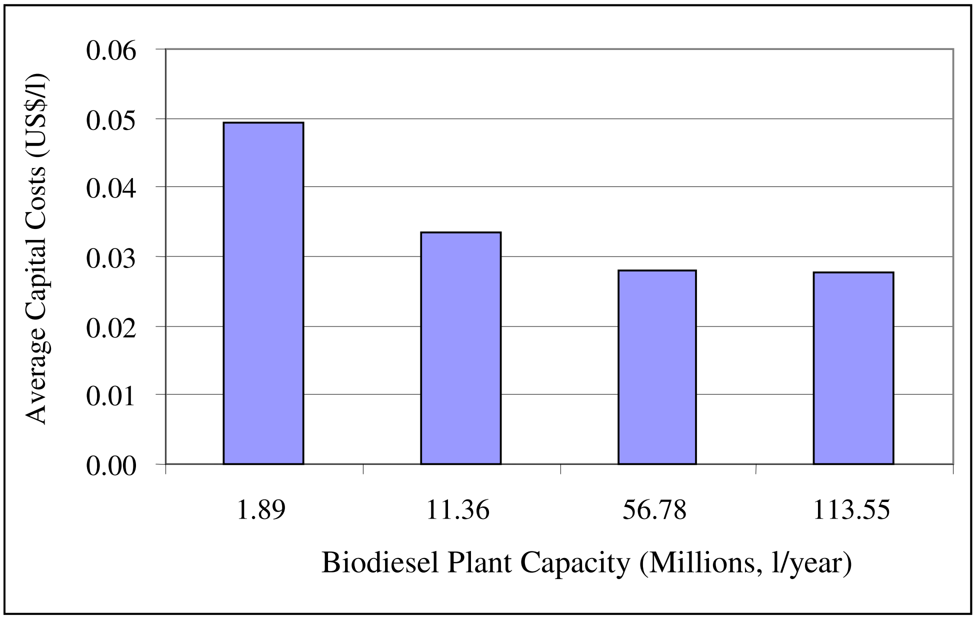

Figure 2.8: Variations of Average Capital Costs with Biodiesel Plant Size

Source: Produced by using data from Shumaker *et. al.*, (2003)

B) Considerations for Biodiesel Plant Size and Location

Just like in the case of ethanol, the most important factor in deciding where a biodiesel plant should be located is the availability of feedstocks which are going to be used to produce the fuel. The need to construct the plant close to the source of feedstocks arises from the fact that oftentimes feedstocks for biodiesel production are bulky and hence it is costly to transport them over long distances. The issue of availability of feedstocks is also important in deciding the capacity (plant size) of the biodiesel plant to be constructed. Although several studies have proved the existence of economies of scale in capital costs for biodiesel production plants, the exploitation of the benefits of scale economies would only be possible if feedstock availability would not pose a problem in increasing plant capacity. Another important factor that need to be considered in deciding where the biodiesel plant should be located is market availability. It is a good idea to ensure that there will not be any problem in delivering the produced biodiesel to the users. This can be achieved by locating the biodiesel plant as close to the market as the availability of feedstocks allows.

2.1.3 An Overview of Biofuels Production Costs in the World

The costs of producing biofuels, *i.e.* ethanol and biodiesel, depend on a number of factors specific to the local situation. The main determinants of biofuels production costs are: (i) the cost of feedstocks, which varies among countries, depending on land availability and quality, agricultural productivity, and labour costs; (ii) processing costs, which depend on the feedstock used, plant size and location. Since the magnitudes of the key determinants of the costs of producing biofuels differ significantly from one location to another, then the costs of producing biofuels are likely to vary widely from one place to another. This section provides a detailed review of ethanol and biodiesel production costs in various parts of the world.

As described in the previous paragraph, the costs of producing biofuels varies widely depending on factors such as feedstock and processing costs. Consequently, studies aimed at estimating the costs of producing ethanol and biodiesel in the world came up with a wide range of values depending on the location of the study, the feedstock used and the plant size considered. For example, McAloon *et al.*, (2000) found that the costs of producing ethanol in the USA were US$ 0.238 per litre when using maize as a feedstock and US$ 0.397 per litre when lignocellulosic materials are used for producing ethanol. A study by Von Lampe (2006) reported ethanol production costs, for USA, of US$ 0.289 and 0.545 per litre when using maize and wheat as feedstocks respectively. According to the study by Von Lampe (2006), the costs of producing ethanol in other countries, with the respective feedstocks in brackets are: Brazil, US$ 0.219 per litre (sugarcane); South Africa, US$ 0.217 per litre (maize), US$ 0.448 per litre (sugarcane); European Union, US$ 0.573 per litre (wheat), US$ 0.448 per litre (maize) and US$ 0.560 per litre (sugarbeet); Canada, US$ 0.563 per litre (wheat); US$ 0.335 per litre (maize). Shapouri *et al.,* (2006) reported ethanol production costs, with the respective countries and feedstocks in brackets, of US$ 0.275 per litre (USA, maize); US$ 0.635 per litre (USA, sugarcane); US$ 0.621 per litre (USA, sugarbeet); US$ 0.214 per litre (Brazil, sugarcane) and US$ 0.764 per litre (European Union, sugarbeet). Roger (2007), estimated the cost of producing ethanol by using maize as a feedstock in the USA to be US$ 0.384 per litre. The costs of producing ethanol in Australia have been estimated to be US$ 0.242 and 0.276 per litre when using molasses and sorghum as feedstocks respectively (Urbanchuk *et al.,* 2005). A study by Henniges and Zeddies (2006) reported ethanol production costs for various countries and feedstocks as follows: US$ 0.390 per litre (USA, sugarcane); US$ 0.325 per litre (Australia, sugarcane), US$ 0.221 per litre (Brazil, sugarcane) and US$ 0.715 per litre (European Union, sugarbeet).

It is important to note that the competitiveness of ethanol production does not only depend on its cost of production, but also the price of fossil petrol which in most cases it intends to replace. Consequently, there are several studies on the feasibility of producing ethanol which have estimated the minimum world oil price at which ethanol could be produced competitively. For instance, a study by Urbanchuk *et al.,* (2005) found that ethanol could be produced competitively in Australia by using molasses as feedstock even if world oil prices would fall to as low as US$ 16.4 a barrel (A$ 20).

Just like the case of ethanol, there is a wide variation in biodiesel production costs for various countries. For instance, a study by Von Lampe (2006) reported the costs of producing biodiesel by using vegetable oils as feedstocks in various countries to be as follows: Canada (US$ 0.455 per litre), European Union (US$ 0.607 per litre), Brazil (US$ 0.568 per litre) and USA (US$ 0.549 per litre). A study by Shumaker *et al.,* (2003) estimated the cost of producing biodiesel by using vegetable oils in the USA to be US$ 0.392 per litre. Moreover, the study found that the cost of feedstocks accounted for almost 90% of the total cost of producing biodiesel. The high contribution of feedstocks costs to the total biodiesel production cost emphasises the significance of feedstock prices in determining the competitiveness of biodiesel.

The wide variation in ethanol and biodiesel production costs, for various countries and feedstocks, which has been described in the previous paragraphs emphasises the specificity of the feasibility of biofuels production. Studies on the viability of producing ethanol and biodiesel have to pay a particular attention to the location of the potential plants and the feedstocks which would be used. Unfortunately, such studies have not yet been conducted in Tanzania. In view of this fact, the present study tries to determine the feasibility of producing ethanol and biodiesel by using various crops which could be grown in the country as feedstocks.

2.2 The Role of Agriculture in Poverty Alleviation

The role of agriculture in the economies of most developing countries is generally acknowledged. However, there is no consensus on the issue of whether agriculture is the most appropriate way to alleviate poverty in those countries. One school of thought argues that since the majority of people in many developing countries are in rural areas and most of them are engaged in agricultural production or agriculture-related activities then improving agriculture productivity is the most effective way to reduce poverty. The second school of thought recognises the contribution of agriculture to poverty alleviation, but attaches more importance to non-agricultural activities. For example, McIntosh and Vaughan (1996) state that the notion that a broadly based smallholder agriculture can be created, and that it can transform the nature of the agricultural production system is an inappropriate premise on which to build policy frameworks designed to improve livelihoods in rural areas. They considered non-farm income generating activities to be too important to ignore in rural poverty alleviation programmes.

In most cases the rural sector consists of three sub-sectors: (i) the smallholders who produce staple food and some commercial goods; (ii) commercial farm sector which is comprised of medium and large scale farmers providing employment to a significant number of the landless; and (iii) the rural non-farm sector.

According to FAO (2004), agricultural growth has a strong and positive impact on poverty, often significantly greater than those of other sectors of the economy. Similarly, a study by Irz *et al*., (2001) found that the poverty-alleviation effects of agricultural growth were stronger than those of other sectors. However, they also concluded that unless agriculture reaches some degree of commercialisation, the impact of the sector's growth on poverty alleviation is likely to be limited. A study conducted in Indonesia found that agricultural growth reduced the depth of poverty by 50% in rural areas while the percentage for urban areas was 36 (FAO, 2004). Similar findings have been reported by Delgado *et al.,* (1998) in their study on the linkages between agricultural growth and poverty alleviation in sub-Saharan African countries.

There are several transmission mechanisms through which changes in agricultural performance are linked to the progress in poverty reduction. These mechanisms include:

direct impact of improved agricultural performance on rural incomes; impact of cheaper food for both urban and rural poor; agriculture's contribution to growth and the generation of economic opportunities in the non-farm sector. The present study is, amongst others, an attempt to shed light on the potential impact of biofuels production on farm profitability among small and medium scale sugarcane and jatropha farmers and hence its contribution towards poverty alleviation efforts in Tanzania. The analysis was based on the first transmission mechanism, *i.e.* direct impact of improved agricultural performance on rural incomes. Given the importance of off-farm income sources on the livelihoods of rural people then the present study also tried to assess the contribution of off-farm income generating activities to the total household income among the producers of potential feedstocks for biofuels production.

2.2.1 The Direct Impact of Improving Farm Productivity on Rural Poverty

In most Sub Saharan African countries, poverty remains a predominantly rural problem and agriculture is generally central to rural livelihoods. Some 70% of the workforce in sub-Saharan Africa are at least partly engaged in agriculture (Maxwell, 2004). The proportion of the workforce that is working in the sector is even higher in Tanzania where it employs about 82.1% of the labour force (URT, 2003). Therefore, any improvement in rural incomes would have a major impact on poverty. Many studies have shown that agricultural productivity gains have raised rural incomes in two ways. The first way is by directly increasing farmers' incomes and the second way is via the increase of employment opportunities and wages (Lanjouw and Stern, 2001). The present study, amongst others, attempted to assess the potential contribution of biofuels production to the improvement of the socio-economic status of the producers of potential feedstocks for biofuels production in Tanzania.

2.2.2 Impact of Improving Farm Productivity on Self-employed Farmers

For self-employed farmers, increases in agricultural productivity should translate directly into increases in household income. This is likely to be the case, unless there are large offsetting behavioural changes, such as a reduction in labour supply or general equilibrium effects, such as a decrease in the price which farm output can command. de Janvry and Sadoulet (1996) estimated that a 10% increase in total factor productivity in agriculture would raise the incomes of small-scale farmers by 5%. Acharya and Sophal

(2002) reported that in a 2001 sample of smallholder rice-producing farms in Cambodia, a 10% increase in yields resulted in an 8.8% increase in household incomes in dry season cultivation and a 4.4% increase in wet season cultivation.

Also, increasing farm productivity is important in coping with decreasing prices for agricultural products. Studies in Bangladesh have shown that farmers had to progressively reduce their unit costs of production in order to remain profitable. For instance, between 1980 and 2000, the real wholesale price for rice in Dhaka fell from 20 to 11 Taka per kg, but over the same period, farmers increased yields from around 2 to 3.4 tonnes per hectare, effectively offsetting the impact of falling prices on their incomes (Maxwell, 2004).

2.2.3 Impact of Farm Productivity Improvement on Farm Employment

The link between productivity and household income for agricultural labourers arises from the fact that the marginal product of labour increases with increasing farm productivity. Thus, assuming competitive markets and workers are paid their marginal products, it is plausible to argue that wages would increase with increasing farm productivity. This implies that farms with higher output per worker are likely to pay higher wages than those with lower labour productivity. Significant increases in agricultural wage rates have been recorded in many countries which experienced increased agricultural productivity. Saxena and Farrington (2003) showed that, in response to increasing farm productivity, agricultural labour wages in India rose at a rate of about 3% per annum during the 1970s and 1980s.

On-farm employment is critically important for poor people's livelihoods, and not just for the landless[21]. In India, increasing agricultural productivity associated with the adoption of new technologies clearly increased demand for labour. Furthermore, the majority of the additional labour used was hired rather than family labour (Hazell and Ramasamy, 1991). Thus, the increase in demand for crops which can be used as feedstocks for biofuels production would increase demand for hired labour in rural areas and hence contribute towards the country's poverty alleviation efforts.

[21] Working as hired labourers is among the main ways by which small-scale farmers in Tanzania supplement the incomes obtained from selling their crops.

2.3 An Overview of Farm Performance in Developing Countries

2.3.1 Economies of Size in Agriculture

The basic force behind the development towards large farms is the well-known theory of economies of size. The theory states that the optimal farm size is the one at which the long run average cost curve (LRAC) has its minimum. Owing to the decrease in average cost with increasing farm size, farms that are small will have an incentive to grow because the decrease in average cost that is associated with increases in farm size would increase farm profit. Over time the LRAC curve will move down and to the right due to technological progress. This means that the farms, which before had an optimal size, will have an incentive to grow further if possible.

2.3.2 Economies of Size in Developing Countries' Agriculture

Despite the theory of economies of size, there are several studies in developing countries which have reported an inverse relationship between productivity and farm size. The existence of this relationship has captivated the imagination of development economists for quite some time. While empirical evidence is far from universal, this relationship has been observed in several contexts of traditional agriculture (Lamb, 2003). From an economic policy perspective, the implications of this relationship are enormous because as much as it helps to justify redistributive land reforms in terms of efficiency gains, in addition to the obvious equity gains.

Many researchers have attributed the productivity decline with farm size to factors such as imperfect land and labour markets (Bardhan, 1973; Newell *et al*., 1997). Feder (1985) showed that the necessity to supervise hired labour and capital markets imperfections could lead to a systematic relationship between yields and farm size, and this relationship was more likely to be negative. Barrett (1996) attributed the observed inverse relationship between farm size and yield to price risk. Assuncao and Ghatak (2003) showed that heterogeneity in farmers' abilities and the endogeneity of time allocation in the presence of imperfect capital markets could be the reason behind the observed inverse relationship between yield and farm size.

From a theoretical point of view, the inverse relationship between farm size and productivity has been attributed to the presumption that the opportunity cost of family labour working on the farm is less than the prevailing wage (Barrett, 1996). Thus, small farms rationally use a production process that is more labour intensive and, in traditional agriculture where labour is the main variable input, obtain higher yields than large farms that use hired labour. The low opportunity cost for family labour implies that the labour cost rises along the gradient of asset endowments that define farm sizes. The increase in labour cost with increasing farm size is thought to be the main reason for the observed inverse relationship between yield and farm size in developing countries' agriculture.

On the other hand, those who found explicit economies of scale in agriculture in developing countries, like Binswanger (1986) suggested several sources of economies of size that could create a productivity advantage for large farms. One of their main arguments was the possibility of reducing unit production costs for large investments such as farm machinery. For instance, Zaibet and Dunn (1998) found that small farms faced a binding constraint in the use of mechanization in Tunisia. Sawers (1998) attributed the lack of an inverse relationship among some farmers in Argentina to policy distortions and credit markets imperfections. Dorward (1999) found that farm size had a positive effect on productivity in Malawi due to land, capital and output markets failures. Eswaran and Kotwal (1986) claimed that while family labour availability and its low opportunity cost create advantages for small farms, the indivisibility of capital works in favour of large farms. Hence, a possible outcome is that yields will be decreasing with farm size for relatively small farms and increasing with farm size above a certain size threshold.

There is a growing group of researchers who think that the inverse relationship depicted by some studies is a result of flaws in the analytical approaches they adopted. In support of the faulty analytical approach argument, there are some studies which showed that the inverse relationship weakens considerably after differences in land quality are taken into account (Benjamin, 1995). Lamb (2003) showed that the inverse relationship could be explained by a combination of land quality differences, rural market imperfections, and measurement errors in farm size. To address the problem of measurement errors, both Lamb (2003) and Benjamin (1995) corrected for measurement errors in plot size by using instrumental variable technique. Kimhi (2003) also accounted for measurement errors in his approach. However, neither Lamb (2003) nor Benjamin (1995) considered the possibility of nonlinear effects of size on productivity, which was pursued in Kimhi's study on the influence of plot size on maize productivity in Zambia. This study also considered the nonlinear effects of farm size on productivity among producers of potential feedstocks for biofuels production in Tanzania.

Moreover, there are some studies which have shown that the existence of the inverse relationship depends on the production technology used by farmers, and other factors such as access to capital. For example, Deolalikar (1981) found evidence for productivity advantages for small farms in districts in which traditional technologies dominate and the opposite in districts where modern technologies dominate. Carter and Wiebe (1990) found a U-shaped effect of farm size on both farm output and family income, and attributed it to access to capital. Heltberg (1998) allowed for a third-degree polynomial in operated land and found a U-shaped effect, after controlling for various market imperfections. The empirical analysis in this study, amongst others, tried to test the inverse relationship hypothesis by using data from sugarcane outgrowers in Tanzania.

2.4 An Overview of Methodologies Relevant to this Thesis

2.4.1 Determining Appropriate Allocation of Production Factors

This section provides a detailed review of one of the main approaches in determining the appropriate allocation of factors of production, *i.e.* linear programming. The main objective of the present study is to explore the potential of producing biofuels and the prospective influence of biofuels production on poverty alleviation among small-scale farmers in the country. The feasibility of producing biofuels, amongst others, depends on the availability of the feedstocks required for their production. Thus, the present study, estimates the amounts of various crops which could be produced for use as feedstocks for producing biofuels if the main factors of production would be allocated appropriately in the country. The present study uses a linear programming approach to determine the amounts of various crops which could be produced and used as feedstocks for producing biofuels in Tanzania. The decision to use linear programming is mainly based on its ability to incorporate economic theory and observed institutional and economic reality into the model. Moreover, recent advances have made linear programming more adaptable to different situations and of even more importance, it provides a realistic portrayal of agriculture reality.

2.4.1.1 Historical Background of Mathematical Programming

Mathematical programming in agriculture has its origin in attempts to model the economics of agricultural production. The mathematical programming format is sometimes known as process or activity analysis. The approach is suitable for agriculture because in most cases farmers and other stakeholders in the sector visualise agriculture production in terms of numbers[22]. Thus, the way farmers visualise agriculture production is close to forming the column vectors of inputs and outputs that constitute the backbone of mathematical programming models. Consequently, mathematical programming models provide a natural way for organising farm production data. Moreover, mathematical programming models can be used to reconcile inconsistent data and perform sensitivity analysis. In performing sensitivity analysis, the models can be useful in calculating the implications of changes in resource endowments, market conditions and/or new technologies on the object of interest to the farmer[23] (Hazell and Norton, 1986). The present study uses the technique to determine how farmers would respond to the introduction of biofuels production in Tanzania.

In 1947, George Dantzig developed the use of linear algebra for determining solutions for problems involving optimal allocation of scarce resources. Advances in computer technology and related computer software have removed the computational burden of solving large linear programming problems. The term 'linear' refers to straight-line relationships. Thus, the term linear programming refers to a family of mathematical programming techniques that can be used to find solutions to optimisation problems whose objective function and constraints are linear expressions of decision variables (Hazell and Norton, 1986).

[22]Inputs and outputs in agriculture are normally measured in units per unit area. For example, the amounts of seeds used are usually reported in terms of kg/ha. The same applies for output where farmers usually measure their farm produce in terms of kilograms or tonnes per unit area.

[23] Profit maximisation, cash-flow improvements, cost minimisation are among the most common farmers' objectives.

Linear Programming, one of the most powerful management decision making tools, enables decision makers to find optimal solutions for problems in which the solution must satisfy a given set of requirements, or constraints. A commonly encountered form of decision making involves situations in which the set of acceptable solutions is restricted, either internally, externally or both. A typical example of internal restrictions in agriculture is the amount of land that a farmer has available for crop production. External restrictions entails things like production quotas and labour regulations, to mention a few. These restrictions are collectively known as constraints in linear programming. The main objective for any linear programming model is to determine the best solution given the set of constraints imposed by the decision situation; hence, the term constrained optimisation (Hazell and Norton, 1986).

Linear programming models are characterised by components and assumptions. Components relate to the structure of the model and assumptions reveal the conditions under which the model is valid. There are four main components and five basic assumptions for any linear programming model. A detailed review for components and the main assumptions of linear programming is provided in the next section.

2.4.1.2 Components and Assumptions of Linear Programming Models

A) Components of a Linear Programming Model

The main components for any linear programming model are: objective function, decision variables, constraints and parameters. A brief description of these components is provided below.

i) **Objective function:** A mathematical statement of profit or cost that is to be maximised or minimised. It can be presented mathematically as:

$$Z = c_1x_1 + c_2x_2 + c_3x_3 + \ldots + c_nx_n \qquad (1)$$

where the c_s stand for the contribution of each unit of a given x (for instance, profit per hectare for a certain crop) to the objective function and the x_s are decision variables.

ii) **Decision variables:** Choices available to the decision maker in terms of either inputs or outputs. These denotes the amount(s) undertaken of the respective unknowns. In a land allocation example, the unknowns are the areas allocated to the various crops which could be grown in the available land.

iii) **Constraints:** Limitations that restrict the alternatives available to decision makers. In the case of farming, these entail things like the amount of land, labour and capital available to the farmer.

iv) **Parameters**: Numerical values that are fixed; the model is solved given these values. For a land allocation problem, they include things like resource requirements per unit of an activity, for example, labour requirement per hectare for a particular crop; returns per unit of an activity, such as profit per hectare for a given crop.

B) Linear Programming Assumptions

There are seven important assumptions in linear programming modelling. The first three assumptions deal with the appropriateness of the formulation and the last four deal with mathematical relationships within the model. A detailed description of the main assumptions underlying any linear programming model is provided in the next section.

Formulation Appropriateness Assumptions

i) **Objective Function Appropriateness**: This assumption requires the objective function to be the sole criterion for choosing among the feasible values of the decision variables. In land allocation problems, the satisfaction of this assumption is often very difficult as, for example, farmers might base their land allocation plans not only on profit maximisation but also on other factors such as ensuring food security, minimising the risk associated with crop failure (through diversification), or even maximising leisure time.

ii) **Decision Variables Appropriateness**: It is among the key assumptions. It requires the specification of the decision variables to be appropriate. This assumption requires the decision variables to be fully manipulatable within the feasible region. Moreover, the assumption requires the manipulation of the decision variables to be under the control of the decision maker. Furthermore, the assumption requires all appropriate decision variables to be included in the model.

iii) **Constraints Appropriateness**: This entails the assumptions that the constraints fully identify the bounds placed on the decision variables by resource availability, technology and the external environment. Consequently, any choice of the decision variables which simultaneously satisfies all the constraints is admissible. Moreover, the assumption requires the resources used and/or supplied within any single constraint to be homogeneous items which can be used or supplied by any decision variable appearing in that constraint. Lastly, the assumption bars the inclusion of constraints which improperly eliminate admissible values of the decision variables.

Assumptions on Mathematical Relationships Within the Model

i. **Proportionality** (*i.e.* linearity): This assumption requires the objective function and the constraints' coefficients to be strictly proportional to the decision variables (for instance, if the first hectare of sugarcane requires 35 man-days of labour, so must the 50^{th} hectare and 100^{th} hectare). Also, implied in this assumption is that the returns to each activity is independent of its level; *i.e.* the profit per hectare of sugarcane is the same whether the farmer grows a single hectare or ten hectares of sugarcane.

It is important to point out that there are several situations where the proportionality assumption is violated. Such circumstances include cases where the product price depends upon the level of production. Consequently, the contribution per unit of an activity varies with the level of the activity. For instance, the assumption would be violated if the return from a given activity varies with the level of that particular activity, for example decreasing profit per unit area with increasing farm size.

ii. **Divisibility**: This assumption means that non-integer values of the decision variables are acceptable. The formulation assumes that all decision variables can take on any non-negative value including fractional ones; (*i.e.* the decision variables are continuous). This assumption is violated when non-integer values of certain decision variables make little sense. For instance, a decision variable may correspond to the purchase of a tractor or the construction of a building where it is clear that the variable must take on integer values. In such cases, it is appropriate to use integer programming.

iii. **Certainty**: This assumptions requires the values for the parameters to be known and constant. This means that the optimum solution so derived is predicted on perfect knowledge of all the parameter values. Since all exogenous factors are assumed to be known and fixed, linear programming models are sometimes known as non-stochastic to distinguish them from models explicitly dealing with stochastic factors. Due to this assumption, studies making use of these models are known as "deterministic" analyses. The problem is that in most cases the exogenous parameters of a linear programming model are not known with certainty. Consequently, after developing a linear programming model, it is often useful to conduct sensitivity analysis by varying one of the exogenous parameters and observing the sensitivity of the optimal solution to that variation. In the case of the present study it was important to vary the world oil prices, amongst others, so as to determine the sensitivity of the feasibility of biofuels production to changes in those prices.

iv. **Additivity:** This assumption requires the terms of the objective function to be additive. Additivity deals with the relationships among the decision variables. Simply put, their contributions to an equation must be additive. The total value of the objective function equals the sum of the contributions of each variable to the objective function. Similarly, total resource use is the sum of the resource utilisation of each variable. This requirement rules out the possibility that interaction or multiplicative terms appear in the objective function or the constraints. For example, if the profit per hectare for maize and sugarcane are TZS 140000 and 210000 respectively, then the total profit for a farmer growing x hectares of maize and y hectares of sugarcane will be $140000x + 210000y$. Changing the area under either of the two crops does not change their respective profits per unit area. This assumption is violated if changing the level of one decision variable affects the returns from other admissible activities/decision variables.

v. **Non-negativity:** Negative values of the decision variables are not allowed. This is mainly because, in the process of making production decisions, negative values do not make sense. For instance, a farmer cannot decide to use minus (-) two bags of fertiliser or produce minus (-) forty tonnes of sugarcane.

2.4.1.3 An Overview of Duality in Linear Programming Problems

Economic theory indicates that scarce resources have value. Thus, in linear programming models, limited resources are allocated so as, amongst others, to value them. Whenever a linear programming problem is solved, there are two problems which are solved simultaneously: the primal resource allocation problem, and the dual resource valuation problem. The knowledge of duality allows the development of an increased insight into linear programming solution interpretation. Moreover, when solving the dual of any problem, one simultaneously solves the primal. Therefore, duality provides an alternative way of solving linear programming problems (Hazell and Norton, 1986). It is important to point out that linear programming is a convex problem. Consequently, there is no duality gap. Since there is no duality gap then the solution obtained when one solves the primal problem is equal to that obtained by solving the dual problem.

Basic Duality in Linear Programming

Generally speaking basic duality entails the relationship between the primal and the corresponding problem known as its dual. This section provides a brief description of how the two problems are related.

The Primal problem can be written as:

$$\begin{aligned} &\text{Max} \quad \sum_j c_j x_j \\ &\text{s.t.} \quad \sum_j a_{ij} x_j \leq b_i, \quad \text{for all } i \\ &\qquad\quad x_j \geq 0, \qquad \text{for all } j \end{aligned} \tag{2}$$

Associated with this primal problem is a dual resource valuation problem. The dual of the above problem can be written as:

$$\begin{aligned} &\text{Min} \quad \sum_i u_i b_i \\ &\text{s.t.} \quad \sum_i u_i a_{ij} \geq c_j \quad \text{for all } j \\ &\qquad u_i \geq 0 \qquad\quad \text{for all } i \end{aligned} \tag{3}$$

where u_i are the dual variables.

If the primal problem has 'n' variables and 'm' resource constraints, the dual problem will have 'm' variables and 'n' resource constraints. There is a one-to-one correspondence between the primal constraints and the dual variables; *i.e.*, u_i is associated with the first primal constraint, u_2 with the second primal constraint, and so on. The dual variables (u_i) can be interpreted as the marginal value of each constraint's resources.

The dual variables are usually called shadow prices and they indicate the imputed value of each resource. A one-to-one correspondence also exists between the primal variables and the dual constraints; x_1 is associated with the first dual constraint, x_2 is associated with the second dual constraint and so on. The resultant dual variables values are measures of the marginal value of the resources. In essence, the objective function minimises the total marginal values of the available resources. Thus it provides the minimum value of the resource endowment (Hazell and Norton, 1986).

2.4.1.4 Validation of Linear Programming Models

Model validation is an important exercise in any empirical analysis. The overall purpose of the validation process is to test how well a model serves its intended purpose. In the case of predictive models, validation tests usually involve comparing the model predictions to real world results. For prescriptive models, decision maker reliance is the ultimate validation test. Unfortunately, however, these tests (especially the comparison of the model predictions to real world results) are rarely used. This is mainly because they are expensive and time-consuming. Consequently, linear programming models in most cases are superficially validated (McCarl and Spreen, 1997).

Although a model may have a broad range of potential uses, it may be valid only for a few of those uses. The validation process usually results in the identification of valid applications. Model validation is fundamentally subjective. Modellers choose the validity tests, the criteria for passing those tests, what model outputs to validate, what setting to test in and what data to use. Thus, the assertion "the model was judged valid" can mean almost anything. Nonetheless, a model validation effort will reveal model strengths and weaknesses which is valuable to users and those who extract information from the model's results. This section provides a brief description of the main approaches for validating linear programming models.

Approaches for Validating Linear Programming Models

There is a wide variation in approaches for validating linear programming models. But the most widely used techniques are: validation by construct and validation by results. Whereas validation by construct asserts that the model was built properly therefore it is valid, validation by results refers to exercises where the model outputs are systematically compared against real world observations (McCarl and Spreen, 1997).

Validation by Construct

This is the most widely used validation approach. Although, theoretically, validation by construct is supposed to be only the starting point for the process of validating a linear programming model, in most studies it is also the end of the validation exercise. The linear programming model used in the present study has been validated by construct. The use of validation by construct, as the sole method of validation, is justified by the following assertions about modelling:

i) The right procedures have been used in the process of building the model. Usually this entails the assertion that the approach is consistent with the industry, previous research and/or theory; and that the data have been specified using reasonable scientific estimation or accounting procedures. Most of the parameters of the model in the present study have been estimated by using data collected through a detail survey of producers of potential feedstocks for biofuels production which was conducted in 2005.

ii) Trial results indicate that the model is behaving satisfactorily. This arises from a nominal examination of model results which indicates they do not contradict the modeller’s, user's, and/or associated experts perceptions of reality.

iii) Constraints have been imposed to restrict the model to realistic solutions. Some exercises use constraints to limit adjustment possibilities and force the model to give results very close to historically observed outcomes. In the present study we imposed minimum acreage constraints for crops such as cassava to ensure their availability for their traditional food use.

iv) The data have been set up in a manner that ensures that real world outcome would be replicated. In some models one can assure replication of a real world outcome through the model structure and data calculation procedures.

Validation by Results

Validation by results involves the comparison of the model solutions with real world outcomes. Models used in such a comparison will always have been built relying on experience, precedence, theory, appropriate data estimation and measurement procedures. Thus, validation by construct will always precede validation by results.

The process of validating a model by results entails five main phases: first, a set of real world outcomes and the data causing that outcome is gathered; second, a validation experiment is selected; third, the model is set up with the appropriate data, the experiment is implemented and a solution is generated; fourth, the degree of association between model output and the real world outcome is tested; and, finally, a decision is made regarding model validity (McCarl and Spreen, 1997).

Common Causes of Validation Failures for Linear Programming Models

From a practical standpoint, models do not always pass validation tests. Since models always involve many assumptions, failure to validate, likely indicates that improper assumptions have been used. Consequently, when models fail validation tests, modellers often ask: What assumptions should be corrected? (McCarl and Spreen, 1997).

As discussed in the previous sections, linear programming models embody assumptions about both mathematical relationships and the model structure. The mathematical relationships assumptions are: additivity, divisibility, certainty, and proportionality. These assumptions, when severely violated, will cause the model to fail validation tests. In such situations, the model designer has to consider whether the assumptions are the real cause of the failure. If so, the use of techniques such as separable, integer, nonlinear, or stochastic programming may be considered in constructing a new model.

Modelling assumptions may also cause a linear programming model to fail a validation test. These assumptions embody the correctness of the objective function, variables, equations included, coefficients, and equation specification. Programming algorithms are quite useful in discovering the violation of linear programming assumptions. Given an optimal solution, one may easily discover what resources have been used, how they have been used, and their marginal values. Thus, when a model fails a validation test, resource usage and valuation should be investigated. Models are most often invalid because of inconsistent data, bad coefficient calculation, bad equation specification, or an incorrect objective function. Thus, common fixes for a model failing a validation test involve data respecification and/or structural corrections (McCarl and Spreen, 1997).

Models may also fail validation tests because of improperly formulated objective function. While the specification of the constraints identifies the set of possible solutions, the objective function determines the single optimal solution. Thus, if the model fails the validation test, the objective function must be carefully reviewed.

Another phenomenon which may cause models to fail validation tests is ignoring the fact that operations, quite often, are performed over several time periods. Consequently, an annual model depicting operations of this type may well be invalid because it ignores initial conditions or does not recognise that parameter expectations may change over time. Thus, unless the model has initial conditions identical to those in the real world, it may be very difficult for it to pass validation tests (McCarl and Spreen, 1997).

2.4.2 Measuring Farm or Sector Productivity

The performance of a farm can be measured by its productivity or efficiency. The literature on production efficiency measurements is extensive. Both input-based and output-based efficiency measures have been widely used. Although the two approaches are equivalent under constant returns to scale, they differ under variable returns to scale (Färe, Grosskopf and Lovell, 1994).

The term productivity is defined as output per unit of input, where input can be land, labour and/or capital, and output is agricultural produce. If output is Y and input is X, productivity p is Y/X. Normally production involves more than one input. If X includes only one of those inputs, then the productivity computed is a partial measure of productivity. In case X is an aggregate of all inputs and Y is an aggregate of all outputs, then the productivity computed is a total measure of productivity [Total Factor Productivity (TFP)].

The efficiency of a production unit refers to the ratio of the actually-achieved total output to the optimal aggregate output it can achieve with the same level of inputs. This differs from its productivity which refers to the ratio of actual total output to the aggregate input that is used to produce the output. The importance of productivity is that it tells us in one figure how much input was used to produce a unit of output. For instance, the labour productivity for sugarcane in Tanzania is a number that tells us the amount of sugarcane that one agricultural worker produces. In this case, the unit of labour productivity is kilograms per worker. In addition to a change in efficiency, a change in productivity can also be caused by changes in the production technology and the environment in which a production unit operates (Lovell, 1993).

The efficiency of a production unit can be divided into two components, *i.e.* technical and allocative efficiency. Generally speaking, technical efficiency refers to the ability of a firm to minimise input use in the production of a given output vector or to obtain the maximum output from a given input vector. On the other hand, allocative efficiency refers to the ability of a firm to use inputs in optimal proportions, given their respective prices. The product of these two measures of efficiency (technical and allocative efficiency) gives the overall economic efficiency.

There are three main quantitative approaches that have been developed for measuring production efficiency. These analytical methods include: parametric, non-parametric approaches based on Data Envelopment Analysis (DEA), and productivity indices based on growth accounting and index theory principles (Coelli *et al.*, 1998). Stochastic Frontier Analysis (SFA) and DEA are the most commonly used methods. Both approaches estimate the efficient frontier and calculate the firm's technical efficiency relative to it.

The SFA approach requires the specification of a functional form for the frontier production function. On the other hand, the DEA approach uses linear programming to construct a piece-wise frontier that envelops the observations of all firms. The frontier shows the best performance observed among the firms, and it is considered as the efficient frontier. The main advantage of the DEA method is that multiple inputs and outputs can be considered simultaneously, and inputs and outputs can be quantified using different units of measurement. Moreover, DEA allows the calculation of scale efficiency. The strong point of SFA, in comparison to DEA, is that it takes into account measurement errors and other noise in the data (Bourguignon and Morrison, 1998). For a detail discussion on the advantages and disadvantages of the SFA and DEA approaches see section 2.4.2.3.

2.4.2.1 Data Envelopment Analysis Approach

DEA is a linear programming technique developed in the work of Charnes, Cooper and Rhodes. It is a non-parametric technique used in the estimation of production functions and has been used extensively to measure technical efficiency in a range of industries. Like stochastic production frontiers, DEA estimates the maximum potential output for a given set of inputs, and has primarily been used in the estimation of efficiency (Cooper, Seiford and Tone, 2000; Färe, Grosskopf and Lovell, 1994).

In DEA, the envelopment surface differs depending on the scale assumptions that underpin the model. Two scale assumptions are generally employed: constant returns to scale (CRS) and variable returns to scale (VRS). The latter encompasses both increasing and decreasing returns to scale. The former (CRS) reflects the fact that output will change by the same proportion as inputs are changed. In the case of VRS the production technology may exhibit increasing, constant and/or decreasing returns to scale (Coelli *et al.*, 2003).

Variable Returns to Scale Model (VRS) and Scale Efficiencies

The CRS assumption is only appropriate when all decision making units (DMU_s) are operating at the optimal scale. However, imperfect competition and constraints such as lack of capital may cause a DMU not to operate at the optimal scale. The use of the CRS specification when not all DMU_s are operating at the optimal scale results in a measure of efficiency which is confounded by scale efficiencies. Having noted the problems facing the use of CRS, Charnes and Cooper suggested an extension of the CRS DEA model to account for variable returns to scale situations (Coelli *et al.*, 2003). The VRS specification permits the calculation of efficiency devoid of the effects of the differences in the operation levels among the DMU_s. Since it was not likely that all producers of potential feedstocks for biofuels production are operating at the optimal scale then the present study finds the use of the VRS specification to be more plausible. Figure 2.9 provides an illustration of the effects of scale assumptions on the measure of efficiency. It can be noted from the figure that there are four data points (A, B, C and D) which are used to estimate the efficient frontier under both scale assumptions. To show the difference between the two cases, the illustration considers only fixed inputs. The frontier defines the full capacity output given the level of fixed inputs. With constant returns to scale, the frontier is defined by point C, all other points fall below the frontier. In the case of variable returns to scale, the frontier is defined by points A, C and D, and only point B lies below the frontier.

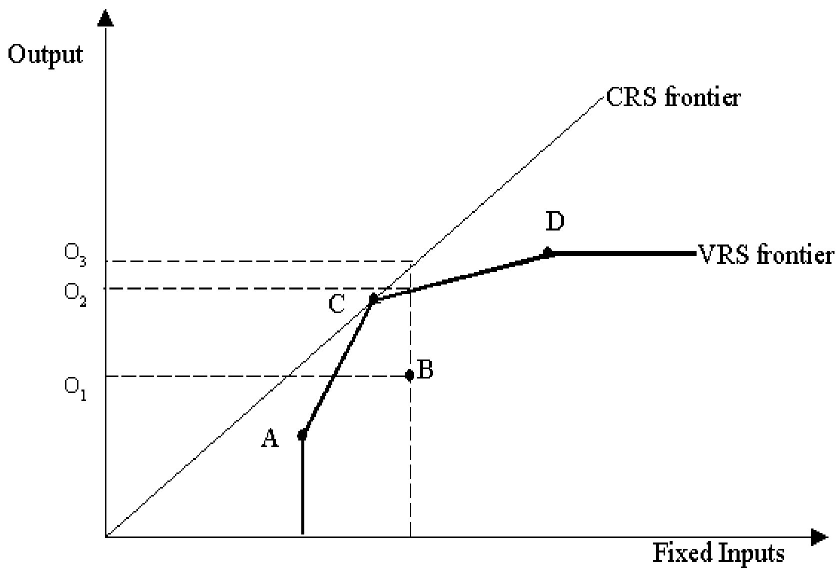

Figure 2.9: CRS and VRS Frontiers

Calculation of Scale Efficiencies

Technical efficiency scores obtained by using DEA can be decomposed into two components, one due to scale inefficiency and the other due to pure technical inefficiency. This may be done by conducting both CRS and VRS DEA upon the same data. If there is a difference between the two technical efficiency scores for a particular DMU, then this indicates that the DMU has scale inefficiency. The scale inefficiency can be obtained by computing the difference between the VRS and the CRS technical efficiency scores (Coelli *et al.*, 2003).

DEA models can be input or output-oriented. With input-oriented DEA, the linear programming model is configured so as to determine how much the input use of a firm could decrease if used efficiently. On the other hand, output-oriented models are aimed at determining the maximum output that can be obtained from a given set of inputs

(Färe, Grosskopf and Lovell, 1994)[24]. It is important to point out that the input and output-based DEA efficiency measures are only equivalent under the assumption of constant returns to scale.

Review of Mathematical Specification of DEA Models

In formulating mathematical programming models, the term Decision Making Unit (DMU) is normally used to refer to individual firms which are evaluated in terms of their respective abilities to convert inputs into outputs. A typical study will have n DMU_s with each DMU consuming varying amounts of m different inputs to produce s different outputs. Specifically, DMU_j consumes amount x_{ij} of input i and produces amount y_{rj} of output r. It is usually assumed that $x_{ij} \geq 0$ and $y_{rj} \geq 0$.

Using the ratio-form of DEA the function to be maximised can be presented as:

$$\max h_o(u,v) = \sum_r u_r y_{ro} \Big/ \sum_i v_i x_{io} \qquad (4)$$ [25]

where u_r's and v_i's are the variables and the y_{ro}'s and x_{io}'s are the observed output and input values respectively of DMU_o, the DMU being evaluated. It is important to note that without further additional constraints, equation 4 is unbounded. A set of normalising constraints (one for each DMU) reflects the condition that the virtual output to virtual input ratio of every DMU , including $DMU_j = DMU_o$, must be less than or equal to one.

The mathematical programming problem may thus be stated as:

$$\max \ h_o(u,v) = \sum_r u_r y_{ro} \Big/ \sum_i v_i x_{io}$$

Subject to,

$$\sum_r u_r y_{rj} \Big/ \sum_i v_i x_{ij} \leq 1 \text{ for } j = 1, \ldots\ldots, n, \qquad (5)$$

u_r, $v_i \geq 0$ for all i and r.

[24] In input oriented DEA models the output is fixed, *i.e.* the objective of the firm is to minimise input usage while holding the output constant.

[25] The u and v , which are weights, can be interpreted as normalised shadow prices.

The ratio form yields an infinite number of solutions, *i.e.* if (u*, v*) is optimal, then $(\alpha u^*, \alpha v^*)$ is also optimal for $\alpha > 0$. However, the transformation for linear fractional programming selects a representative solution [*i.e.*, the solution (u, v) for which the denominator in the objective function in equation (5), *i.e.* $\sum_{i=1} v_i x_{io}$ = 1], and yields the equivalent linear programming problem in which the change of variables from (u, v) to (μ, v) can be formulated as follows:

Max z = $\sum_{r=1}^{s} \mu_r y_{ro}$

Subject to:

$$\sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 \qquad (6)$$

$$\sum_{i=1}^{m} v_i x_{io} = 1$$

$$\mu_r, v_i \ge 0$$

For which the dual problem is

$\theta^* = \min \theta$

subject to

$$\sum x_{ij} \lambda_j \le \theta x_{io} \qquad i = 1, 2, \ldots, m;$$

$$\sum_{j=1}^{n} y_{rj} \lambda_j \ge y_{ro} \qquad r = 1, 2, \ldots, s; \qquad (7)$$

$$\lambda_j \ge 0 \qquad j = 1, 2, \ldots, n$$

By virtue of the dual theorem of linear programming, we have z* = θ^*. Hence either problem may be used. We can solve say (7) to obtain an efficiency score. Because we can set θ = 1 and λ_k^* = 1, with $\lambda^*_k = \lambda^*_0$ and all other $\lambda^*_j = 0$, a solution for (7) always exists. Furthermore, this solution implies $\theta^* \le 1$. The optimal solution, θ^*, yields an efficiency score for a particular DMU. The DMU_s for which $\theta^* < 1$ are inefficient, while DMU_s for which θ^* = 1 are boundary points. Some boundary points may be weakly efficient[26] because (7) does not take into consideration the possibility of having non-zero slacks. The problem can be solved by invoking the following linear program in which the slacks are taken to their maximal values.

$$\max \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+$$

subject to:

$$\sum_{j=1}^{n} x_{ij}\lambda + s_i^- = \theta^* x_{io} \qquad i = 1, 2, \ldots, m; \qquad (8)$$

$$\sum_{j=1}^{n} y_{rj} - s_r^+ = y_{ro} \qquad r = 1, 2, \ldots, s;$$

$$\lambda_{j,} s_i^-, s_r^+ \geq 0 \ \forall i, j, r$$

It is important to note that the choices of s_i^- and s_r^+ do not affect the optimal solution which is determined from model (7).

Solving (8) is equivalent to solving the following problem in two steps:

$$\min \theta - \varepsilon(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+)$$

subject to:

$$\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = \theta x_{io} \qquad i = 1, 2, \ldots, m; \qquad (9)$$

$$\sum_{j=1}^{n} y_{rj} - s_i^- = y_{ro} \qquad r = 1, 2, \ldots, s;$$

$$\lambda_{j,} s_i^-, s_r^+ \geq 0 \ \forall i, j, r, \ldots, s;$$

where the s_i^- and s_r^+ are slack variables used to convert the inequalities in (7) to equivalent equations. Here $\varepsilon > 0$ is a non-Archimedean element defined to be smaller

[26] The performance of a DMU is "weakly efficient" if and only if both (i) θ^* = 1, and (ii) $s_i^{-*} \neq 0$ and $s_r^{+*} \neq 0$ for some i and r in some alternate optima, *i.e.* there are non-zero slacks. Taking the slacks to their respective maximal values, as in equation (8) above, helps to solve the problem of having "weakly efficient" DMUs.

than any positive real number. This is equivalent to solving (7) in two stages, *i.e.* by first minimising θ, then fixing $\theta = \theta^*$ as in (5), where the slacks are to be maximised without altering the previously determined value of $\theta = \theta^*$. Formally, this is equivalent to granting pre-emptive priority to the determination of θ^* in (6). In this manner, the fact that the non-Archimedean element is defined to be smaller than any positive real number is accommodated without having to specify the value of ε.

2.4.2.2 Stochastic Frontier Approach

The stochastic frontier approach is based on the specification of the relationship between output and input levels and using two error terms. One error term is the traditional normal error term in which the mean is zero and the variance is constant. The other error term represents technical inefficiency. The latter is normally expressed as a half-normal, truncated normal, exponential, or two-parameter gamma distribution. Technical efficiency scores are subsequently obtained via maximum likelihood estimation of the production function subject to the two error terms (Lovell, 1993).

If *U* is the technical inefficiency error term, then technical efficiency is estimated as the ratio of the expected value of the predicted frontier output conditional on the value of *U* to the expected value of the predicted frontier output conditional on the value of *U* being *0*. A description of how efficiency is calculated is provided below.

$$EFF_i = \frac{E(Y^* | U_i, X_i)}{E(Y^* | U_i = 0, X_i)} \qquad (10)$$

where *E* is the expectation operator, *Y** is the predicted frontier output, *U* is the error term for technical inefficiency and *X* is a vector of inputs used to produce the output, *Y*. In such a case, the maximum output is assumed to be equal to the frontier output for which *U* equals *0*. A primal-based measure of capacity utilisation may be determined by calculating the ratio of the observed output to the frontier output; this can be done for individual firms or for the industry as a whole (Färe, Grosskopf and Lovell, 1994).

Production efficiency is usually analysed by its two components – technical and allocative efficiency. Recent developments combine both measures into one system, which enables more efficient estimates to be obtained by simultaneous estimation. The technical efficiency component, entails the use of production function frontier. However, Yotopolous *et al.,* argued that using the production function approach to measure efficiency may not be appropriate when farmers face different prices and have different factor endowments. In view of this weakness, and the knowledge that in most cases farmers have different factor endowments, the use of the profit function technique to estimate farm efficiency has been suggested, and it seems to be more plausible.

The profit function approach combines the concepts of technical and allocative efficiency in the profit relationship. In this method, any errors in production decisions are assumed to be translated into low profits or revenue for the farmer. Profit efficiency is defined as the ability of a farm to achieve the highest possible profit given the prices and levels of fixed factors of that farm, and profit inefficiency is defined as the loss of profit from not operating on the frontier (Ali *et al*., 1994).

Due to the problems of the two-stage estimation procedure when using parametric approaches[27], a number of recent studies have made use of an extended stochastic profit frontier model in which the inefficiency effects are expressed as a linear function of explanatory variables. The variables included in the model reflect farm-specific characteristics. The advantage of this approach is that it allows the estimation of farm specific efficiency scores and the factors explaining efficiency differentials among farmers in a single stage (Ali *et al*., 1994).

As pointed out previously, the use of the SFA approach requires the specification of a functional form. There are three main factors that one needs to consider when selecting the functional form to use. These are: (i) the domain of applicability (extrapolative domain), *i.e.* the set of values of the exogenous variable(s) over which the algebraic functional form satisfies all the requirements for theoretical consistency; (ii) theoretical consistency, *i.e.* the algebraic functional form chosen must be capable of possessing all of the theoretical properties required by the particular economic relationship for an

[27] The two stage approach involves estimating efficiency in the first stage and then regressing the predicted efficiency indices against a number of household characteristics, in an attempt to explain the observed differences in efficiency among farms.

appropriate choice of parameters, and (iii) Flexibility, *i.e.* the ability to map different production structures, at least approximately, without determining the parameters by the functional form. It is important to point out that, for most functional forms, there is a fundamental trade-off between flexibility, theoretical consistency, and the domain of applicability. The solution to this (the trade-off) problem depends on the type of violation. The most common approaches for solving the problem are: (a) the choice of functional forms which could be made globally theoretically consistent by corresponding parameter restrictions; (b) to opt for functional flexibility and check or impose theoretical consistency for the proximity of an approximation point only.

2.4.2.3 Advantages and Disadvantages of DEA and SFA Approaches

Advantages of the DEA Approach

A key advantage of DEA, over other approaches of measuring efficiency, is that it can easily accommodate both multiple inputs and multiple outputs. As a result, it is particularly useful for analysing farm efficiency, because prior aggregation of the outputs is not necessary. Furthermore, unlike the Stochastic Frontier Analysis (SFA) approach, with DEA a specific functional form, for the production process, does not need to be imposed on the model. Moreover, it is possible to determine the input reduction needed for a given farm to achieve technical efficiency (Cooper; Seiford and Tone, 2000).

Disadvantages of the DEA Approach

Despite its several strengths, the major weakness of DEA, for use in measuring farm performance, is that it does not take into account the effects of weather variations, disease incidences and/or measurement errors. To take care of this weakness, studies have to be based at a regional level (small geographical area), where potential variations in weather conditions, pests and disease incidences are likely to be minimal. Notwithstanding this weakness of DEA, the method is still suited to the present study, as the detailed economic analysis of the performance of the producers of potential feedstocks for biofuels production (which focussed on sugarcane) covers a small geographical area, with minimal variations in weather, common pests and diseases.

Moreover, the difficulties involved in imposing various constraints to the distance functions framework when using the stochastic frontier analysis approach to estimate farm performance undermine its perceived superiority over DEA. The estimated parameters of output distance functions frequently violate the monotonicity, quasiconvexity and convexity constraints implied by economic theory (Färe and Primont, 1995; Reinhard and Thijssen (1998); O'Donnell and Coelli, 2003). This, inevitably, causes the estimated elasticities and shadow prices to have incorrect signs, and ultimately leads to perverse conclusions concerning the effects of input and output changes on relative efficiency levels. This emphasises the credibility of the decision to make use of DEA in assessing efficiency among the producers of potential feedstocks for producing biofuels.

Advantages of the SFA Approach

The main advantage of the SFA approach is that it accounts for data noise, *i.e.* data errors and omitted variables. Moreover, with this approach, standard statistical tests can be used to test hypotheses on model specification and significance of the variables included in the model. It is also more amenable to modelling effects of other variables, like land quality and variations in weather conditions.

Disadvantages of the SFA Approach

The main disadvantage of the SFA approach is that it requires the specification of a functional form (to represent the production technology). Also, the separation of noise and inefficiency relies on strong assumptions on the distribution of the error term which might not be true in certain circumstances.

Furthermore, in most cases the stochastic frontier approach is used to determine the maximum output given a set of inputs. A long standing major criticism of this method is that it cannot adequately handle multiple outputs. Although there are two frameworks which have been developed in an attempt to make the stochastic frontier approach suitable for multiple outputs situations, they (the frameworks) have several drawbacks. The first framework is the stochastic distance function approach and the second is the polar coordinates approach (Ray, 2003).

Fare *et al.,* (1994) introduced the concept of using distance functions to express the output bundle of a multiple-products technology. In their approach, the distance function is specified as a function of variable and fixed inputs and output levels. The technology is specified as a translog function, and subsequently estimated by linear programming procedures. Unfortunately however, multi-products stochastic distance functions suffer from input-output separability and linear homogeneity in outputs (Ray, 2003).

Despite the drawbacks of the multi - products stochastic distance functions, there are several studies which have managed to extract information on the shadow prices of inputs and/or outputs from the estimated distance functions by exploiting various duality theorems. The duality results rely on particular theoretical properties of distance functions, *i.e.* they rely on the fact that the output distance function is non-decreasing, convex and homogenous of degree one in outputs, and non-increasing and quasi-convex in inputs. The input distance function is non-increasing, concave and homogenous of degree one in inputs, and non-decreasing and quasiconcave in outputs. This (the need to use duality theorems which depend on theoretical properties of distance functions to extract information, such as shadow prices for inputs) emphasises the importance of ensuring that the distance function does not violate the monotonicity, quasiconvexity and convexity constraints implied by economic theory. Unfortunately, however, there are very few empirical studies (if any) in which all these properties, *i.e.* monotonicity, quasiconvexity and convexity have been imposed on parametric (input or output) distance functions. In addition, there are only few studies which have bothered to report the degree to which their estimated functions satisfy these properties. And for those few studies which report the degree to which their estimated functions satisfies the theoretical conditions, their functions violate significantly the theoretical conditions (O'Donnell and Coelli, 2003).

O'Donnell and Coelli (2003) reported that in their survey of distance function applications, they found that all papers had imposed homogeneity and monotonicity (*i.e.* the non-increasing/decreasing properties), but they did not find any paper which had attempted to impose the curvature conditions (*i.e.* the convexity/quasi-convexity and concavity/quasi-concavity properties). They attributed the large proportion of studies which managed to impose the homogeneity and monotonicity constraints to the relative ease with which they can be imposed. The homogeneity constraints can be written as linear equality constraints on the parameters and can be easily imposed using either linear programming or econometric methods. Likewise, the monotonicity constraints are linear inequality constraints which are easy to impose using linear programming, but difficult to impose using traditional econometric approaches, especially since they need to be imposed at each data point. On the other hand, they attributed the lack of studies which attempted to impose the curvature constraints to the difficulties involved in imposing them. For a distance function to satisfy the curvature conditions, one has to impose non-linear inequality constraints at each data point. Unfortunately, this is very difficult when using traditional sampling theory econometric methods. While sampling theorists have developed methods for imposing convexity and concavity constraints, extension of the methods to deal with quasi-convexity and quasi-concavity is not straightforward (Gallant and Golub's, (1984); O'Donnell and Coelli, 2003).

As a result of the difficulties involved in imposing various constraints to the distance functions which have been described in the previous paragraphs, the estimated parameters of output distance functions frequently violate the monotonicity, quasiconvexity and convexity constraints implied by economic theory. This, inevitably, causes the estimated elasticities and shadow prices to have incorrect signs, and ultimately leads to perverse conclusions concerning the effects of input and output changes on productivity growth and relative efficiency levels.

The second framework developed in an attempt to make the SFA approach suitable for multi-products (production) technologies is the polar coordinate framework. The polar coordinate framework specifies a translog flexible functional form of a multiple product technology. The dependent variable is specified as a distance function relative to the distances of all outputs from the origin. The independent variables are the usual factors of production but include polar coordinate values obtained relative to the various outputs. Estimation is accomplished by conventional maximum likelihood procedures with two error terms, as in the single product stochastic frontier approach. The main drawback of the polar coordinate framework is that there is likely to be a problem of implicit simultaneous equation bias. This is because functions of the dependent variable appear on both sides of the equation (Ray, 2003).

3.0 Description of the Study Area and the Data

3.1 Description of the Study Area

3.1.1 Background Information

This section provides a detailed description of the study area and the data collected for the present study which is aimed at determining the feasibility of producing biofuels in the country. The feasibility of producing biofuels depends on the availability and the costs of the feedstocks required for their production. An overview of the potential production and costs for various crops which can be used for producing biofuels in Tanzania revealed that sugarcane is the most promising feedstock for ethanol production. Thus, a detailed analysis of the feasibility of producing ethanol in the country focuses on the use of sugarcane as a feedstock. Furthermore, the present study examines the potential of producing biodiesel by using jatropha and oil palm as feedstocks. The decision to focus on those crops is based on the fact that the opportunity costs of using them as feedstocks for producing biodiesel are lower than other crops which could also be used to produce biodiesel.

3.1.2 Study Location

To ensure a comprehensive assessment of the country's biofuels production potential, the general review covered all crops which can be used to produce ethanol and biodiesel. Data were collected from various parts of the country where crops which can be used as feedstocks for biofuels production were grown or the conditions allow them to be produced. Most of the data were obtained from: Kigoma in western Tanzania; Arusha, Kilimanjaro and Manyara in northern Tanzania; Morogoro in eastern Tanzania, and Kagera in north-western Tanzania.

As pointed out previously, owing to its high potential, the detailed analysis of the feasibility of producing ethanol in the country focussed on the use of sugarcane as a feedstock. Data for the detailed analysis were collected in Morogoro region in eastern Tanzania. The region was selected because it was the only part of the country which had sugarcane outgrowers. The main focus of the detailed analysis was outgrowers who operate small farms around the two main sugar factories in the country. Both factories are located in Morogoro region and are about 280 kilometres apart. The decision to focus on small-scale farmers was based on the assumption that their involvement in the supply of feedstocks for biofuels production would increase their incomes and hence enhance the country's efforts to pull them out of poverty. A detailed description of the areas from which data were collected is provided in figure 3.1.

Figure 3.1: Map of Tanzania Showing the Main Study Sites

Tanzania mainland is divided into 21 administrative regions with a total land area of 881,289 square kilometres. The total population of the country was estimated to be 33,461,849[28] people in 2002 (URT, 2003). Morogoro is one of the 21 regions in Tanzania mainland. The region lies between latitudes 5°58" and 10°0" to the south of the equator, and longitudes 35°25" and 35° 30" to the east. It is bordered by seven other regions. Arusha and Tanga regions to the north, the Coast region to the east, Dodoma

[28] This is according to the population census conducted in 2002.

and Iringa regions to the west, and Ruvuma and Lindi regions to the south. The region occupies a total of 72,939 square kilometres. Morogoro region accounts for approximately 8.2 percent of the total area of Tanzania mainland (URT, 2006).

Despite its relatively large size, Morogoro is not among the highly populated regions in the country. The total human population in the region was estimated to be 1753362 people in 2002 (URT, 2003). It has a population density of 24 persons per square kilometre. The average household size in the region is 4.8. The population density in Morogoro region is clearly lower than the average population density for mainland Tanzania as a whole which was estimated to be 38 people per square kilometre in 2002 (URT, 2003).

There is uneven population distribution in the region. More than two thirds of the inhabitants (70 percent) live in the northern districts of Mvomero, Kilosa, and Morogoro. The southern districts of Kilombero and Ulanga, which account for 53 percent of the total area of the region, constitute only a third of the region's population (URT, 2003). The low population density in the southern districts could be attributed to their, relatively, poor infrastructure which lead to difficulties in transporting agricultural produce to urban centres. The poor market access is likely to be among the major factors which discourage people from settling in the southern districts. A detailed description of the population distribution and growth trends for various districts in Morogoro region is provided in table 3.1.

Table 3.1: Morogoro Region Population Size (1967-2002)

Administrative area	1967	1988	2002
Morogoro Urban	24 999	117 601	227 921
Morogoro Rural	291 373	430 202	263 012
Mvomero[29]	-	-	259 347
Kilosa	193 810	346 526	488 191
Kilombero	74 222	187 593	321 611
Ulanga	100 700	138 642	193 280
Morogoro Region	685 104	1 220 564	1 753 362

Source: URT (2003) Population census

[29]Mvomero district was formed after the 1988 population census. In the past it used to be part of Morogoro rural district. The effects of the formation of the new district on the population of Morogoro rural district are clearly depicted by the decrease in its population. The number of inhabitants in the district decreased from 430202 in 1988 to 263012 in 2002.

3.1.3 Natural Conditions

3.1.3.1 Climate and Topography in Tanzania

Tanzania has four main climatic zones. The first zone covers the coastal area and the immediate hinterland, where conditions are mainly tropical, with temperatures ranging from 20 to 30°C. The costal area and the immediate hinterland are characterised by high humidity. Rainfall in this zone varies from 1000 to 1930 mm. The average humidity in the costal area and the immediate hinterland is 78 percent. The second zone is made of the central plateau, which is hot and dry. The average temperature in this zone is 27°C. Rainfall in the central plateau ranges from 500 to 760 mm. It is important to point out that the central plateau experiences considerable daily and seasonal temperature variations. The third zone includes the semi-temperate highland areas, where temperature varies from 15 to 21°C. The average rainfall in this zone is 1700 mm. The last zone comprise the moist lake regions. In this zone rainfall ranges from 1000 to 2300 mm (URT, 2006).

In Morogoro region, where the survey of sugarcane outgrowers was conducted in order to determine the feasibility of producing ethanol by using the crop as a feedstock, annual rainfall ranges from 600 mm in low lands to 1200 mm in the highland plateau. However, there are areas which experience exceptional droughts (with less than 600 mm of rainfall). These areas are in Gairo and Mamboya divisions in the north of Kilosa district and Ngerengere division in the east of Mvomero district. Mean annual temperatures in the region vary with altitude, from valley bottoms to mountain tops. The average annual temperature varies from 18°C on the mountains tops to 30°C in river valleys. In most parts of the region, the average temperatures are almost uniform at 25°C. In general the hot season runs from September to March. Almost all agro-ecological zones found in Tanzania can be found in Morogoro region as well (URT, 2006).

Most of the respondents for the survey conducted for the detailed analysis of the potential of producing ethanol by using sugarcane as feedstock are found in the low land and river valleys zone. This is where sugarcane is mainly grown. Other crops which are grown in large quantities in this zone are maize and rice. Bananas, cocoyams, cassava and sweet potatoes are produced in small amounts. The main rivers in this zone are Wami, Mkindo and Kilombero. Though the area is blessed with several rivers and rivulets, yet, almost all small-scale sugarcane farmers practice rain-fed agriculture.

3.1.3.2 Major Soil Types in Tanzania

Tanzania has a wide range of soil types with varying fertility levels. The reddish brown soils of volcanic origin in the highland areas are the most fertile. Many river basins also have fertile soils, but they are subject to flooding and require drainage control. The red and yellow tropical loams of the interior plateaus, on the other hand, are of moderate to poor fertility. In these regions (tropical countries), high temperatures and low rainfall encourage rapid rates of oxidation, which result in low humus content in the soil and consequently, a clayey texture rather than the desired crumblike structure which is common for temperate soils. Also tropical downpours, which are often short in duration but very intense, compact the soil. By compacting the soils, the heavy tropical rains lead to drainage problems. Moreover, they lead to considerable leaching of soil nutrients making them infertile (IRA, 2005). A detailed description of the distribution of the major soil types in Tanzania is provided in figure 3.2.

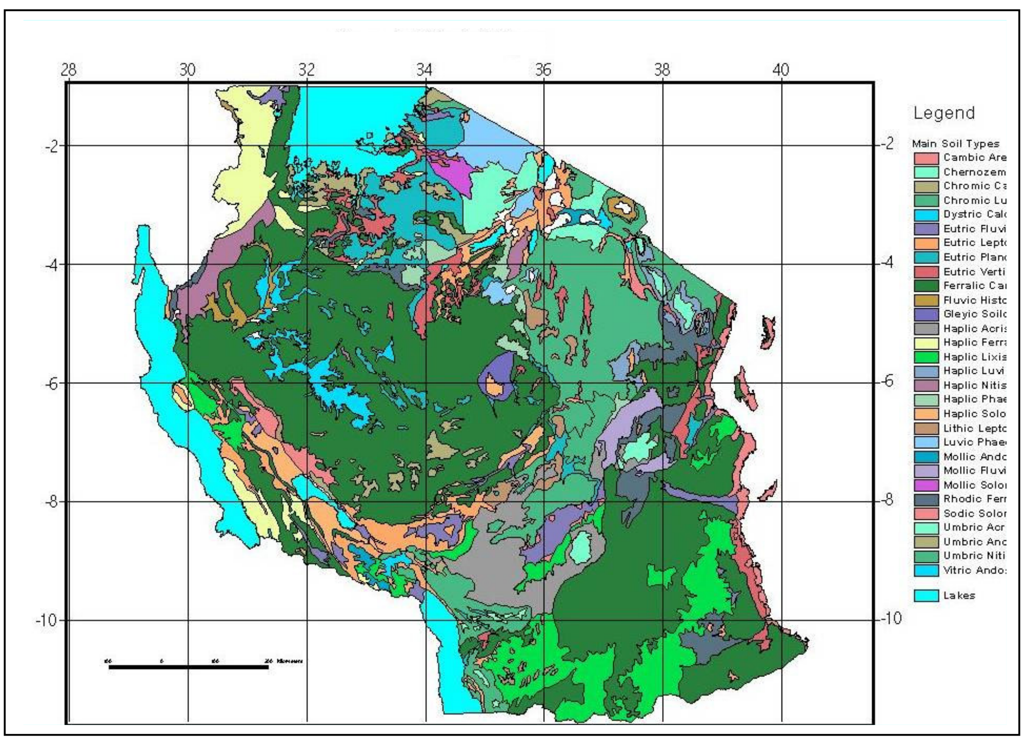

Figure 3.2: Distribution of Major Soil Types in Tanzania

Source: Institute for Resource Assessment, Dar es Salaam

3.1.4 Main Economic Activities in Tanzania

The economy of Tanzania is overwhelmingly agricultural. It relies on smallholder production of crops such as maize, rice, coffee, cotton, cashews and tobacco. Crops such as tea, sisal, and sugarcane are grown in both small and large farms. Other crops which are grown by small-scale farmers include wheat, millet, sorghum, vegetables, bananas, and cassava. In addition to crop growing, large numbers of cattle, sheep and goats are kept. Small industries dealing with processing of agricultural goods, producing beverages, paper, and basic consumer items, also, constitute an important part of the country's economy. The mining sector is among the fastest growing in Tanzania. The minerals which are extracted in significant quantities include gold, salt, gypsum, phosphates, kaolin, diamonds, and tanzanite (URT, 2006).

The crop and livestock sub-sectors play an important role in the socio-economic development of Tanzanians. As pointed out in the previous section, the agricultural sector in the country is mainly based on small-scale peasant farming. It is estimated that smallholders' production under labour intensive farms with low production technology account for more than 75 percent of the total agricultural production. Moreover, almost 90 percent of the marketed agricultural output in the country comes from small-scale farmers. The predominance of rudimentary production technologies is signified by the fact that, about 70 percent of the country's cropped area is cultivated by hand hoe and 20 percent by ox-plough. Only 10 percent of the land is cultivated by using tractors. The use of low production technologies means that farmers are not likely to cultivate large farms. Thus, it is not surprising that nearly 93 percent of all farmers in the country cultivate less than two hectares (URT, 2006).

The agriculture sector is connected to the non-farm sector through forward linkages to agro-processing, consumption and export. The sector provides raw materials to industries and a market for manufactured goods. Unfortunately, however, most of the traditional export crops such as coffee, cotton, sisal, cashew nuts and tobacco undergo little or no processing at all before being exported. This in a way denies the local producers the benefits associated with the export of processed products. A detailed description of the contributions of selected economic activities to the total GDP, from 1992 to 2005, is provided in figure 3.3.

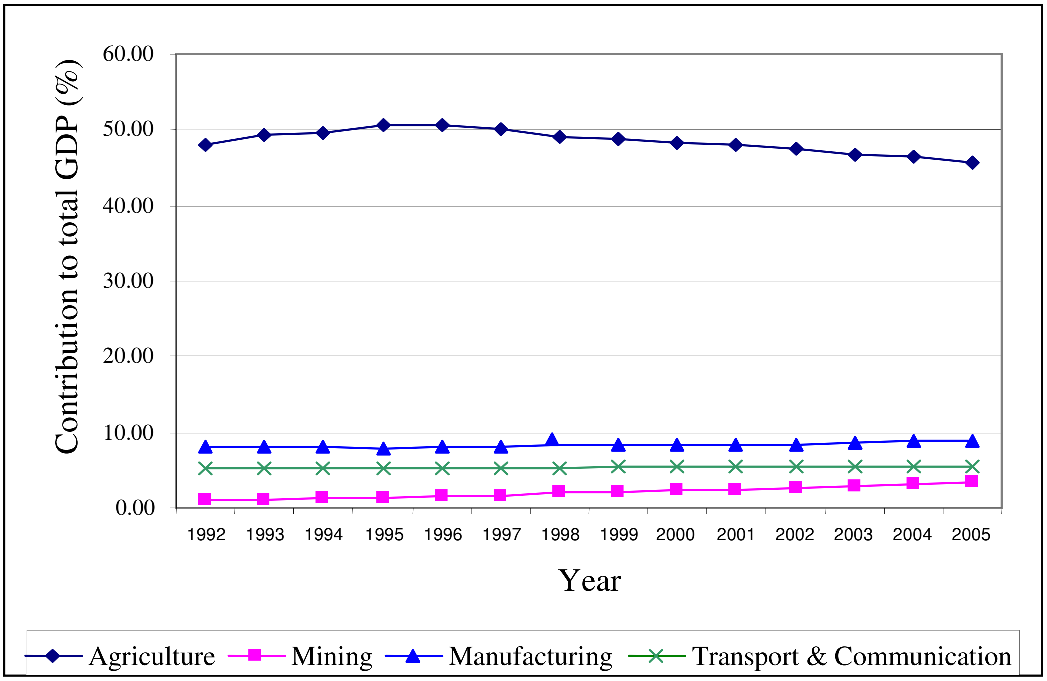

Figure 3.3: GDP by Economic Activity in Tanzania

Source: Produced by using data from NBS (2006)

Figure 3.3 shows that the contribution of the agriculture sector to the total GDP has been declining, slightly, in recent years. The decline of the sector's share of the total GDP can be attributed to the rapid growth of the mining sector. Despite the slight decrease, yet the agriculture sector is the mainstay of the Tanzanian economy. The contributions of the manufacturing and transport sectors, to the total GDP, have remained more or less constant during the considered period.

Just like in the other 20 regions, agriculture is the main economic activity in Morogoro. Small-scale subsistence farming is the mainstay of agriculture in the region. The small-scale peasant farmers constitute more than 80 percent of the total population in the region. The region has a total arable land of 5,885,700 ha, but only 1.2 million hectares are currently cultivated. The land, which is under crop production, constitute about 20 percent of the total arable land in the region. Most of the land in Morogoro is cultivated by small-scale farmers who use rudimentary technologies. The predominance of rudimentary production technologies, inevitably, leads to small farm sizes. Thus, it is not surprising that almost 80 percent of the arable land in the region remains uncultivated.

Morogoro region has three main agroecological zones. The highlands, above the altitude of 600 metres, are suitable for the cultivation of perennial crops such as coffee, fruits, cocoa as well as maize and vegetables. The plateaus, at the altitudes of 300-600 metres, are mainly used for growing maize, cassava, sesame and sorghum. Lowlands and river valleys are suited for growing crops such as rice, sugarcane, banana, cocoyam, cassava and sweet potatoes (URT, 1997). Cultivation of most traditional cash crops such as cotton, coffee and sunflower has declined considerably due to unreliable markets.

There is a wide income difference between rural and urban areas in the region. According to the household budget survey of 2000/01, the mean monthly income in the region was TZS 18400. This was slightly lower than the national average which was TZS 19320. The mean urban monthly income which was TZS 37400 per month in 2001 was almost three times higher than the mean rural monthly income which was just TZS 13100 (URT, 2003). The average monthly income in the region has increased from TZS 18400 in 2001 to TZS 31200 in 2005 (URT, 2006). The national average in 2005 was TZS 30000. This shows that the monthly income in the region is slightly higher than the national average.

3.2 Description of the Data

3.2.1 Data Types and Sources

The main objective of the present study is to determine the feasibility of producing biofuels in Tanzania. To ensure a comprehensive assessment of the viability of producing biofuels in the country, several types of data were collected. With the exception of the detailed analysis of the feasibility of producing ethanol by using sugarcane as a feedstock, where most of the data were obtained through an intensive farm survey, data for the general assessment of the potential of producing biofuels in the country were mainly obtained through review of documentary materials.

The data collected for the general assessment entailed: land availability for the cultivation of the various crops which could be used as feedstocks for producing biofuels; the productivities of the potential feedstocks for ethanol and biodiesel production; estimates of labour requirements and production costs for crops which could be used for producing biofuels. The prevailing prices for petrol, diesel, and the various potential feedstocks for ethanol and biodiesel production were also collected. Moreover, biofuels processing costs were collected. These were obtained from various studies conducted in parts of the world where the production of ethanol and biodiesel was being undertaken. Most of the processing data were extracted from studies conducted by: Shapour *et al.,* (2006), Shumaker *et al.,* (2003), Von Lampe (2006), Urbanchuk *et al.,* (2005), McAloon *et al.,* (2000), and Roger (2007). The processing costs were adjusted to take care of the local labour, capital and utilities costs. Furthermore, prices for other products, such as sugar, which will compete with biofuels for feedstocks were collected.

Data for the detailed analysis of the feasibility of producing ethanol, by using sugarcane as a feedstock, were collected through an intensive survey of the producers of the crop. The survey was conducted from July to November, 2005. A total of 267 sugarcane farmers, from 23 villages, were interviewed. A stratified random sampling procedure was used to make sure that there was a fair representation of sugarcane farmers from the various villages selected for the present study. The data collected were in three main categories, *i.e.:* i) Farm household characteristics: *i.e.* age, education, farming experience and household composition; ii) Various sugarcane production data: *i.e.* size of the farms; total production cost, input use (amounts and prices of inputs such as land, fertilisers, herbicides, insecticides, fungicides, seed cane, labour, tractor services), output amounts and prices, output quality indices as measured by sucrose content; iii) data on other crops grown by the farmers: *i.e.* inputs and outputs of the main crops, other than sugarcane, were also collected. The focus was on rice and maize which were among the main crops in the study area.

Moreover, secondary data were collected to supplement those obtained via the intensive farm survey. These were mainly obtained from various documentary materials. Data on the socio-economic status of the study area and the availability of support services were extracted from reports and other documentary materials from relevant bodies/institutions, such as regional administration offices, NGOs, farmers' associations, *i.e.* Mtibwa Outgrowers Association (MOA), for sugarcane farmers selling their cane to Mtibwa Sugar Estates Ltd; Ruembe Outgrowers Association (ROA), for farmers selling their cane to Kilombero Sugar Company Ltd, and the two sugar factories in the study area. The main agriculture support services on which data were collected were extension services, credit facilities and input supply services. Data concerning the demand and price trends for petroleum products in the country were obtained from the Tanzanian Petroleum Development Company (TPDC).

3.2.2 Description of the Data Used for the Linear Programming Model

3.2.2.1 Estimation of the Land Constraint Variable

Most of the data on land availability for the various crops included in the present study were obtained from the National Bureau of Statistics (NBS) and the Ministry of Agriculture, Cooperatives and Food Security. The present study focussed on those areas where crops which could be used as feedstocks for producing biofuels were grown or could be produced. The crops which have been considered in the present study are: sugarcane, maize, rice, sorghum, cassava, oil palm and jatropha. The areas on which the crops which could be used as feedstocks for producing biofuels were grown or could be produced were divided into four different zones.

The categorization, of the zones, was based on the prevailing and/or potential cropping patterns. The first zone includes areas suited for the production of sugarcane, rice, maize and cassava; the second zone includes areas suited for maize, cassava and sorghum growing; the third zone includes areas where oil palm, maize, cassava and sorghum could be produced and the last zone was made of areas where jatropha and sorghum were grown or could be produced. A detailed description of the four cropping patterns and their respective areas is provided in table 3.2.

Table 3.2: Cropping Zones and their Respective Areas

Cropping Zone	Regions	Total Area (ha)
Sugarcane, Rice, Maize and Cassava	Morogoro, Kilimanjaro, Arusha, Coast and Kagera	570,000
Maize, Cassava and Sorghum	Morogoro, Coast, Mtwara, Lindi, Kigoma, Mbeya, Ruvuma, Rukwa, and Dodoma	11,700,000
Oil palm, Maize, Cassava and Sorghum	Kigoma, Morogoro and Cost	1,200,000
Jatropha and Sorghum	Arusha, Manyara, Dodoma, Singida, Kilimanjaro and Shinyanga	8,000,000
Total Area		21,470,000

Source: NBS and Own Adjustments

3.2.2.2 Assessment of Labour Availability in the Study Area

Labour availability for the four zones was computed by using data from the National Bureau of Statistics. In estimating the number of man-days available for crop production in the four zones, the number of people working in the agriculture sector was multiplied by the average number of man-days per person per year[30]. Since it was assumed that farm workers could move freely from one zone to another, a single figure was used for the four zones. The assumption that labourers could move from one zone to another was based on the fact that such movements were common in the country.

3.2.2.3 Estimation of Minimum Acreage for Various Crops

These were computed by using the national demands for sugar, palm oil, maize, rice, cassava and their respective productivities. The annual demands for sugar and palm oil in Tanzania were estimated to be 450000 and 200000 tonnes respectively. The productivities, for the two crops, were 5.6 and 1.6 tonnes per hectare respectively. Given the demand and productivity figures for the two crops, their respective minimum areas under production were estimated to be 79947 and 125000 hectares respectively. Moreover, in order to ensure food security, minimum areas under maize, rice and cassava were determined and imposed as constraints in the model. The estimates were based on data obtained from NBS and MoACFS. The estimated minimum acreages for rice and cassava were 42940 and 186462 respectively. These, minimum acreage values, were used in the first scenario which took into consideration both local food and biofuels demands.

It is important to point out that, although maize is among the main staple foods in the country, the area required to meet the local demand for the crop (for its traditional food use) was not imposed as a constraint in the model in the first scenario. The decision not to include it was based on the fact that preliminary analyses showed that the introduction of biofuels production would not affect the availability of maize for use as food. This was mainly due to the fact that the opportunity cost of using the crop as a feedstock for producing ethanol was very high.

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[30] In computing the number of man-days available for each crop it was assumed that labourers would move freely from one zone to another depending on the variations in labour requirements in the different zones.

3.2.2.4 Estimates of Labour Requirements for Various Crops

Labour requirements for sugarcane, maize, sorghum, cassava, oil palm and jatropha were computed from own survey data for maize, sugarcane and rice, and by using secondary data for oil palm, jatropha, cassava and sorghum. In the case of sugarcane the present study also considered the possibility of changing the weeding frequency. Three different options have been considered, *i.e.* weeding two times (26.5 man-days/ha), weeding three times (37.5 man-days/ha) and weeding four times (53 man-days/ha). This (the consideration of various weeding options) is aimed at establishing the optimal weeding frequency for the different uses of the crop. A detailed description of the labour requirements for various crops which can be used as feedstocks for biofuels production is provided in table 3.3.

Table 3.3: Labour Requirements for Various Crops

Crop	Labour requirements (Man-days/ha)				
	Land Preparation	Planting	Weeding	Harvesting	Total
Sugarcane	20.00	12.50	37.50	12.50	82
Maize	20.00	7.50	30.00	10.00	67
Rice	22.50	15.00	40.00	20.00	98
Sorghum	15.00	7.50	27.50	20.00	63
Cassava	17.50	7.50	20.00	17.50	70
Oil Palm	45.00	10.00	15.00	30.00	100
Jatropha	45.00	10.00	20.00	55.00	130

Source: Own computation

3.2.2.5 Indicative Prices for Various Crops in the Study Area

The present study uses the opportunity costs of using the various crops as feedstocks for producing ethanol and biodiesel, alongside the processing costs, in estimating the costs of producing biofuels in the country. This section presents a brief description of the main sources of price data for the various crops which are considered to be potential feedstocks for producing biofuels. The prices for the various crops have been used by the present study to estimate the opportunity costs of using those crops as feedstocks for producing ethanol and biodiesel. Prices for rice, sugarcane, sugar, maize, petrol and diesel were obtained from own survey data. Prices for other crops were obtained from the Tanzanian Ministry of Agriculture, Cooperatives and Food Security. A detailed description of the prices for the various crops and fuels is provided in table 3.4.

Table 3.4: Indicative Prices for Various Crops

Crops	Price (TZS/Tonne)
Sugarcane	16,470.00
Maize	160,370.00
Rice	300,725.00
Sorghum	165,000.00
Cassava	80,000.00
Oil Palm	400,000.00
Jatropha	150,000.00
Sugar	800,000.00
Fuels	**Price (TZS/l)**
Petrol	1380
Diesel	1320

Source: Own survey data and MoACFS

3.2.2.6 Estimation of Production Costs for Various Crops and Biofuels

The production costs for maize, sugarcane and rice were computed from own survey data. Costs for other crops were obtained from various secondary sources, including NGOs such as KAKUTE, which is promoting jatropha production in Tanzania. Production costs for biofuels include feedstock and processing costs. Feedstock costs were estimated by using the survey data. The process of estimating the feedstock costs was mainly based on the opportunity costs of using the various crops for producing biofuels.

Since, when the survey was conducted for the present study, there was no commercial production of biofuels in Tanzania, processing costs were estimated by using data from various parts of the world where commercial production of biofuels was undertaken (see section 3.2.1 for a description of the main sources of processing data). The processing costs were adjusted to take care of local labour charges, interest rates and costs for various services. Estimates of the production costs for the various crops and biofuels are provided in table 3.5.

Table 3.5: Average Production Costs for Various Crops and Biofuels

Crop	Production cost (TZS/Tonne)
Sugarcane	7088
Maize	63424
Rice	150715
Sorghum	110530
Cassava	39515
Oil Palm	187188
Jatropha	47667

Biofuels	Feedstock	Production Cost (TZS/l)
Ethanol	Sugarcane	351
	Maize	570
	Rice	768
	Sorghum	676
	Cassava	584
Biodiesel	Oil palm	601
	Jatropha	648

Source: Own computation

3.2.2.7 Estimation of Average Yields for Various Crops

Yield estimates, for maize, sugarcane and rice were computed by using own survey data. Average yields for other crops, which could be used as feedstocks for biofuels production, were calculated by using data from the National Bureau of Statistics and the Ministry of Agriculture, Cooperatives and Food Security. Indicative figures, of biofuels quantities, were computed by using the average yields for the various feedstocks and their respective biofuel yields per tonne. A detailed description of the yields for the different crops and their respective potential biofuels outputs is provided in table 3.6.

Table 3.6: Average Yields and Biofuel Outputs for Various Crops

Crop	Yield (Tonnes/ha)	Biofuel output (l/ha)
Sugarcane	61.82	4,714
Maize	1.62	517
Rice	1.77	760
Sorghum	0.85	251
Cassava	2.90	484
Oil Palm	1.60	1,520
Jatropha	3.60	1,152

Source: Own computation and MoACFS

3.2.2.8 Estimates of Average Returns Per Hectare for Various Crops

The average returns per hectare, for the crops which could be used as feedstocks for producing biofuels, were estimated by using the average yields, prices and production costs figures computed in the previous sections. With the exception of jatropha, which cannot be used as food, returns were estimated for the two alternative uses of the crops, *i.e*. food use and production of biofuels. In order to facilitate the comparison of the profitability of using the various crops for their alternative uses, the present study estimated the total gross margins, *i.e.* the sum of the producers and processors margins for all crops. In estimating the processors margins, the present study assumed medium scale biofuel plants. The returns for the various crops were estimated by using two different approaches. In the first approach, hired labour was taken into consideration. In the second approach hired labour was not considered in estimating the returns. The estimates obtained by using the second approach were used in the linear programming model which was used to estimate the amounts of the various crops that are likely to be produced for use as feedstocks for producing biofuels. It was important to use the estimates computed by using the second approach because we include labour availability among the constraints in the model. On the other hand, the estimates obtained via the first approach were used in determining the potential contribution of the production of the various crops towards the efforts to alleviate poverty among small-scale farmers in the country. A detailed description of the returns for the various crops for the two alternative uses is provided in table 3.7.

Table 3.7: Estimates of Returns for Alternative Crop Uses

Crop	Returns for Alternative Uses of the Crops			
	Food (TZS/ha)		Biofuel Production (TZS/ha)	
	Hired labour considered	Hired labour not considered	Hired labour considered	Hired labour not considered
Sugarcane	2,514,611.95	2,714,152.49	3,018,428.00	3,207,301.50
Maize	510,300.00	603,256.96	155,034.00	251,936.53
Rice	1,194,750.00	1,329,414.43	77,451.60	219,731.60
Sorghum	229,500.00	314,564.93	48,645.50	135,414.82
Cassava	188,500.00	286,695.30	137,680.40	238,306.73
Oil Palm	540,500.00	688,500.00	363,280.00	521,120.00
Jatropha	Not estimated	Not estimated	221,184.00	392,784.00

Source: Own computation

4.0 Study Methodology

4.1 Conceptual Framework

As stated in the background, the general objective of the present study is to explore the potential of producing biofuels and the prospective influence of biofuels production on poverty alleviation among small-scale farmers in Tanzania. The feasibility of producing biofuels depends, amongst others, on the availability and costs of the feedstocks required for their production. Thus, any attempt to determine the viability of producing biofuels should consider the productivity and the prices of the potential feedstocks for biofuels production. Given this fact, the present study assessed the performance of the producers of potential feedstocks for producing biofuels. Efficiency and profitability were used in assessing the performance of the producers of potential feedstocks for producing biofuels. The assessment was aimed at providing a clear picture of the availability and costs of the various crops which could be used to produce ethanol and biodiesel. The variables used to measure farm performance, *i.e.* efficiency and profitability, are to a large extent, influenced by the farmers' endowments of the factors of production, mainly land, labour and capital that jointly play a central role in any production process. In order to facilitate the assessment, the present study developed a conceptual or analytical framework on the performance of producers of potential feedstocks for biofuels production. The framework provided a guideline for identifying important variables for effective and efficient data collection. Moreover, it helped to indicate the most useful area(s) on which to focus limited research resources, and ensure that the data collected were relevant to the objectives of the research. This section presents a brief description of the conceptual framework that was used for information generation during the field work (primary) and in the course of secondary (literature search) data collection.

In addition to the resource endowments, which have been mentioned in the previous paragraph, there are also some institutional factors which are likely to influence the performance of the producers of potential feedstocks for biofuels production in one way or the other. They include availability of extension services, credit services and market access. Access to credit facilities helps to ease off farmers' capital constraints and hence facilitate both capital widening and deepening which are important for increasing farm productivity. Extension services are essential in promoting adoption of new technologies which help to improve farm performance. Market access is crucial because most of the crops which have been considered as potential feedstocks for producing biofuels by the present study are grown mainly for sale. Consequently, introducing alternative uses, such as production of ethanol and biodiesel, which enhances the market for those crops is likely to have a positive impact on their production. Moreover, the increased demand, for crops such as sugarcane, coupled with the likely competition among the different buyers is likely to have a positive impact on producer prices. The potential increase in production and producer prices are likely to lead to increases in incomes for producers of crops which could be used as feedstocks for producing biofuels and hence augment the country's efforts to pull small-scale farmers out of poverty. It is important to note that the increase in production, for the various crops which can be used to produce biofuels, would also benefit those who derive their livelihoods from working as hired labourers. They would benefit through the increased employment opportunities, and the increase in wages which are likely to be associated with the increase in production and profitability of crops which can be used for producing biofuels.

Other factors, which are likely to influence the performance of the producers of potential feedstocks for biofuels production are: farm size, land tenure, farming experience and soil quality. It is envisaged that the increase in demand, for crops such as sugarcane, that would be associated with the introduction of alternative uses for those crops, will have a positive influence on farm size. Thus, the effect of the increased demand on farmers' incomes is not only likely to be caused by the potential increase in producer prices but also from the increased output that would be associated with the expansion of farm sizes for the various potential feedstocks for producing biofuels[31].

Since most of the crops which are considered to be potential feedstocks for producing biofuels are, to a large extent, cash crops in the country, then farmers can reasonably be assumed to have profit maximisation as one of their main objectives. This is not only true for sugarcane, jatropha and oil palm which are grown exclusively for sale, but also

[31] This argument is based on the assumption that the increase in the production of the crops which could be used as feedstocks for producing biofuels would not lead to significant decreases in their respective producer prices, *i.e.* the benefits of increased outputs are not likely to be offset by changes in producer prices.

for crops such as maize, rice, cassava, and sorghum which, despite being traditional food crops, are increasingly becoming key cash earners in the country. The present study assumes that part of the profit obtained from farming activities would be retained and combined with debt capital to expand farmers' capital base. The increase in profitability, associated with capital widening, is likely to increase farmers' incomes and hence pull them out of absolute poverty.

As described in the previous paragraphs, there are several factors which influence the performance of farmers and hence their economic status. The present study focuses on, amongst others, output markets and resource allocation at the household level. To facilitate the analysis, data were collected for various variables which were deemed to be important determinants of farm performance. A schematic presentation of the key variables on which data were collected is provided in figure 4.1.

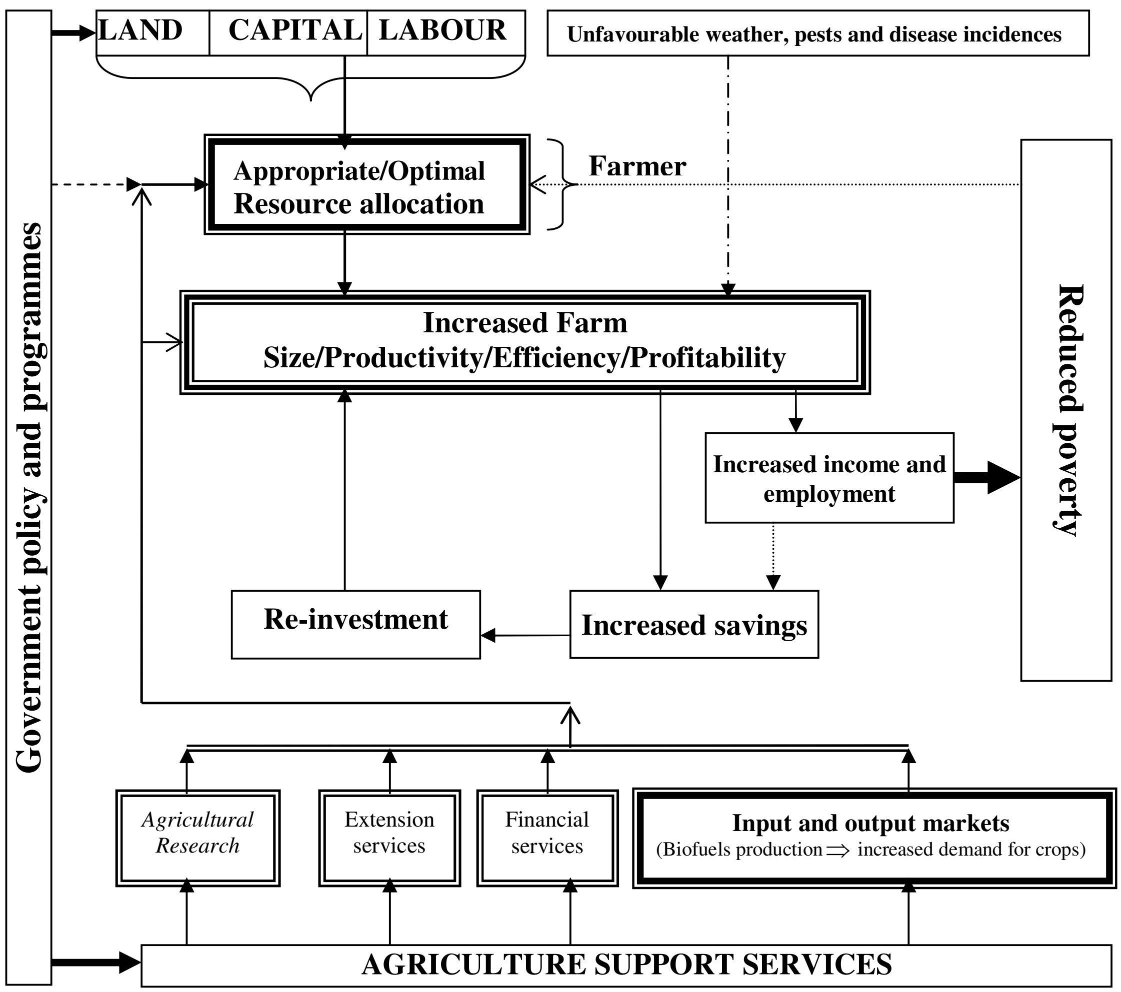

Figure 4.1: Conceptual Framework

4.2 Exploration of the Potential of Producing Biofuels in Tanzania

4.2.1 Background Information

The main objective of the present study is to explore the potential of producing biofuels and the prospective influence of biofuels production on poverty alleviation among small-scale farmers in Tanzania. To achieve this objective, the present study undertook an analysis of the feasibility of producing ethanol and biodiesel, from various crops which could be grown in the country. The crops which have been considered by the present study are sugarcane, cassava, maize, rice, and sorghum for ethanol production, and oil palm and jatropha for biodiesel production. Moreover, the present study explored the potential of producing biofuels from lignocellulosic feedstocks. Regarding the feasibility of producing ethanol from lignocellulosic feedstocks, the analysis focussed on crop residues which are thought to have high potential of being used as feedstocks for ethanol production.

The analysis (of the feasibility of producing biofuels) entailed estimations of potential production for the various feedstocks, costs of producing biofuels from the different feedstocks considered and the returns likely to be obtained from alternative uses of the feedstocks (*i.e.* the opportunity costs of using the various crops as feedstocks for producing biofuels). It is important to note that the cost of producing biofuels falls into two main categories, *i.e.* feedstock and processing costs. The feedstock costs were estimated by using their respective opportunity costs[32]. Since at the time of data

[32] The opportunity costs, used to estimate the costs of producing biofuels, were determined at the household level. For instance, in the case of sugarcane which is currently used for producing sugar, the opportunity cost for this feedstock was estimated by using the returns obtained by farmers from selling their sugarcane to sugar factories. For example, if farmers get TZS 16470 for every tonne of sugarcane they sell to sugar factories, and a tonne of sugarcane produces about 76 litres of ethanol, then the feedstock cost (for producing a litre of ethanol) when using sugarcane as a feedstock would be 16470/76 = 216 TZS. The same procedure was used in estimating the feedstock cost component for other feedstocks for producing ethanol and biodiesel. On the other hand, the processing costs were estimated by using the transport costs, capital expenditure, and the costs for utilities and labour. For instance, the transport cost, assuming a medium scale ethanol plant, utilising sugarcane as a feedstock, and hence a transport distance of less than 20 kilometres, is TZS 3610 per tonne. Thus, the transport costs component (*i.e.* contribution of transport costs to the total processing costs) when using sugarcane as a feedstock for producing ethanol would be given by 3610/76 = 47.50 TZS/l. A similar procedure was used in estimating the contribution of transport costs to the total costs of producing biofuels for other feedstocks. Other processing costs, such as labour charges and costs for utilities, and capital expenditure were obtained from various studies (see section 3.2.1, in chapter three, for a detailed description of the sources of processing data). These (the processing data obtained from other studies) were adjusted accordingly to take care of local labour charges, interest rates and utilities costs. For instance, the labour costs were estimated by using the relationship: $L_T = (W_T/W_S)*L_S$; where: L_T , L_S, W_T and W_S stand for the labour costs per litre of biofuel and Average wage for Tanzania and source (of data) country respectively.

collection there was no commercial biofuels production in the country, as described in the previous chapter, processing costs were estimated by using data from various parts of the world where commercial production of biofuels is undertaken. The processing costs (from other parts of the world) were adjusted to take care of local wages, interest rates and charges for various services. The estimated biofuels production costs, for the various feedstocks, were compared with the landed costs[33] for fossil fuels to find out whether ethanol and biodiesel produced in the country would be able to compete with fossil petrol and diesel. Moreover, the present study tried to determine the quantities of ethanol and biodiesel which are likely to be produced and the impact of introducing biofuels production on the cropping and crop use patterns for selected areas of the country. This study employed a linear programming approach in its quest to determine the quantities of ethanol and biodiesel which are likely to be produced, and the impact of biofuels production on the cropping and crop use patterns for the country[34].

In addition to the estimation of the potential production for the various crops which could be used to produce biofuels, the present study also tried to determine the optimal size(s) and locations for potential biofuels plants. The estimation of the optimal plant size(s) was based on the estimated feedstock availability and the variations in annual capital costs per litre of biofuel at various levels of biofuel plant capacities. In determining optimal plant capacities, this study focussed on minimising the distance from where the feedstocks would be collected. It is important to point out that one should also consider transport costs in determining the appropriate location and capacity for a biofuel plant. A brief discussion on the significance of transport costs in deciding the appropriate size and location for a biofuel plant is provided in the next paragraph.

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[33] We recognise the differences in energy content between fossil fuels and biofuels. Thus, our computation of the landed costs (for petrol and diesel), which are used as estimates for the threshold production costs for ethanol and biodiesel has taken into consideration those differences. The landed costs for fossil fuels were estimated by using the following equation: Landed Cost = World Oil price [US$(x)/Barrel] + Processing Costs (US$2.52/Barrel) + Transport Costs (US$2.7/Barrel) + Insurance (1% of cost and freight charges) + Seller's Premium (US$1.36/Barrel) + Storage at Dar es Salaam Port (US$0.41/Barrel) + Allowance for Transit Losses (1% of the total costs and freight charges). Since one Barrel is approximately equal to 158.76 litres [42 United States gallons (for liquid)], then to get the landed cost per litre of fossil fuel, the estimated landed costs per barrel were divided by 158.76. (This equation, for estimating landed fossil fuels costs, has been adopted, with slight own modifications, from Shumaker *et al.,* (2003), and TaTeDo, 2005).

[34] It is important to determine the impact of introducing biofuels production on both cropping and crop use patterns because some of the potential feedstocks for ethanol and biodiesel production are important food crops in the country. Thus, the analysis is aimed at shedding light on the possible effects of biofuels production on the availability of those crops for their traditional food use.

The emphasis on minimising transport distance for feedstocks is based on the fact that the transport infrastructure is not well developed in the country. Moreover, transport costs are fairly high in Tanzania. Thus, long feedstocks transport distances would inevitably lead to high biofuels production costs[35]. The present study considered four different biofuels plant capacities in its attempt to determine the most appropriate plant sizes for the various feedstocks. The plant capacities considered are: 1.89, 11.36, 56.78 and 113.55 million litres per year. The decision to make use of these four size categories was partly based on a similar categorisation by Shumaker *et al.,* (2003). The reliance on secondary data for capital investment costs meant that the present study could only use plant size categories for which such data were available. There are several studies which report capital investment costs for different plant size categories. The decision to adopt the categorisation used by Shumaker *et al.,* (2003) is based on the fact that it is the only classification which includes very small plants which are likely to be more appropriate for countries like Tanzania which have poor transport infrastructure and high transport costs. The estimates of optimal plant capacities are not aimed at providing rigid figures but rather a guide for prospective investors in biofuels production in the country.

Moreover, the present study tried to determine the impacts of various policy incentives on the feasibility of producing biofuels in Tanzania. The main incentive that was considered was tax exemption. The present study considered several scenarios which entailed various levels of world oil prices and tax exemptions[36]. The world oil prices considered ranged from US$ 20 to 85 per barrel. Also, the present study assumed VAT exemption levels which ranged from zero, *i.e.* no any tax incentive, to 100 percent VAT exemption. The consideration of a wide range of world oil prices was necessitated by their high volatility. The decision to determine the effects of various levels of government support was based on the fact that providing such incentives was a common practice in most countries which were leading in the production of biofuels in the world. Moreover, in recent years the government of Tanzania has used such measures in promoting investments in several sectors in the economy.

[35]High production cost undermines the ability of biofuels to compete with fossil petrol and diesel.
[36] The decision to use world oil prices in determining the probable impact of various levels of tax incentives on the competitiveness of biofuels produced in the country is based on the fact that world oil prices influence local petrol and diesel prices which are among the main determinants of the competitiveness of ethanol and biodiesel.

The present study also tried to determine the effects of changes in sugar and world oil prices on the feasibility of producing biofuels in the country. The analysis involved establishing the ethanol and sugar prices which would make the profit likely to be obtained from using a tonne of sugarcane for ethanol production to be equal to the profit obtained from using it to produce sugar. The estimation of the prices that would equate the profit likely to be obtained from the two alternative uses of sugarcane enabled this study to establish minimum ethanol prices (for different sugar prices) that would make the use of sugarcane to produce ethanol economical.

Since local ethanol prices are likely to be influenced by world oil prices, then the present study tried to establish the relationship between those prices. Moreover, the present study tried to determine threshold biofuels production costs, *i.e.* the production cost above which biofuels cannot compete with the conventional fossil fuels, at various levels of world oil prices. The establishment of the prices of sugar and ethanol that would equate the net returns likely to be obtained from using a tonne of sugarcane for sugar and ethanol production, coupled with the estimates of the local ethanol prices and the threshold production costs at various levels of world oil prices enabled the present study to explain the three way relationship between world oil prices, local sugar and ethanol prices.

4.2.2 Description of the Empirical Model

This section describes the model used to determine the quantities of ethanol and biodiesel which are likely to be produced and the impact of introducing biofuels production on the cropping and crop use patterns for selected areas of the country. In essence the model tried to determine the impact of biofuels production on the availability of the various crops, which could be used as feedstocks for biofuels production, for their alternative uses. The model assumed that farmers aim at maximising profit. This is normally an important part of every firm's objective function, but it is not necessarily the only objective. Farmers normally have a multitude of objectives, such as ensuring food security and minimising losses associated with crop failure, to mention a few. To take care of other farmers' objectives and probable national objectives, such as attaining self sufficiency in sugar production, several other constraints, in addition to the traditional resource restrictions, were imposed to the objective function.

4.2.2.1 Mathematical Presentation of the Empirical Model

The form of the linear programming model used to determine the potential biofuels quantities, and the impact of introducing ethanol and biodiesel production on the cropping and output (crop) use patterns is described below:

The objective function was formulated as follows:

$$Y = \sum_{i=1}^{4} \sum_{j=1}^{14} \overset{n}{C}_{ij} X_{ij} \qquad (11)$$

Subject to the following constraints:

Land availability: The present study covered an area with four different cropping zones.

$$\sum_{j=1}^{14} a_{ij} X_{ij} \leq L_i \text{ for all } i \qquad (12)$$

Labour availability:

$$\sum_{j=1}^{14} a_{ijg} X_{ijg} \leq w_g \text{ for all } i \text{ and } g \qquad (13)$$

Minimum acreage constraint:

$$\sum_{j=1}^{n} a_{ij} X_{ij} \geq \min_j \text{ for all } i \text{ and } j \qquad (14)$$

Non-negativity constraints:

$$X_{ij} \geq 0 \text{ for all } i \text{ and } j \qquad (15)$$

Where:

Y = Gross Margin, *i.e.* Gross Income – Variable Costs

C_{ij} = Gross Margin for the *J*-th activity in the *i*-th zone

i = 1, Zone one (sugarcane, rice and maize)

i = 2, Zone two (cassava, maize and sorghum)

i = 3, Zone three (oil palm, maize and cassava)

i = 4, Zone four (jatropha and sorghum)

j = 1, Sugarcane grown for sugar production

j = 2, Sugarcane grown for ethanol production

j = 3, Maize grown for human consumption (food)

j = 4, Maize grown for ethanol production

j = 5, Rice grown for human consumption (food)

j = 6, Rice grown for ethanol production

j = 7, Sorghum grown for human consumption (food)

j = 8, Sorghum grown for ethanol production

j = 9, Cassava grown for human consumption (food)

j = 10, Cassava grown for ethanol production

j = 11, Oil palm grown for human consumption (food)

j = 12, Oil palm grown for biodiesel production

j = 13, Jatropha grown for biodiesel production

j = 14, hiring labour

X_{ij} = Level of the j-th activity in the i-th zone

a_{ij} = Amount of land (hectares) required per unit of the j-th activity in the i-th zone

b_{ij} = Amount of labour (man-days) required per unit of the j-th activity in the i-th zone

L_i = Amount of land (hectares) available in the i-th zone

w_g = Total amount of labour available for all zones in month g,
where $g_1 = January,...,g_{12} = December$

$\min_j$ = Minimum acreage for the j-th activity

4.2.2.2 Description of the Scenarios Considered

The linear programming model, described in the previous section, was run under three different scenarios. In the first scenario, the local food and biofuels demands were included among the constraints in the model. This was aimed at making sure that the solution obtained satisfies the country's requirements for food and biofuels. This scenario took into consideration the poor transport infrastructure in the country. The poor transport infrastructure means that it is difficult to transport food and fuels over long distances. Furthermore, transport costs in the country are fairly high. Thus, long transport distances would inevitably lead to high prices for biofuels and hence reduce their ability to compete with fossil fuels. Therefore, the constraints (in the model) were set in such a way that the transport distances for both food and biofuels are minimised.

The local food demand was not imposed as a constraint in the model in the second scenario. In this case only the local biofuels demands were included among the constraints in the model. The main assumption underlying this scenario is that the use of food crops as feedstocks for producing biofuels will not affect the availability of those crops for their traditional food use, *i.e.* despite the use of crops such as maize and sorghum for producing ethanol, there would be enough quantities of those crops to meet their local demands for their food use. The assumption that the introduction of biofuels production would not have a significant impact on the availability of the main food crops for their food use is based on the fact that the opportunity costs of using most of those crops as feedstocks for producing ethanol and/or biodiesel are quite high. However, it is important to point out that increases in world oil prices might lead to significant changes in the profitability of using food crops as feedstocks for producing biofuels. Consequently, if world oil prices will continue to increase there is a possibility that large quantities of food crops would be converted into ethanol and/or biodiesel and hence reduce their availability for use as food. Thus, the model would also be useful in determining the world oil price above which policy interventions to ensure the availability of food crops for their traditional food use would be required.

In the third scenario, both local food and biofuels demands were not included among the constraints in the model. In this case the amounts of the various crops which would be available for use as food or feedstocks for producing biofuels would purely be determined by the objective of the model. Thus, in this scenario, the amounts of the various crops which would be available for the alternative uses will largely be determined by the returns expected from those uses. As pointed out in the previous scenario, increases in world oil prices make the use of food crops as feedstocks for producing biofuels more profitable. Consequently, if world oil prices will continue to increase, it will reach a point where policy interventions would be required to ensure that food crops are available for their traditional food use at reasonable prices. The good news is that the model could also be used to identify the world oil prices at which policy interventions would be required to ensure the availability of the various crops for use as food. Likewise, the model would be useful in determining the world oil prices at which government support would be required by producers of biofuels. For a detailed description of the food and biofuels demands constraints imposed in the various scenarios considered by the present study see appendix 2.

4.3 Determining the Impact on Profitability of Biofuels Feedstocks

The present study also assessed the impact of biofuels production on the profitability of sugarcane and jatropha farming. The assessment involved determining the prevailing profitability figures and compare them with the potential profitability of the crops when they would be used to produce ethanol and biodiesel respectively. In estimating the impact of using sugarcane as a feedstock for producing ethanol on the net returns for small-scale producers of that crop, the farmers' share of the total returns obtained when the crop is used to produce sugar was adjusted to take care of the differences in processing costs between sugar and ethanol. A similar approach was used in estimating the impact of using jatropha as a feedstock for producing biodiesel on the net returns for the producers of the crop in the country. The assessment enabled the present study to determine the potential contribution of biofuels production to the country's poverty alleviation efforts among the producers of those crops. A similar approach was used in a study in Fiji by Reddy (2003).

Furthermore, the present study estimated farm profitability at various levels of farm size for the alternative uses of the crops. This was aimed at establishing the minimum farm size required for an average Tanzanian household to move out of absolute poverty. Moreover, the present study estimated the number of new employment opportunities that would be created by the introduction of biofuels production. This analysis was necessitated by the fact that most of the rural poor depend on incomes obtained from working as hired labourers to supplement their meagre farm incomes. Thus, estimates, of the new employment opportunities, provide an additional yardstick for assessing the potential contribution of biofuels production to the livelihoods of very small farmers. Determining biofuels productions' poverty alleviation potential for smallholder farmers is important because such farmers account for a large proportion of the Tanzanian poor.

4.4 Determining Farm Size-Profitability Relationship

A review of the most recent studies on developing countries agriculture revealed that there is no consensus regarding the farm size-profitability relationship in those countries' agriculture. The lack of complete knowledge regarding the influence of farm size on profitability compelled the present study to determine its influence among the producers of crops which can be used as feedstocks for producing biofuels in Tanzania.

This was deemed to be important as the knowledge of the influence of size on farm profitability will provide an important input to the process of formulating strategies for alleviating poverty in rural areas where agriculture is the main source of livelihoods. This is the main focus for the third objective of the present study.

To achieve its third objective, *i.e.* to examine the relationship between sugarcane profitability and farm size, average profit values were computed for each of the farms included in the present study. Then the variations of the computed average profit figures with changes in farm size was established. To get a general idea of how profitability changes with farm size, the average profit figures were plotted against farm size. The attempt to establish the relationship between farm size and profitability followed similar efforts by Carter (1984), Byiringiro and Reardon (1996), Kimhi (2003) and Helfand (2003) whose studies were aimed at establishing whether the inverse relationship between farm size and productivity was a rule in developing countries' agriculture. The use of profitability as a measure of farm performance is based on the assumption that farmers have profit maximisation as one of their main objectives.

4.5 Problems Facing Producers of Potential Feedstocks for Biofuels

The feasibility of producing biofuels would largely depend on the availability of crops which can be used as feedstocks for producing ethanol and biodiesel. In order to determine whether there would be a smooth feedstock supply, the present study undertook a detailed analysis of the production of various crops which can be used to produce biofuels. The analysis entailed, amongst others, the identification of the main problems encountered by the producers of potential feedstocks for ethanol and biodiesel production. To be precise, this is the fourth objective of the present study.

To achieve this objective (identifying the main problems encountered by the producers of potential feedstocks for biofuels production) farmers were asked to name and state their perceptions regarding the severity of the main problems encountered in their day-to-day farming activities. Respondents were provided with a four point scale in order to facilitate the analysis. The scale also provided an option for farmers who were not sure whether certain issues, such as availability of inputs and access to credit services, were important problems or not.

The responses of the producers of crops which can be used as feedstocks for producing ethanol and biodiesel were used, by the present study, to draw a list of the key obstacles encountered by the producers of potential feedstocks for biofuels production in the study area. Percentages were computed for each problem mentioned in order to establish its severity. Then the scores of each of the obstacles were used in ranking the various problems which were mentioned by the producers of potential feedstocks for biofuels production. This enabled the present study to identify the areas where the efforts to improve the performance of the producers of the crops which can be used for producing ethanol and biodiesel should be directed.

4.6 Measuring Efficiency Among Sugarcane Farmers

4.6.1 Background Information

The present study undertook a detailed analysis of the feasibility of producing ethanol by using sugarcane as a feedstock. The focus on sugarcane is based on the fact that the crop has a high potential for being used as a feedstock for producing ethanol. As pointed out in the previous chapters, the economics of producing and using biomass ethanol depend on a number of factors specific to the local situation. These factors include: (i) the cost of feedstocks, which varies among countries, depending on land availability and quality, agricultural productivity, and labour costs; (ii) processing costs, which depend on plant size and location; and (iii) the cost of fossil petrol, which depends on world oil prices. This section provides a detailed description of approach used to measure production efficiency among sugarcane outgrowers in Tanzania. To be precise, this is the fifth and final objective of the present study.

The present study made use of DEA to measure the efficiency of sugarcane outgrowers. In addition to sugarcane, the outgrowers were also producing maize and rice. Thus the ability of DEA to handle multi-outputs situations made it a natural choice for this study. Moreover, the relationships between the efficiency indices computed and the various factors which were presumed to be among the key determinants of efficiency among the producers of crops which can be used to produce biofuels were established. The socio-economic characteristics, of the respondents, which were included in the assessment were: farm size, farming experience, and household heads' levels of education. The established relationships, between efficiency and the selected socio-economic characteristics, enabled the present study to have a rough idea on what could be done to improve the performance of the producers of potential feedstocks for producing biofuels.

4.6.2 Specification of the DEA Model

The present study made use of the DEA approach to determine the efficiency of producers of various crops which can be used as feedstocks for ethanol production. The general form of the model employed to determine the efficiency of those farmers is described below:

$$\begin{aligned} &\max_{\Phi,\lambda} \Phi, \\ &\text{st } -\Phi y_i + Y\lambda \geq 0, \\ &\quad x_i - X\lambda \geq 0, \\ &\quad \lambda \geq 0, \end{aligned} \qquad (16)$$

Where,

y_i is a $M\times 1$ vector of output quantities for the *i*-th farm;
x_i is a $K\times 1$ vector of input quantities for the *i*-th farm;
Y is a $N\times M$ matrix of output quantities for all N farms;
X is a $N\times K$ matrix of input quantities for all N farms;
λ is a $N\times 1$ vector of weights; and
Φ is a scalar.

Under this specification, Φ will take a value greater than or equal to one, and φ -1 is the proportional increase in outputs that could be achieved by the *i-th* farm, with input quantities held constant. It should be noted that $1/\Phi$ defines a technical efficiency (TE) score which varies between zero and one. The Linear Programming (LP) model described in equation (16) was solved N times – once for each farm in the sample. Each LP produces a φ and a λ vector. The φ-parameter provides information on the technical efficiency score for the *i-th* farm and the λ-vector provides information on the peers of the *i-th* farm. The peers of the *i-th* farm are those efficient farms that define the facet of the frontier against which the *i-th* farm is projected.

5.0 Results and Discussion

5.1 Exploration of Biofuels Production Potential in Tanzania

5.1.1 Biofuels Production Costs and Net Returns for Various Feeedstocks

5.1.1.1 Ethanol Production Costs and Net Returns for Various Feedstocks

This section presents the results of the estimation of the costs of producing ethanol and the net returns for various crops. The estimates of both the costs of producing ethanol and the returns likely to be obtained for the various crops are important in identifying crops which have high potential for providing feedstocks for producing ethanol. The estimates (of ethanol production costs) have been computed by using the opportunity costs of using the various crops as feedstocks for producing ethanol and the processing costs. Moreover, the present study estimated the expected revenues (from ethanol production) at the prevailing world oil prices. The production costs and the revenue estimates were used to compute the net returns likely to be obtained from using the various crops as feedstocks for producing ethanol. A detailed description of the costs of producing ethanol by using sugarcane, maize, rice, sorghum, and cassava as feedstocks and the respective net returns per hectare for each of those crops is provided in table 5.1.

Table 5.1: Ethanol Production Costs and Net Returns for Various Feedstocks

Feedstock	Ethanol Cost (TZS/l)	Net Returns (TZS/ha)
Sugarcane	351	3,018,428.00
Maize	570	155,034.00
Rice	768	77,451.60
Sorghum	676	48,645.50
Cassava	584	137,680.40

Source: Own computation

It can be noted from table 5.1 that, with an estimated cost of TZS 351 (US$ 0.276) per litre, sugarcane is the cheapest feedstock for producing ethanol in Tanzania. This (the cost) is relatively higher than the costs of producing ethanol from sugarcane in Brazil and Thailand which have been estimated to be US$ 0.220 and 0.260 per litre respectively (Henniges and Zeddies, 2006; Von Lampe, 2006). But it is lower than the cost of producing ethanol by using the same feedstock in the USA (US$ 0.390/litre), South Africa (US$ 0.437/litre), Australia (US$ 0.325/litre), and China (US$ 0.546/litre) (Henniges and Zeddies, 2006; Von Lampe, 2006). Furthermore, the table shows that maize is the second cheapest feedstock for producing ethanol. Unlike sugarcane, the cost of producing ethanol by using maize in the country [TZS 570 (US$0.448) per litre] is higher than the cost of producing ethanol by using maize in the USA and South Africa which have been estimated to be US$ 0.289 and 0.217 per litre respectively (Von Lampe, 2006). The relatively high ethanol production cost when using maize as a feedstock could be attributed to the high opportunity cost of using maize for producing ethanol. Maize is followed closely by cassava. It could be noted further that the costs of producing ethanol from sorghum and rice are very high. The cost of producing ethanol by using sorghum as a feedstock which is TZS 676 (US$ 0.531) per litre is higher than the cost of producing ethanol by using the same feedstock in Australia which is estimated to be US$ 0.276 per litre (Urbanchuk *et al*., 2005). Just like the case of maize, the high ethanol production cost when using sorghum as a feedstock is likely to be caused by the high opportunity cost of using the crop for producing ethanol[37].

Moreover, table 5.1 shows that there is a wide variation in ethanol production costs for the various crops considered by the present study. Since the differences in processing costs for the various crops are quite small, then the wide variations in ethanol production costs are likely to be caused by the large differences in the opportunity costs of using those crops as feedstocks for producing ethanol.

It is worthwhile pointing out that although ethanol could also be produced from lignocellulosic feedstocks, such as crop residues, the cost of producing ethanol by using those materials, for standalone plants, are higher than the cost of ethanol produced by using the traditional sugar and starchy feedstocks. The cost of producing ethanol from

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[37] The total ethanol production cost, for instance, when using sugarcane as a feedstock, includes the opportunity cost of using sugarcane for producing ethanol and the processing costs. The opportunity cost component was estimated by using the returns the farmers get from selling their cane to sugar factories. For example, if farmers get TZS 16470 for every tonne of sugarcane they sell to sugar factories, and a tonne of sugarcane produces about 76 litres of ethanol, then the feedstock cost (for producing a litre of ethanol) when using sugarcane as a feedstock would be 16470/76 = 216 TZS. The same procedure was used in estimating the feedstock cost component for other feedstocks for producing ethanol and biodiesel. On the other hand, the processing costs were estimated by using the transport costs, construction costs, and the costs for utilities and labour. For instance, the transport cost, assuming a medium scale ethanol plant, utilising sugarcane as a feedstock, and hence a transport distance of less than 20 kilometres, is TZS 3610 per tonne. Thus, the transport costs component, when using sugarcane as a feedstock for producing ethanol, would be given by 3610/76 = 47.50 TZS/l. A similar procedure was used for estimating the contribution of transport costs to the total costs of producing biofuels for other feedstocks. Other processing costs, such as construction costs, labour charges and costs for utilities, were computed by using data from various studies as described in chapter three and four. In the case of sugarcane, assuming a medium scale ethanol plant, transport costs accounts for about 35% of the total processing costs.

lignocellulosic materials is estimated to be TZS 880 (US$ 0.693) per litre. This was obtained by adjusting the estimates of McAloon, *et al.,* (2000) and Lindstedt (2003) to take care of local wages, interest rates, and local charges for other services. Since the opportunity costs of using lignocellulosic materials for producing ethanol is quite low, then the high cost for ethanol produced by using those materials is likely to be caused by high processing costs. The high processing costs for lignocellulosic ethanol could be attributed to the fact that the technology for producing ethanol from such materials is still in its infancy stage. Given the high production costs for standalone lignocellulosic ethanol plants, the present study considered the use of such feedstocks only in a combined setup with traditional feedstocks.

Integrating traditional and lignocellulosic ethanol production processes is known to reduce the cost of producing lignocellulosic ethanol. Due to insufficient data on the cost of ethanol produced from lignocellulosic feedstocks in integrated processing facilities, the present study was unable to undertake a detailed assessment of ethanol production costs for such feedstocks in those plants. It suffices to point out that although the cost of ethanol produced by using lignocellulosic materials in integrated plants would be lower than the cost of ethanol produced from such materials in standalone plants, it would still be higher than the cost of ethanol produced from traditional feedstocks, such as sugarcane and maize, in standalone plants. Thus, taking advantage of the abundance of lignocellulosic feedstocks would only be possible if the opportunity costs of using them for producing biofuels would be lower enough to offset their high processing costs.

5.1.1.2 Biodiesel Production Costs and Net Returns for Oil Palm and Jatropha

The present study also assessed the potential of producing biodiesel in Tanzania. The assessment focussed on two main crops which are considered to be potential feedstocks for producing biodiesel in the country. The crops which have been considered in assessing the viability of producing biodiesel are oil palm and jatropha. Just like in the case of ethanol, the estimation of biodiesel production costs took into account both feedstock and processing costs. A description of the estimates of biodiesel production costs and the returns likely to be obtained from using jatropha and oil palm as feedstocks for producing biodiesel is provided in table 5.2.

Table 5.2: Biodiesel Production Costs and Net Returns for Oil Palm and Jatropha

Feedstock	Biodiesel Production Cost (TZS/l)	Net Returns (TZS/ha)
Oil Palm	601	363,280.00
Jatropha	648	221,184.00

Source: Own computation

The results presented in table 5.2 show that the costs of producing biodiesel in the country are TZS 601 (US$ 0.473) and 648 (US$ 0.510) per litre for oil palm and jatropha respectively. These are relatively lower than the costs of producing biodiesel in the USA (US$ 0.549/litre), Brazil (US$ 0.568/litre) and in the European Union (US$ 0.607/litre) (Von Lampe, 2006). Thus it is plausible to argue that there is a high potential for producing biodiesel competitively in the country.

Table 5.2 shows that oil palm is a cheaper source for producing biodiesel than jatropha. Since the processing costs are more or less the same for both feedstocks, then the variation in total biodiesel production costs is likely to be caused by differences in the costs of feedstocks. Since jatropha has no other significant commercial use, then the relatively high production cost for biodiesel produced by using the crop as a feedstock is likely to be caused by its high labour requirements.

Although the cost of producing biodiesel by using jatropha is relatively higher than that of palm oil, still jatropha seems to be a more promising feedstock than palm oil. This is because the production of palm oil in Tanzania is well below its local demand for its food use. Furthermore, the ability of jatropha to grow in harsh climatic conditions means that there is a large land area on which it can be cultivated. Also, its drought resistance, would ensure a reliable feedstock supply for biodiesel production. The importance of drought resistant sources of feedstocks arises from the fact that the country experiences frequent droughts.

A quick comparison of the costs of producing biodiesel and ethanol (from their cheapest feedstocks) shows that the cost of biodiesel production is higher than that of ethanol. Since the processing costs for ethanol and biodiesel are more or less the same, then the difference in production cost could be attributed to the high opportunity cost of using palm oil as a feedstock for producing biodiesel.

5.1.2 Comparison of Fossil Fuel Prices and Biofuels Production Costs

5.1.2.1 Comparison of Petrol Prices and Ethanol Production Costs

The present study also tried to determine the relationship between world oil prices and the landed petrol prices in Tanzania. This (relationship between world oil and local petrol prices) is important as it enables the present study to establish the minimum world oil price at which ethanol would be able to compete with petrol in the local market. The estimates of landed petrol prices were compared with the cost of producing ethanol from the various feedstocks so as to determine the minimum world oil price required for ethanol produced from the various feedstocks considered to be able to compete with fossil petrol. The estimates of the landed petrol prices and the corresponding differences between those prices and ethanol production costs for various feedstocks at different levels of world oil prices are provided in table 5.3.

Table 5.3: Comparisons of Petrol Landed Costs and Ethanol Production Costs

World Oil Price (US$/Barrel)	Landed Price (TZS/l)	Landed Price – Ethanol Production Costs for Various Feedstocks (TZS/l)				
		Sugarcane	Maize	Rice	Sorghum	Cassava
20	210	-141	-360	-558	-466	-374
25	253	-98	-317	-515	-423	-331
30	296	-55	-274	-472	-380	-288
35	339	-12	-231	-429	-337	-245
40	382	31	-188	-386	-294	-202
45	425	74	-145	-343	-251	-159
50	468	117	-102	-300	-208	-116
55	511	160	-59	-257	-165	-73
60	554	203	-16	-214	-122	-30
65	597	246	27	-171	-79	13
70	640	289	70	-128	-36	56
75	683	332	113	-85	7	99
80	726	375	156	-42	50	142
85	769	418	199	1	93	185

Source: Own computation

Table 5.3 shows that there is a wide variation in the world oil prices at which ethanol produced by using the different feedstocks considered in the present study would be able to compete with conventional fossil petrol. The table shows that ethanol produced by using sugarcane as feedstock would be able to compete with fossil petrol if world oil prices would not fall below US$ 40 a barrel. Given this estimate, one could argue that at the prevailing world oil prices, of more than US$ 50 a barrel[38], ethanol can be produced competitively from sugarcane without any preferential government treatment. The production of ethanol, by using sugarcane as a feedstock, would save the country a substantial proportion of the foreign currency it is currently spending on oil imports. Furthermore, the table shows that if world oil prices will go beyond US$ 80 a barrel then it would be possible to produce ethanol competitively from any of the feedstocks considered in the present study.

The present study also tried to establish the relationship between world oil prices and the differences between petrol and ethanol production costs. The established relationship provides a clear picture of the influence of changes in world oil prices on the feasibility of producing ethanol in the country. Figure 5.1 provides a graphical presentation of the variations of world oil prices and the differences between the landed petrol prices and ethanol production costs for sugarcane, maize, sorghum, rice and cassava[39].

Figure 5.1 shows that if world oil prices will go beyond US$ 63 per barrel, then it will be possible to produce ethanol competitively by using sugarcane, maize, and cassava as feedstocks. Furthermore, the figure shows that the use of sorghum and rice for ethanol production would require either very high world oil prices (US$ 75 and 85 a barrel respectively) or decreased opportunity costs for using them as feedstocks for producing biofuels. Also the figure emphasises the existence of a wide variation in the minimum

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[38] Refers to the world oil price in early October, 2006, which was about US$ 58 per barrel.

[39] The estimation of the differences between petrol landed costs and ethanol production costs, which (the differences) have been used as indicators of the profitability of producing ethanol, at various levels of world oil prices, and for various feedstocks, is aimed at establishing the minimum world oil prices that will be required for ethanol produced by using sugarcane, maize, rice, sorghum, and cassava to be able to compete with the traditional fossil fuels. Although we recognise the fact that world oil prices are likely to influence ethanol production costs, in the present study we assume that, in the short run, changes in world oil prices would not have significant impacts on ethanol production costs. We use a similar approach and assumption in determining the profitability of biodiesel production, when using oil palm and jatropha as feedstocks, at various levels of world oil prices. A similar approach was used in a study aimed at determining the feasibility of producing biodiesel in Georgia, USA, conducted by Shumaker *et al.,* in 2003. Their analysis involved estimating the profitability of biodiesel production at various prices (of biodiesel) [these (biodiesel prices) are influenced by world oil prices]; and using assumptions similar to those being used in the present study, they came up with relationships (between profitability and prices) similar to those presented in figure 5.1 and 5.2.

world oil prices required for ethanol produced from the various feedstocks to be able to compete with fossil petrol. This was first revealed by table 5.3. Since there are no significant differences in processing costs for the various crops considered to be potential feedstocks for ethanol production, then the wide variation of the world oil price at which they could be used to produce ethanol competitively could be attributed to the large differences in the opportunity costs of using them as feedstocks for producing ethanol.

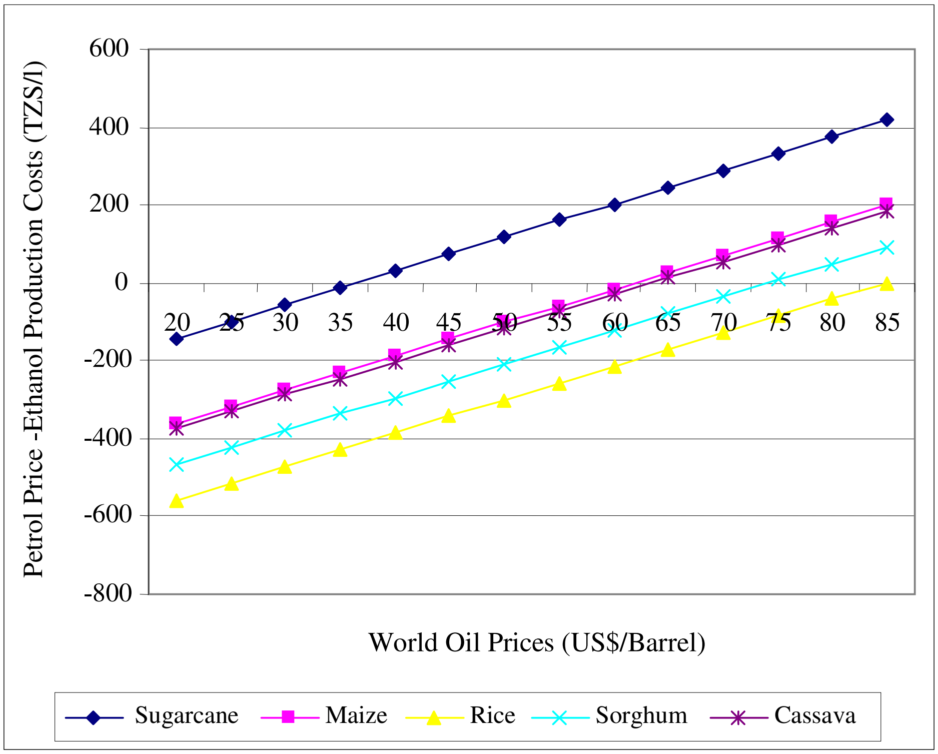

Figure 5.1: Variations of World Oil Prices and Feasibility of Ethanol Production

5.1.2.2 Comparison of Diesel Prices and Biodiesel Production Costs

Just like in the case of ethanol, the present study also tried to establish the landed diesel prices at various levels of world oil prices. These were then compared with the costs of producing biodiesel from oil palm and jatropha. The comparison of the estimates of the landed diesel prices and biodiesel production costs enables the present study to establish the minimum world oil prices required for the biodiesel produced by using jatropha and oil palm as feedstocks to be able to compete with fossil diesel. The estimates of the diesel landed prices and the differences between those prices and the costs of producing biodiesel, using oil palm and jatropha as feedstocks, are provided in table 5.4.

Table 5.4: Comparisons of Diesel Landed Costs and Biodiesel Production Costs

World Oil Price (US$/Barrel)	Landed Price (TZS/l)	Diesel Landed Price - Biodiesel Production Costs for Oil Palm and Jatropha(TZS)	
		Palm Oil	Jatropha
20	187	-414	-461
25	230	-371	-418
30	273	-328	-375
35	316	-285	-332
40	359	-242	-289
45	402	-199	-246
50	445	-156	-203
55	488	-113	-160
60	531	-70	-117
65	574	-27	-74
70	617	16	-31
75	660	59	12
80	703	102	55
85	746	145	98

Source: Own computation

Table 5.4 shows that for biodiesel produced from palm oil to be able to compete with fossil diesel the world oil price would have to be at least US$ 60 per barrel[40]. The table shows that the minimum world oil price that is required for competitive biodiesel production, by using jatropha as a feedstock, is US$ 65 per barrel. Thus, it is reasonable to argue that at the prevailing world oil prices, there is a slight chance of producing biodiesel profitably in the country[41]. Unlike the case of ethanol production (especially when sugarcane is used as a feedstock) where preferential treatment was not necessary, if world oil prices would not continue to increase, the production of biodiesel in the country would require significant government support.

The present study also established the relationship between the feasibility of producing biodiesel in the country and changes in world oil prices. A graphical illustration of the variations of world oil prices and the differences between the landed costs for diesel and the cost of producing biodiesel (which is a key determinant of the feasibility of

[40] A margin of TZS 100 has been allowed to take care of probable variations in production costs.
[41] The prevailing world oil price at the time of writing was US$ 58 a barrel.

producing biodiesel) when using oil palm and jatropha as feedstocks, at various levels of world oil prices is provided in figure 5.2.

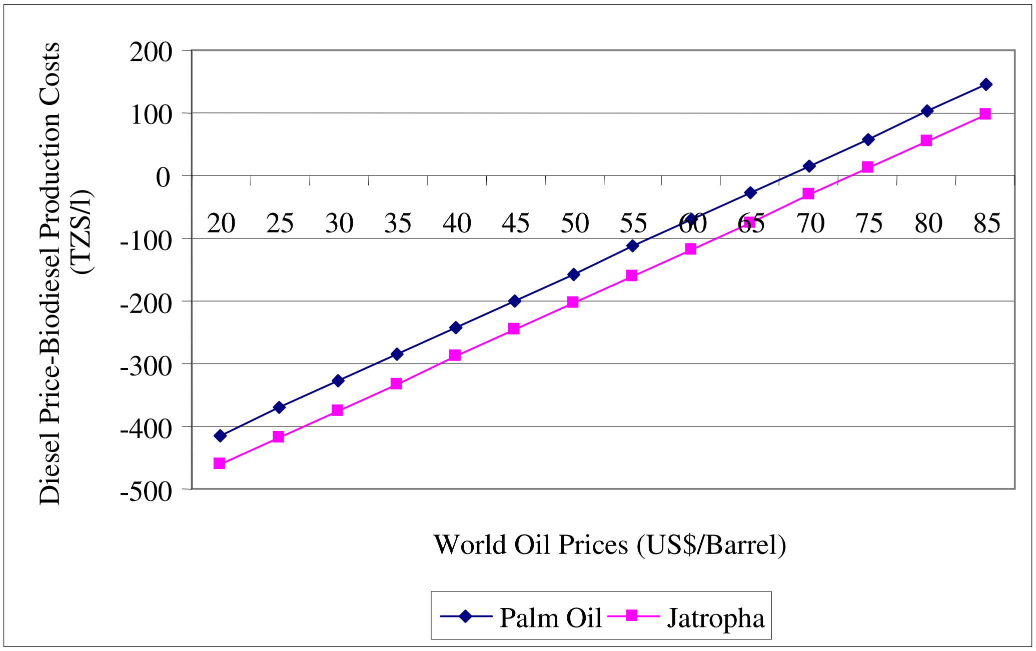

Figure 5.2: Variations of World Oil Prices and Feasibility of Biodiesel Production

It can be noted from figure 5.2 that the minimum world oil prices required for the production of biodiesel, by using oil palm and jatropha, to be feasible are fairly high. The high world oil prices which are required for the production of biodiesel, by using oil palm and/or jatropha, to be competitive might be attributed to the high local prices for palm oil (used as food) and the high labour costs for collecting jatropha seeds. The high palm oil price means that the opportunity cost of using it for producing biodiesel would, inevitably, be high. The high local prices for palm oil could be attributed to the fact that its production is well below its local demand for its use as food. Thus, there is a need to increase both the production and productivity of oil palm in the country in order to enhance the competitiveness of biodiesel produced by using palm oil as a feedstock. The same could be said for jatropha. The high cost for this feedstock can be attributed to its low productivity which leads to high labour costs for seed collection. The low productivity of the crop implies that labourers spend many hours to collect only a few kilograms of jatropha seeds. Since the improvement of both production and productivity, for the two crops, is not likely to be achieved in the near future then government support would be crucial for attracting investments in biodiesel production in the country.

5.1.3 Analysis of the Interactions of Oil, Sugar and Biofuels Prices

5.1.3.1 Relationship Between Ethanol and Sugar Prices

There are two main determinants of the availability of feedstocks for producing ethanol. The first is the availability of resources required for their production, *i.e.* land, labour and capital. The second is the returns from their alternative uses, *i.e.* the opportunity costs of using the various crops as feedstocks for producing ethanol. In view of this fact, the present study tried to establish the relationship between sugar and ethanol prices. The main objective of the analysis is to determine sugar and ethanol prices that would make the profit obtained from using a tonne of sugarcane to produce sugar equal to that likely to be obtained when using the feedstock to produce ethanol. A graphic presentation of the relationship between sugar, ethanol and world oil prices at which a tonne of sugarcane would provide equal profits for its two alternative uses is provided in figure 5.3.

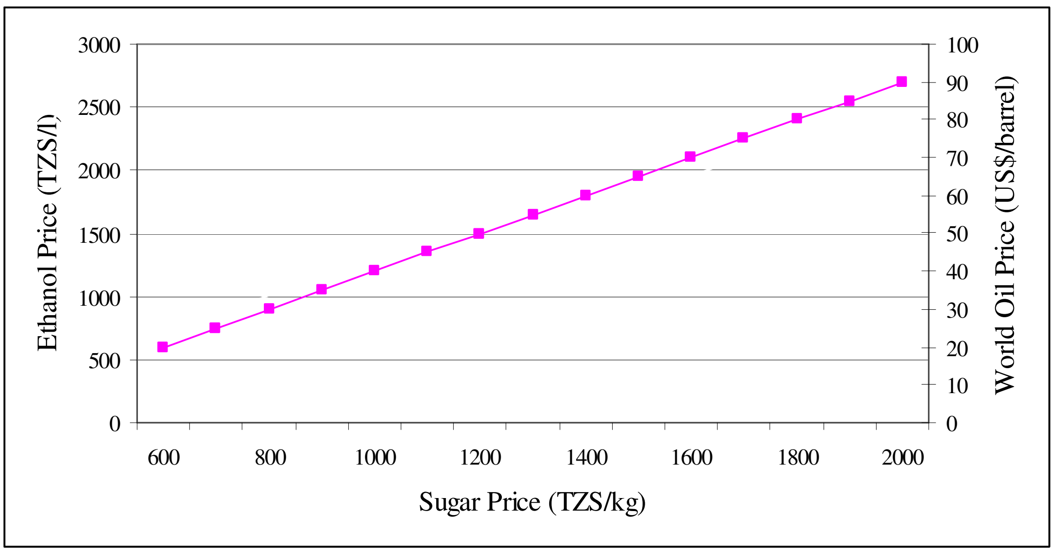

Figure 5.3: Ethanol - Sugar - World Oil Prices Relationship

Figure 5.3 shows that for the use of sugarcane for producing ethanol to be economical the price of ethanol should be higher than that of sugar. This, high ethanol price, is required for the returns from using sugarcane as a feedstock for ethanol production to be equal to that obtained from using it for producing sugar. The relatively higher ethanol price that is required for the profit obtained from using a tonne of sugarcane to produce ethanol to be equal to that obtained from using it for sugar production could be attributed to the fact that a tonne of sugarcane produces more kilograms of sugar than litres of ethanol. Moreover, the disparity may possibly be caused by differences in processing costs for ethanol and sugar. The estimates of the sugar and ethanol prices at which a tonne of sugarcane provides equal profits for the two alternative uses are significant as they are among the key determinants of the likelihood of the crop being available for use as a feedstock for producing ethanol.

The present study made use of the established sugar-ethanol-world oil prices relationship to determine whether, under the prevailing local sugar prices, the use of sugarcane to produce ethanol would be economical. The sugar price at the time of analysis was TZS 800 per kilogram. At this price ethanol has to sell for at least TZS 1000 a litre for the use of sugarcane for producing ethanol to be economical. Since the present study, given the prevailing world oil prices, estimated the probable ethanol price to be more than TZS 1000 a litre, then it is plausible to argue that it would be more profitable to use sugarcane as a feedstock for producing ethanol[42].

5.1.3.2 Ethanol Threshold Production Cost Variations with Oil Prices

The ability of ethanol to compete with fossil petrol is among the key factors in analysing the feasibility of its production. In view of this fact the present study also estimated the threshold ethanol production costs at various levels of world oil prices[43]. The estimates of the threshold production costs (for ethanol) are important in determining whether, at the prevailing world oil prices, ethanol can be produced competitively in Tanzania. It is important to point out that, although the estimates of the ethanol threshold production costs can be used to determine the feasibility of producing ethanol by using any feedstock, the present study focuses its analysis on sugarcane. As mentioned earlier, the decision to focus on sugarcane is based on its high potential for use as a feedstock for producing ethanol in the country. A full picture of the variation of

[42] The ethanol price was estimated by using the prevailing petrol price and the ethanol-petrol energy content ratio of 0.66. This ethanol-petrol energy content ratio has been obtained from a study by Von Lampe (2006).

[43] Threshold ethanol production cost as used here refers to the cost above which ethanol cannot compete with petrol. The threshold ethanol production costs have been estimated by computing petrol landed prices at various levels of world oil prices. The threshold ethanol production costs enable the study to determine the competitiveness of ethanol produced by using various feedstocks that could be grown in Tanzania.

threshold ethanol production costs with changes in world oil prices is provided in figure 5.4.

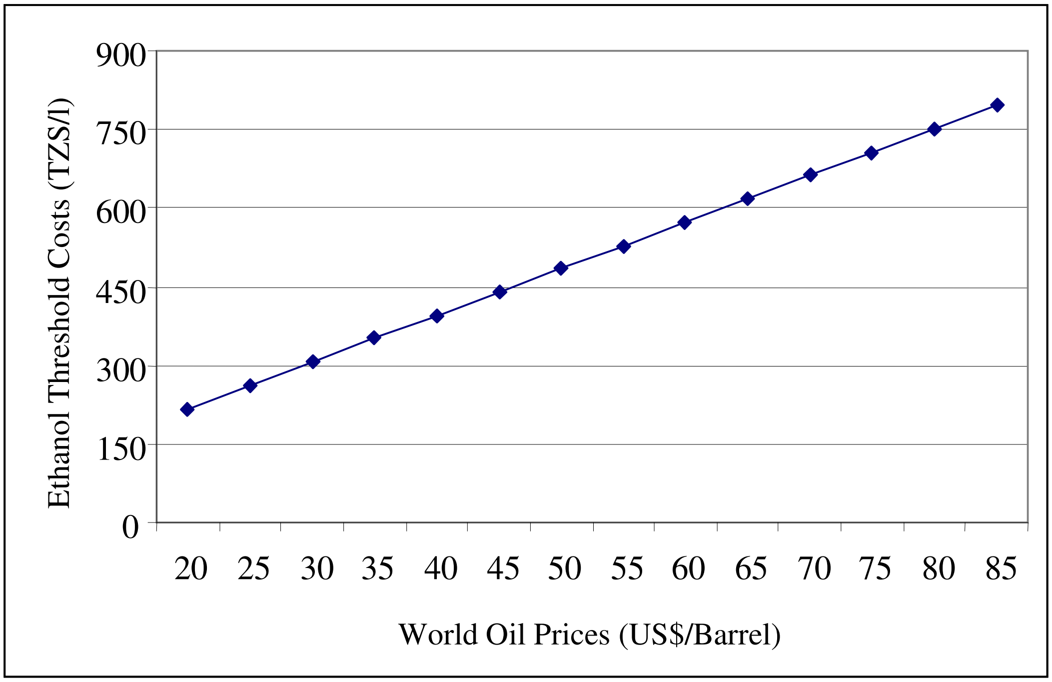

Figure 5.4: Variations of Ethanol Threshold Costs With World Oil Prices

Figure 5.4 shows that there is a strong correlation between ethanol threshold production costs and world oil prices. A quick observation of the figure reveals that the estimated ethanol production cost, which is TZS 351 a litre, would require the world oil price to be just over US$ 35 a barrel for ethanol produced by using sugarcane as a feedstock to be able to compete with fossil petrol. Given the fact that the world oil price is well above US$ 35[44] a barrel and it is unlikely to fall below US$ 40 a barrel, then it is reasonable to argue that ethanol can be produced competitively by using sugarcane as a feedstock[45]. The unlikelihood of world oil prices falling below US$ 40 a barrel is significant as it ensures potential investors that the production of ethanol from sugarcane would continue to be feasible for the foreseeable future.

[44] The prevailing world oil price at the time of writing (early October, 2006) was US$ 58 a barrel.
[45] The view that world oil prices are unlikely to fall below US$ 40 a barrel is held by many experts in the oil industry, among them is the former OPEC's acting secretary general, Adnan Shihab Eldin.

5.1.3.3 Biodiesel Threshold Production Cost Variations with Oil Prices

Just like in the case of ethanol, the present study also tried to determine the relationship between the threshold biodiesel production costs and world oil prices. This relationship is important in establishing the minimum world oil prices at which biodiesel produced by using oil palm and jatropha could compete with fossil diesel. The relationship between the threshold biodiesel production costs and world oil prices is provided in figure 5.5.

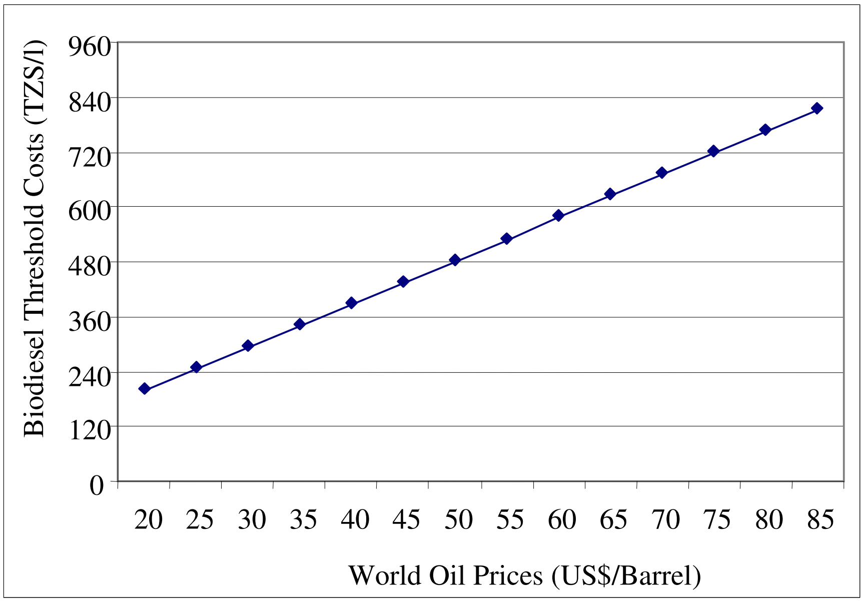

Figure 5.5: Variation of Biodiesel Threshold Costs With World Oil Prices

Figure 5.5 shows that the prevailing world oil prices of around US$ 60 a barrel require biodiesel production costs to be around TZS 600 a litre for the production of biodiesel in the country to be feasible. As reported previously, the costs of producing biodiesel in the country have been estimated to be TZS 601 and 648 a litre when using oil palm and jatropha as feedstocks respectively. These are slightly higher than the threshold cost. Thus, the production of biodiesel in the country would require either sustained high world oil prices or drastic reduction of feedstocks (oil palm and jatropha) costs. Since a drastic reduction in the costs of jatropha and palm oil is not likely in the near future then the government should provide preferential treatments for biodiesel so as to enhance its competitiveness. The government should take the burgeoning negative environmental impacts of the increasing use of fossil fuels and the potential poverty alleviation impacts of biodiesel production as incentives to attract investments in biodiesel production. A detailed analysis of what could be done to attract investments in biofuels production is provided in the next section.

5.1.4 Probable Policy Support Measures for Biofuels Production

5.1.4.1 Policy Measures for Supporting Ethanol Production

Providing incentives for biofuels producers is among the common practices used to attract investments in the production of ethanol and biodiesel around the world. Moreover, the government of Tanzania is already using similar measures to attract investments in the mining and tourism sectors. In view of these facts, the present study tried to determine the effects of providing incentives, such as tax exemptions, on the minimum world oil prices required for ethanol produced by using sugarcane, maize, sorghum, and cassava to be able to compete with fossil fuels. The present study considered five different scenarios. The analysis started with a situation whereby there was no any preferential treatment for ethanol, then the present study tried to determine the effects of 25%, 50%, 75%, and 100% tax exemptions on the competitiveness of ethanol produced by using sugarcane, maize, sorghum and cassava as feedstocks. The results for those five scenarios are presented in table 5.5.

Table 5.5: Feasibility of Ethanol Production at Various Levels of Tax Incentives

Oil Price (US$/Barrel)	Feasibility of Ethanol Production at Various Levels of Tax Incentives (% of VAT Exempted)																			
	Sugarcane					Maize					Sorghum					Cassava				
	0	25	50	75	100	0	25	50	75	100	0	25	50	75	100	0	25	50	75	100
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
35	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	+	+	+	+	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+
50	+	+	+	+	+	-	-	-	+	+	-	-	-	-	-	-	-	-	+	+
55	+	+	+	+	+	-	-	+	+	+	-	-	-	-	+	-	-	+	+	+
60	+	+	+	+	+	-	+	+	+	+	-	-	-	+	+	-	+	+	+	+
65	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+
70	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+
75	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
80	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
85	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Source: Own computations

Note: + = Feasible - = Not feasible

Table 5.5 shows that with a total VAT exemption, ethanol produced by using sugarcane as a feedstock would be able to compete with fossil petrol even if world oil prices would fall to US$ 25 per barrel. With the same level of support, the threshold world oil prices, *i.e.* the minimum world oil prices required for ethanol to be able to compete with petrol, are US$ 45 per barrel for maize/cassava and US$ 55 per barrel for sorghum.

A comparison of the threshold world oil prices (with and without tax incentives) shows that the provision of tax incentives lowers the threshold world oil price for ethanol produced by using sugarcane as a feedstock from US$ 40 to 25 per barrel. Similarly, the threshold world oil prices fall from US$ 65 to 45 per barrel for maize and cassava, and from US$ 75 to 55 per barrel for sorghum when ethanol producers are supported by providing them with a total VAT exemption.

The sensitivity of the threshold world oil prices to tax incentives implies that the government of Tanzania could use such incentives to promote ethanol production in the country. Moreover, tax incentives could be used to support ethanol producers if world oil prices would fall beyond the level required for ethanol produced in the country to be able to compete with fossil fuels. As pointed out in the previous section, the provision of such incentives is a common practice in most leading ethanol producers in the world. For instance, in 1991, the European Community proposed a 90% tax reduction in order to promote the production and use of biofuels in Europe (Gustafson, 2003). Similarly, the USA has been using motor fuel excise tax credits and small producers tax credits in an attempt to promote the production and use of ethanol (Shapour *et al.,* 2006).

It is worthwhile pointing out that the production of ethanol in Tanzania would not only reduce the country's spending on oil imports but would also provide a reliable market for a large number of small-scale producers of crops which can be used as feedstocks for producing ethanol. A reliable market is likely to provide a large incentive for small-scale farmers to increase crop production and hence pull them out of absolute poverty. The assumption that a reliable market would provide a big incentive for smallholders to increase crop production is based on the fact that unreliable markets is among the main problems encountered by small-scale farmers in their day-to-day farming activities. For a detailed discussion on the significance of the problem of unreliable markets see section 5.5.1.4. The likely poverty alleviation impacts of introducing ethanol production would provide an additional incentive for the government to support ethanol producers through measures such as tax exemptions whenever they are deemed to be necessary.

5.1.4.2 Policy Measures for Supporting Biodiesel Production

Just like in the case of ethanol, the present study also tried to determine the effects of various levels of tax incentives on the feasibility of producing biodiesel. The analysis was aimed at finding out the influence of various levels of tax exemptions on the minimum world oil prices required for biodiesel produced by using oil palm and jatropha as feedstocks to be able to compete with fossil fuels. The levels of tax incentives considered during the analysis ranged from 0% (no tax incentive) to 100% VAT exemption. A detailed description of the effects of various levels of tax incentives on the threshold world oil prices for biodiesel produced by using oil palm and jatropha as feedstocks is provided in table 5.6.

Table 5.6: Feasibility of Biodiesel Production at Various Levels of Tax Incentives

Oil Price (US$/Barrel)	Feasibility of Biodiesel Production at Various Levels of Tax Incentives (% of VAT Exempted)									
	Oil Palm					Jatropha				
	0	25	50	75	100	0	25	50	75	100
20	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-	-
50	-	-	-	+	+	-	-	-	-	-
55	-	+	+	+	+	-	-	-	+	+
60	+	+	+	+	+	-	+	+	+	+
65	+	+	+	+	+	+	+	+	+	+
70	+	+	+	+	+	+	+	+	+	+
75	+	+	+	+	+	+	+	+	+	+
80	+	+	+	+	+	+	+	+	+	+
85	+	+	+	+	+	+	+	+	+	+

Source: Own computation
Note: + = Feasible - = Not feasible

Table 5.6 shows that supporting biodiesel producers by providing a 100% VAT exemption would lower the world oil price at which biodiesel could be competitively produced in the country by using oil palm and jatropha as feedstocks to US$ 50 and 55 per barrel respectively. It is important to note that even if the production costs for biodiesel would be equal to the landed diesel costs, producing biodiesel locally would be a much better option. This is because, amongst others, the production of biodiesel is likely to provide a reliable market for thousands of small-scale farmers of jatropha and oil palm.

A reliable market, especially for jatropha which has limited demand in its alternative uses, would provide an incentive for small-scale farmers to increase the production of that crop. Assuming that the increase in production would not influence prices to the extent of offsetting the effects of the increased production to the incomes of small-scale farmers, the production of biodiesel is likely to lead to increases in incomes for producers of jatropha. Thus, introducing biodiesel production would augment the efforts of the Tanzanian government to pull its citizens out of absolute poverty.

5.1.5 Considerations for Biofuel Plant Size and Location

5.1.5.1 Maximum Feedstock Transport Distance for Various Plant Sizes

Most of the potential feedstocks for producing biofuels are bulky. The bulkiness of those feedstocks implies that their transport costs are likely to be fairly high. Thus, the decision on where the plant for producing biofuels should be located has, amongst other things, to make sure that the distance from where the feedstocks would be collected is minimised. The present study tried to estimate the areas and hence the maximum transport distances for various plant capacities and feedstock land shares for each of the crops considered to be potential feedstocks for producing biofuels. The maximum feedstock transport distance estimates are based on the average yields presented in chapter four. The present study assumed sixteen different scenarios for each of the feedstocks considered. Those assumptions entailed four different feedstocks land shares and plant capacities[46.] A detailed description of the variations of the maximum distances over which feedstocks would have to be transported for various feedstocks, feedstock land shares and plant capacities is provided in figure 5.6.

[46] The present study considered four different biofuel plant sizes, *i.e.* 1.89, 11.36, 56.78 and 113.55 million litres per year. The considered feedstock land shares, around the biofuel plants, are 10%, 20%, 30% and 40%. The feedstocks considered are sugarcane and cassava for producing ethanol, and jatropha and oil palm for biodiesel production.

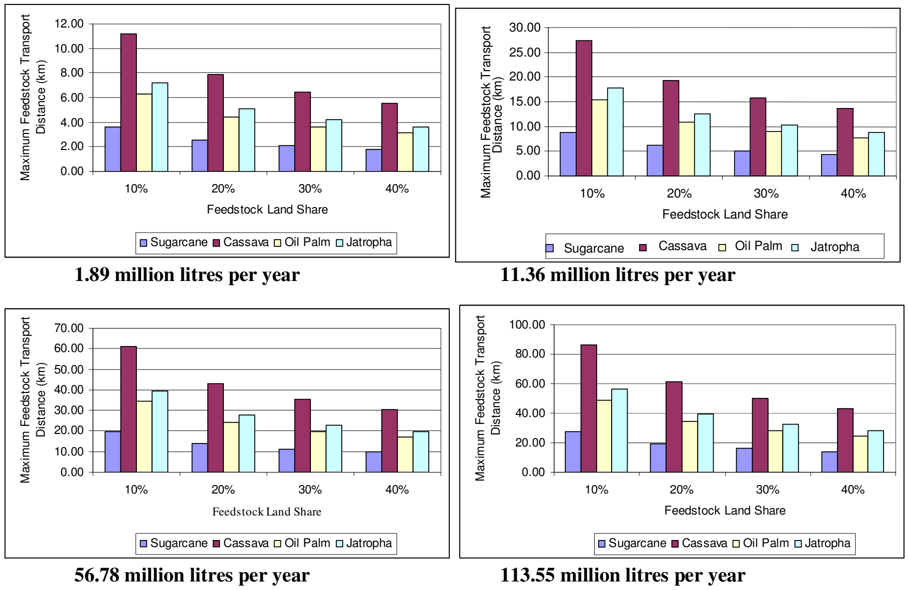

Figure 5.6: Variations of Maximum Transport Distances for Various Feedstocks

Figure 5.6 shows that, at the lowest plant capacity, *i.e.* 1.89 million litres per year, the maximum feedstocks transport distances are lower than twelve kilometres for all feedstocks and land shares. It could also be noted that feedstocks with low yields (based on current production data) would have to be transported over long distances to satisfy the requirements of large biofuels plants. Thus, it is plausible to argue that the decision on the appropriate location and size for a biofuel plant should not only consider the availability of the potential feedstock but also its productivity. This is because the productivity of a feedstock has a large influence on its accessibility for use by the biofuel plant.

It is also interesting to note that, at all assumed plant capacities and proportions of land under sugarcane production, the maximum distance from where the feedstock would have to be transported is not far from the current sugarcane transport distance for sugar production. Thus, it sounds reasonable to argue that, given the current sugarcane productivity levels in Tanzania, the availability of sugarcane as a feedstock for producing ethanol is not likely to pose a problem even for large ethanol plants[47]. Regarding other feedstocks, it seems that having small plants would be more economical as the distances from where those feedstocks would need to be collected are

[47] The low sugar production in Tanzania is not necessarily caused by low cane production as there were several farmers who were blaming the factories for not buying their sugarcane.

fairly high for large plants. Low plant capacities, for biofuels plants utilising feedstocks other than sugarcane, have been suggested because they will reduce feedstocks transport distances. This is important as transport costs are quite high in Tanzania. Moreover, the transport infrastructure is not well developed in the country. Thus, small plant sizes for feedstocks with low productivities are necessary in minimising transport costs.

5.1.5.2 Influence of Transport Distance on Biofuels Production Costs

Given the high feedstocks transport costs, the present study tried to determine its influence on the total biofuels production costs. The main objective of the analysis is to establish the variations of transport costs (expressed as a percentage of total biofuel production cost) with changes in feedstock transport distance. The assessment enabled the present study to have a clear picture of the influence of feedstock transport distance on the total biofuel production cost. The analysis was done by using sugarcane transport costs figures which were collected during the survey conducted from July to November 2005. The relationship between feedstock transport distance and the contribution of transport costs to the total biofuel production cost is provided in figure 5.7.

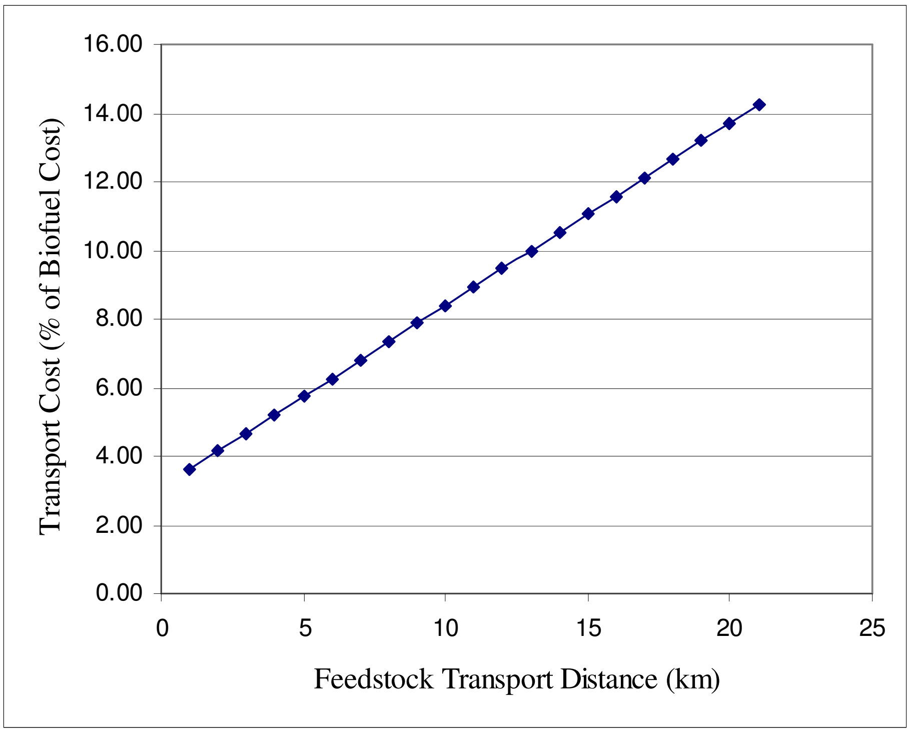

Figure 5.7: Feedstock Transport Distance-Biofuel Production Cost Relationship

Note: The intercept represents the loading/unloading cost (does not vary with transport distance) which at the time of data collection was TZS 810 per tonne.

Figure 5.7 shows that the contribution of transport costs to the total biofuel production cost increases rapidly with increasing distance through which the feedstock has to be transported. The average feedstock transport cost for one tonne was estimated to be TZS 140 per kilometre[48]. The figure shows that at a distance of 20 kilometres, the cost of transporting feedstocks would account for about 13% of the total ethanol production cost. Thus, given the rapid increase in transport costs with increasing feedstock transport distance, and the current state of the transport infrastructure in Tanzania, then it is appropriate to suggest medium scale biofuel production plants. Such plants will minimise feedstock transport distances, and hence reduce total biofuel production costs. Reducing the cost of producing biofuels is important as it enhances their ability to compete with traditional fossil fuels.

5.1.6 Estimates of Quantities of Various Feedstocks and Biofuels

5.1.6.1 Validation of the Linear Programming Model

Model validation is an important exercise in any empirical analysis. The overall purpose of the validation process is to test how well a model serves its intended use. There is a wide variation in approaches for validating linear programming models. But the most widely used techniques are: validation by construct and validation by results. Whereas validation by construct asserts that the model was built properly therefore it is valid, validation by results refers to exercises where the model outputs are systematically compared against real world observations. Unfortunately, however, these tests (especially the comparison of the model predictions to real world results) are rarely used. This is mainly because they are expensive and time-consuming. Consequently, linear programming models in most cases are superficially validated (McCarl and Spreen, 1997).

It is important to note that model validation is fundamentally subjective. This is mainly because modellers choose the validity tests, the criteria for passing those tests, what model outputs to validate, what setting to test in and what data to use. Thus, the assertion "the model was judged valid" can mean almost anything. Nonetheless, a model

[48] This estimate is based on sugarcane transport costs data for the 2005/2006 season.

validation effort will reveal model strengths and weaknesses which is valuable to users and those who extract information from the model's results. This section provides a brief discussion on the validity of the linear programming model used in the present study.

Owing to the lack of data on the production of the various crops which are considered to be potential feedstocks for producing biofuels in the study area, the present study had to validate the model by construct. The use of validation by construct, as the sole method of validation, is justified by the following assertions about modelling:

i) The right procedures have been used in the process of building the model. Usually this entails the assertion that the approach is consistent with the industry, previous research and/or theory; and that the data have been specified using reasonable scientific estimation or accounting procedures. In line with this assertion, most of the parameters of the model in the present study have been estimated by using data collected through a detail survey of producers of potential feedstocks for biofuels production which was conducted in 2005.

ii) Trial results indicate that the model is behaving satisfactorily. This arises from a nominal examination of model results which indicates they do not contradict the modeller's, user's, and/or associated experts perceptions of reality. In line with this assertion, the results of the model do not contradict our perception of reality. For instance, in the base scenario, where we do not include the production of feedstocks for producing biofuels among the decision variables in the model, the results show that most of the land in zone one, where rice, sugarcane and maize can be grown, would be under sugarcane production (for producing sugar). This is exactly what we observed during data collection. With the exception of land that is prone to flooding, most of the land was under sugarcane production. Rice was grown in small pockets of land which are prone to flooding during the long rains season.

iii)Constraints have been imposed to restrict the model to realistic solutions. Some exercises use constraints to limit adjustment possibilities and force the model to give results very close to historically observed outcomes. In line with this assertion, we imposed minimum acreage constraints for crops such as cassava to ensure their availability for their traditional food use. This (imposing minimum acreage constraints) is important because farmers do not only aim at maximising profit. They have other objectives, such as ensuring food security. Consequently, imposing constraints to ensure that enough food is produced to meet the local demand enhances the validity of the model. Thus, the imposition of local food demand constraints, coupled with the description provided previously in (i) and (ii), make it reasonable to argue that “the model is valid”.

5.1.6.2 An Overview of the Linear Programming Model Results

This section provides an overview of the results of the linear programming model. The crops which have been considered in the present study are: sugarcane, maize, rice, cassava, sorghum, oil palm and jatropha. The main constraints considered are land and labour availability. The results show that labour availability would not be a problem in February and from June to September. The excess labour in these months can be attributed to the low labour demand. Most farmers in the country practice rain-fed agriculture. Therefore, during the dry season, *i.e.* June to September, the demand for labour is likely to be low. For the case of February, the labour surplus can be attributed to the fact that in this month there are few crops that require weeding. Farmers in areas which experience bimodal rainfall, which constitute a large proportion of the area covered by the present study, usually use this month for preparing land ready for planting during the onset of the long rains in March. Consequently, since weeding is among the farm operations which have a high labour demand, then it is not surprising that there is excess labour in February.

Furthermore, the results show that in all scenarios considered the production of biofuels will not affect the availability of most of the crops which can be used as feedstocks for producing biofuels for their traditional food use. The insensitivity of the availability of the various crops which are considered to be potential feedstocks for producing biofuels to the introduction of ethanol and biodiesel production could be attributed to the high opportunity costs of using them for producing biofuels. Since the present study focuses on the feasibility of producing biofuels, we will not provide a detailed discussion on the production of the crops considered to be potential feedstocks for producing biofuels for their food use. For a detailed description of the results on the production of sugarcane, maize, rice, sorghum, cassava, oil palm and jatropha for their alternative uses see appendices 3-5. A detailed discussion on the availability of feedstocks for producing biofuels for the various scenarios considered by the present study is provided in the next section.

5.1.6.3 Quantities Taking into Account Local Food and Biofuels Demands

This section presents the results of the estimation of the quantities of various feedstocks and biofuels which could be produced in Tanzania. As pointed out in the previous sections, the feasibility of producing biofuels in the country will largely depend on the availability and costs of the feedstocks required for their production. Thus, this study estimated the amounts of various crops which could be produced for use as feedstocks for producing ethanol and biodiesel in the country. The present study employed linear programming approach to determine the amounts of sugarcane, maize, cassava, sorghum, palm oil, and jatropha that are likely to be available for use as feedstocks for producing biofuels at the optimal allocation of land and labour resources in the country.

It is important to note that the present study focuses on land which has high potential for producing feedstocks for biofuels production. The main factors which have been taken into account during the selection of those areas are: the possibility of obtaining large quantities of feedstocks in a small area so as to reduce feedstocks transport distances, the ease with which the biofuels could be transported to consumption centres, and the possibility of establishing large and/or medium scale farms for producing feedstocks for biofuels production.

As described in the previous chapter, the linear programming model (aimed at determining the quantities of the various crops which are likely to be available for use as feedstocks for producing biofuels) was run under three different scenarios. In the first scenario, both the local food and biofuels demands were imposed as constraints in the model. A detailed description of the quantities of the various crops which are likely to be available for use as feedstocks for producing biofuels when local food and biofuels demands are taken into account is provided in table 5.7.

Table 5.7: Estimates of Feedstocks and Potential Biofuels Quantities (Scenario 1)

Feedstock	Potential Feedstock Quantity (Millions, Tonnes/year)	Potential Biofuel Quantity (Millions, Litres/year)
Sugarcane	27.64	2,107.58
Maize	5.00	1,597.43
Sorghum	0.77	227.67
Cassava	0.46	77.42
Total Ethanol		**4010.10**
Oil Palm	0.12	114.00
Jatropha	5.04	1612.80
Total Biodiesel		**1726.80**

Source: Own computation

Table 5.7 shows that the country can produce more than 27 million tonnes of sugarcane for use as a feedstock for producing ethanol per year. It can also be noted from the table that cassava, maize and sorghum are capable of providing substantial quantities of feedstocks for producing ethanol. The large quantity of sugarcane that is likely to be produced and used as a feedstock for ethanol production could be attributed to the higher returns from using the crop for producing ethanol and the low opportunity cost of using the crop as a feedstock for ethanol production. The same argument could be used to explain the large amount of jatropha seeds that is likely to be available for use as a feedstock for producing biodiesel. The high returns from using sugarcane and jatropha as feedstocks for producing biofuels, coupled with the low opportunity costs of using them to produce ethanol and biodiesel respectively mean that farmers would allocate most of their resources to the production of these crops. Thus, it is not surprising that the results show that sugarcane and jatropha would account for a large proportion of the feedstocks for producing ethanol and biodiesel in the country.

It can be noted further, from the table, that the country has a potential of producing more than four billion litres of ethanol per year. It is interesting to note that the potential annual ethanol production from the least cost feedstock (sugarcane) is more than two billion litres. The large amount of ethanol that is likely to be produced by using sugarcane as a feedstock is significant because it is the only feedstock that can be used to produce ethanol profitably even at relatively lower world oil prices. The amount of ethanol that could be produced from sugarcane alone is well above the estimated

(TPDC, 2004 estimates) annual gasoline consumption in the country which stood at 375 million litres. Furthermore, the table shows that maize has the second largest contribution to the estimated potential ethanol production in Tanzania. Despite its high potential, its use for ethanol production is likely to face competition from its use as food as the crop is among the main staple foods in the region. Thus cassava and sorghum, which have relatively lower demands in their alternative uses in the region are likely to be more reliable feedstocks for ethanol production than maize.

The use of cassava and sorghum for producing ethanol would provide a reliable market for those crops. A reliable market for cassava and sorghum would have a significant impact on the livelihoods of millions of Tanzanian small-scale farmers who are currently facing problems of unreliable markets for those crops. Sorghum and cassava are important in the country because they are among the few crops which are well adopted to survive long droughts which are common in most parts of the country. Their ability to withstand adverse weather conditions would not only ensure a constant supply of feedstocks for ethanol production, but would also provide a reliable source of income for small-scale farmers who would be growing those crops.

Furthermore, table 5.7 shows that the country has a potential of producing more than 1.7 billion litres of biodiesel per year. It is interesting to note that jatropha-based biodiesel accounts for more than 90% of the estimated potential biodiesel production in the country. This finding is significant as the crop, just like cassava and sorghum in the case of ethanol production, is well adopted to survive long dry spells which are common in most parts of the country. Its ability to withstand adverse weather conditions would ensure a stable supply of feedstocks for producing biodiesel. Moreover, the crop is capable of growing in marginal lands. Its ability to grow on marginal lands means that the crop would provide an alternative source of income to thousands of livestock keepers in the Tanzanian central plateau where the soils are not suitable for growing most of the other important cash crops.

It is worthwhile pointing out that the amount of biodiesel that could be produced per year is well above the estimated annual diesel consumption in the country. The annual diesel demand was estimated to be around 789.05 million litres (TPDC, 2004). It is important to note that although the country has a large potential for producing biodiesel, as mentioned previously, its production by using oil palm and/or jatropha as feedstocks would only be feasible if world oil prices would not fall below US$ 60 a barrel.

Since the minimum world oil price at or above which the production of biodiesel would be feasible is fairly high, then there should be deliberate efforts to improve the productivities of oil palm and jatropha so as to reduce the cost of producing biodiesel in the country. Notwithstanding the relatively high world oil prices that are required for the production of biodiesel in the country to be feasible, yet there exists a real possibility of producing biodiesel profitably in the country. This is because the prevailing world oil prices are high enough to allow competitive biodiesel production in the country. Moreover, even if the world oil prices would decrease to the extent of making the production of biodiesel less attractive, its potential contribution to the welfare of small-scale farmers would justify government support for the producers of biodiesel.

5.1.6.4 Quantities Without Considering Local Food Demand

As described in the previous chapter, in the second scenario the local food demand constraints were dropped from the model. Table 5.8 provides estimates of the quantities of various feedstocks and biofuels when local food demand is not included among the constraints in the model. The table shows that, if the model is not forced to take into consideration the local food demand, then the amount of sugarcane that would be available for use as a feedstock for producing ethanol would increase from 27.64 to 35.24 million tonnes per year. The increase in the amount of sugarcane that would be available for use as a feedstock for ethanol production could be attributed to the low opportunity cost of using the crop for producing ethanol. On the other hand, the quantities of other crops which would be available for use as feedstocks for biofuels production remain more or less the same. The insensitivity of the amounts of other crops that would be available for use as feedstocks for producing biofuels could be attributed to the high opportunity costs of using them for ethanol and/or biodiesel production.

Table 5.8: Estimates of Feedstocks and Potential Biofuels Quantities (Scenario 2)

Feedstock	Potential Feedstock Quantity (Millions, Tonnes/year)	Potential Biofuel Quantity (Millions, Litres/year)
Sugarcane	35.24	2,686.98
Maize	5.00	1,597.43
Sorghum	0.77	227.67
Cassava	0.46	77.42
Total Ethanol		**4589.50**
Oil Palm	0.12	114.00
Jatropha	5.04	1612.80
Total Biodiesel		**1726.80**

Source: Own computation

Moreover, the table shows that relaxing the local food demand constraint would increase the amount of ethanol, likely to be produced in the country, from 4010.10 to 4589.50 million litres per year. This is about 12% increase. The increase of the amount of ethanol that would be produced in the country, when the local food demand is not imposed as a constraint in the model, could be attributed to the increase in the quantity of sugarcane that would be available for producing ethanol if the model would not be forced to ensure that the country produces enough sugar to meet the local demand. The insensitivity of the amounts of crops such as maize, sorghum and cassava to the relaxation of the local food demand constraint implies that there would be enough quantities of those crops for their traditional food use.

Unlike the case of ethanol, which has been described in the previous paragraph, relaxing the local food demand constraint has no impact on the amount of biodiesel that would be produced in the country. The insensitivity of biodiesel production to the removal of the food demand constraint could partly be explained by the fact that a large proportion of biodiesel is expected to be produced by using jatropha which is not a food crop. Furthermore, the insensitivity of biodiesel production to the relaxation of the local food demand constraint is likely to be caused by the high opportunity cost of using oil palm as a feedstock for producing biodiesel.

5.1.6.5 Quantities Without Considering Local Food and Biofuels Demands

This section presents results of the third and final scenario considered during the estimation of the quantities of the various feedstocks and biofuels which could be produced in Tanzania. As described in chapter four, in the third scenario, both food and biofuels demands were not imposed as constraints in the model. The estimates of the amounts of various crops which could be produced for use as feedstocks for producing biofuels and their respective biofuels quantities when both local food and biofuels demands are not imposed as constraints in the model are provided in table 5.9.

Table 5.9: Estimates of Feedstocks and Potential Biofuels Quantities (Scenario 3)

Feedstock	Potential Feedstock Quantity (Millions, Tonnes/year)	Potential Biofuel Quantity (Millions, Litres/year)
Sugarcane	35.24	2,686.98
Maize	0.00	0.00
Sorghum	0.00	0.00
Cassava	0.00	0.00
Oil Palm	0.00	0.00
Jatropha	0.00	0.00

Source: Own computation

Table 5.9 shows that if both local food and biofuels demands are not imposed as constraints in the model then only sugarcane would be available for use as a feedstock for producing biofuels. The unavailability of other crops could be attributed to the high opportunity costs which are associated with their use as feedstocks for producing biofuels. This shows that, with the exception of local sugar demand, the introduction of biofuels production would not affect the availability of the considered crops for their traditional food use.

Furthermore, the table shows that relaxing the local food and biofuels demands constraints would reduce the amount of ethanol likely to be produced in the country by 33%. Despite the decrease in the potential ethanol quantity when the local food and biofuels demands are not imposed as constraints in the model, still the amount of ethanol that would be produced (2,686.98 million litres per year) exceeds the local demand for petrol which it is intended to replace. Thus, it can be plausibly argued that the country has a large potential of using sugarcane to produce enough ethanol to meet the local demand for the fuel (ethanol). Moreover, the table shows that if the model is not forced to make sure that the local food and biofuels demands are satisfied then there would be a limited possibility of producing biodiesel in the country.

A close look at the three scenarios considered in the present study shows that in all three situations, there will be enough feedstocks to produce ethanol to meet the local demand. Furthermore, it is only the third scenario which shows that it will be difficult to get feedstocks for producing biodiesel in the country. Notwithstanding the findings of the third scenario, the country has a high potential of producing both ethanol and biodiesel by using sugarcane and jatropha as the main feedstocks. This is mainly because other crops which would be competing for land with jatropha have limited markets. Therefore, there is a very large possibility that jatropha would be produced for use as a feedstock for producing biodiesel. Moreover, due to the high transport costs and the poor state of the transport infrastructure in the country, it would be better to minimise transport distances for both food and biofuels. This implies that the first scenario, in which both the local food and biofuels demands have been imposed as constraints in the model is more appropriate.

5.1.6.6 Quantities of Lignocellulosic Ethanol Production Feedstocks

This section presents the results of the estimation of the quantities of lignocellulosic feedstocks and the amount of ethanol that could be produced by using those materials. As described in chapter two, the cost of producing ethanol by using lignocellulosic materials in standalone plants is quite high. Thus, the use of those materials has been considered for integrated plants, *i.e.* processing facilities capable of utilising both lignocellulosic and the traditional sugar and/or starchy feedstocks. Due to the focus on integrated plants and the fact that most lignocellulosic feedstocks are bulky, the estimation of the quantities of those materials which would be available for use as lignocellulosic ethanol production feedstocks was limited to areas close to where the traditional feedstocks, such as sugarcane, are grown or could be produced. This is aimed at minimising the transport distances for both lignocellulosic and traditional feedstocks.
The estimation of the quantities of lignocellulosic materials that would be available for use as feedstocks for ethanol production focussed on crop residues. This decision is based o the fact that these materials (crop residues) have limited alternative uses in the country. Moreover, their disposition, by burning, is among the most common sources of

air pollution in Tanzania. Thus, their use for producing ethanol would not only increase the incomes of smallholder farmers, but would also help to reduce the problem of air pollution that is associated with their inappropriate disposition. Estimates of annual residues quantities for selected crops and the amount of ethanol that can be produced from those materials are provided in table 5.10.

Table 5.10: Annual Residues Quantities for Selected Crops

Crop	Residue Type	Quantity (Tonnes/year)
Maize	Stalks and Cobs	7070385
Sorghum	Straw	864625
Rice	Straw and Husks	2133296
Coconut	Husks and Shells	413413
Sugarcane	Molasses and Bagasse	1217670
Sisal	Sisal Waste	900000
Total	-	12599389
Ethanol Output (Millions, l/year)	-	881.95

Source: Own computation

Table 5.10 shows that crop residues alone could provide about 12,599,389 tonnes of lignocellulosic feedstocks for producing ethanol per year. Using a conservative conversion factor of 70[49] litres of ethanol for every tonne of lignocellulosic ethanol production feedstocks, there is a potential of producing almost 900 million litres of ethanol per year from crop residues. Since the energy content of a litre of ethanol is estimated to be equal to 66% of that contained in a litre of fossil petrol, then the amount of ethanol that could be produced from crop residues is equivalent (in terms of energy content) to 594 million litres of fossil petrol. This (the large potential ethanol production from lignocellulosic feedstocks) emphasises the high potential of producing ethanol in the country which has been pointed out in the previous section. The annual gasoline demand in Tanzania was estimated to be 375 million litres (TPDC, 2004). A quick comparison of the two figures shows that the amount of ethanol that could be produced by using crop residues is well above the demand for petrol in the country.

[49] According to Mosier (2006), studies in the USA have found that on average a tonne of lignocellulosic materials, such as maize stover, and other forages can produce up to 253.26 litres of ethanol. A lower rate has been used here to take care of the possible differences in the main sources of lignocellulosic materials between the USA and Tanzania which could lead to differences in the average ethanol production per tonne of lignocellulosic feedstocks.

5.2 Biofuels Production's Implications on Poverty Alleviation

5.2.1 Impacts on Net Returns for Sugarcane Producers

This section presents the results of the assessment of the potential impact of introducing biofuels production on the net returns of the crop with the highest potential for providing feedstocks for producing ethanol, *i.e.* sugarcane. The impact of biofuels production on the profitability of sugarcane production was then used as a yard stick for measuring the potential contribution of biofuels production to the country's poverty alleviation efforts.

As described in the previous chapter, the estimation of the impact of using sugarcane for producing ethanol on the net returns for small-scale sugarcane producers was mainly based on the farmers' share when the crop is used to produce sugar. The farmers' share, when the crop is used for producing sugar, was adjusted to take care of the differences in processing costs between sugar and ethanol. The adjusted farmers' share was used to estimate the net returns likely to be obtained by sugarcane producers once ethanol production is introduced in the country. The average net returns, per hectare, for sugarcane when using the crop for producing sugar and ethanol, and the change in net returns for the crop are provided in table 5.11.

Table 5.11: Impact of Ethanol Production on Net Returns for Sugarcane

Variable	Crop Use	Net Returns/Per Capita Income
Net Returns (TZS/ha)	Sugar Production	580000
	Ethanol Production	743346
Average Farm Size (ha)	-	4.8
Average Household Size	-	6
Per Capita Income (TZS)	Sugar Production	464000
	Ethanol Production	594676
Change in Per Capita Income (%)	-	28

Source: Own computation

Table 5.11 shows that the average net returns per hectare for sugarcane are TZS 580000, when using the crop for sugar production, and TZS 743346, when the crop is used as a feedstock for producing ethanol. Moreover, the table shows that the use of sugarcane for producing ethanol would increase the per capita incomes for households producing the crop from the current TZS 464000 to TZS 594676. This is about TZS 130676 increase.

Furthermore, the table shows that using sugarcane for producing ethanol would increase the net returns for small-scale producers of the crop by 28%[50].

In addition to increasing the net returns per hectare, the use of sugarcane for producing ethanol would also lead to an increase in the production of the crop in the country. The estimates of ethanol production provided in table 5.7, the average ethanol production (per hectare) provided in table 3.6, and the fact that at least one more farm labourer would be required for each additional hectare of sugarcane, means that the production of ethanol by using sugarcane as a feedstock would create about 447100 new employment opportunities for the rural poor. This (the creation of new employment opportunities) is crucial for small-scale farmers because most of them depend on working as hired labourers (selling their labour) to supplement the incomes obtained from selling their crops. Therefore, the production of ethanol would increase the incomes of small-scale sugarcane farmers by (i) increasing the returns from sugarcane farming and (ii) providing them with more employment opportunities.

It is important to point out that, assuming competitive markets, the increase in returns that would be associated with the use of sugarcane for producing ethanol would lead to increases in the wages paid to hired labourers. Thus, in addition to the increase in employment opportunities, small-scale farmers (working as hired labourers) would benefit from the likely increase in wages. Therefore, it is plausible to argue that the use of sugarcane for producing ethanol would contribute significantly in pulling small-scale producers of the crop out of absolute poverty. The high potential contribution of ethanol production towards the efforts to alleviate poverty among small-scale sugarcane producers makes it plausible to recommend deliberate efforts to attract investments in ethanol production in the country.

Although the present study focuses on the potential contribution of biofuels production towards the efforts to alleviate poverty among small-scale producers of crops which can be used as feedstocks for producing biofuels, the production of ethanol would also contribute significantly in increasing the government revenue. For instance, a study by

[50] This figure was estimated by using the prevailing world oil price at the time of writing, which was US$ 58 per barrel. The impact will be much higher if world oil prices would continue to increase.

Shumaker *et al.,* (2003) found that the total tax revenue from a small-scale biofuel plant (with annual capacity of about 11 million litres) was US$ 806029 per year. The increased tax revenue would enhance the Tanzanian government's ability to fund various poverty alleviation programs. Therefore, the poverty alleviation impacts of ethanol production would not be limited to the producers of sugarcane and other crops which can be used as feedstocks for producing biofuels.

5.2.2 Impacts on Net Returns for Jatropha Producers

The present study also tried to determine the potential impact of introducing biofuels production on the net returns for the crop which has the highest potential for providing feedstocks for producing biodiesel, *i.e.* jatropha. As described in chapter four, the analysis followed a similar procedure to that used in assessing the impact of using sugarcane as a feedstock for producing ethanol on the profitability of the crop. The impact of using jatropha for producing biodiesel on the incomes of the producers of the crop was then used as a measure of the probable contribution of biodiesel production to the efforts to alleviate poverty among small-scale jatropha farmers. The average net returns, per hectare, for jatropha when using the crop for producing biodiesel and soap; and the change in net returns for the crop are provided in table 5.12.

Table 5.12: Impact of Biodiesel Production on Net Returns for Jatropha

Variable	Crop Use	Net Returns (TZS/ha)
Net Returns (TZS/ha)	Soap Production	57000
	Biodiesel Production	87187
Change in Net Returns (%)	-	53

Source: Own computation

Table 5.12 shows that the use of jatropha for producing biodiesel would increase the net returns for small-scale producers of the crop by about 53%. In addition to increasing the net returns per hectare, the use of jatropha for producing biodiesel would also lead to an increase in the production of the crop in the country. The estimates of biodiesel production provided in table 5.7, the average biodiesel production (per hectare) provided in table 3.6, and the fact that at least one more farm labourer would be required for each additional hectare of jatropha, means that the production of biodiesel by using jatropha as a feedstock would create about 1400000 new employment opportunities for the rural poor. Just like in the case of sugarcane, the increase in returns for jatropha production (assuming competitive markets) would lead to increases in the wages paid to hired labourers [a similar argument was raised by Lanjouw and Stern, (2001)]. Thus, the use of jatropha for producing biodiesel would increase the incomes of small-scale farmers by increasing the returns from their own farms and the wages they would get by working as hired labourers.

To get a clear picture of the potential contribution of using jatropha for producing biodiesel towards the country's efforts to alleviate poverty, the present study also estimated the impact of growing the crop for producing biodiesel on the returns to land in the Tanzanian central plateau. As described in the previous chapter, the average value for the returns from the main crop in this zone, *i.e.* sorghum is TZS 45750 per hectare. Therefore, the production of jatropha for use as a feedstock for producing biodiesel would increase the average net returns per hectare in this zone by almost 90%.

It is important to point out that farmers would not only benefit from the likely increase in net returns, but would also benefit from the reliable market[51] for Jatropha that is likely to be associated with the introduction of biodiesel production in the area. Thus, it is plausible to argue that the production of jatropha for use as a feedstock for producing biodiesel would contribute significantly towards the efforts to alleviate poverty in the Tanzanian central plateau.

As pointed out in the case of ethanol, although we focus on the impact of biodiesel production on the livelihoods of small-scale producers of crops that can be used as feedstocks for producing biodiesel, the production of biodiesel will benefit even those who would not be supplying feedstocks for producing biodiesel. The benefits (for those who would not be supplying feedstocks), as described earlier, will be through the increased government spending on poverty alleviation programs.

Having estimated the potential impacts of ethanol and biodiesel production on the incomes of small-scale producers of the crops that would be used as feedstocks for producing biofuels and the rural poor in general, the present study also estimated the

[51] For a detailed discussion on the significance of the problem of unreliable markets see section 5.5.1.4.

overall potential contribution of biofuels production on poverty alleviation in rural Tanzania. The present study used the estimated increase in net returns and employment opportunities for the rural poor to determine the proportion of the population which is below the poverty line that would be pulled out of absolute poverty by the production of biofuels in the country. The results show that the production of ethanol and biodiesel in the country would reduce the proportion of the rural poor living on less than one dollar a day by about 31%. Thus, it is plausible to conclude that the production of biofuels would enhance the country's chances of achieving the millennium development goal of halving the extent of extreme poverty by the year 2015. Also the large number of employment opportunities that would be created by the production of biofuels in the country makes it reasonable to conclude that the Tanzanian government would be well placed to achieve its target of creating at least 200,000 new employment opportunities per year if it would attract investments in ethanol and biodiesel production.

5.3 Measures for Improving Farmers' Incomes

5.3.1 Improving Farmers' Access to Credit Services

Considering the average net returns per hectare for sugarcane presented in table 5.11, the poverty line of TZS 438000, and the average household size of 4.9 persons, then the minimum acreage that would provide enough income to pull a household out of poverty would be 2.8 hectares. Unfortunately, however, almost 40% of the sugarcane outgrowers interviewed during the survey conducted for the present study have farms which are below the minimum size required for an average household in the area to move out of absolute poverty.

The low average farm size in the study area coupled with the high average household size implies that the incomes obtained from farming activities are not likely to satisfy the households' needs throughout the year. Consequently, most farmers have to supplement their farm incomes by actively participating in off-farm income generating activities. Moreover, farmers are usually forced to sell their labour to supplement the incomes obtained from their non-farm income generating activities and the sell of crops obtained from their farms. Selling labour implies less time for working on their own farms, little attention for their farms means low yields, and hence low income from the sell of the crops obtained from their farms, less farm income means that they would have to sell their labour to supplement the incomes obtained from their own farms and the circle continues. Figure 5.8 provides a graphic presentation of the predicament of small-scale farmers who oftentimes work as hired labourers.

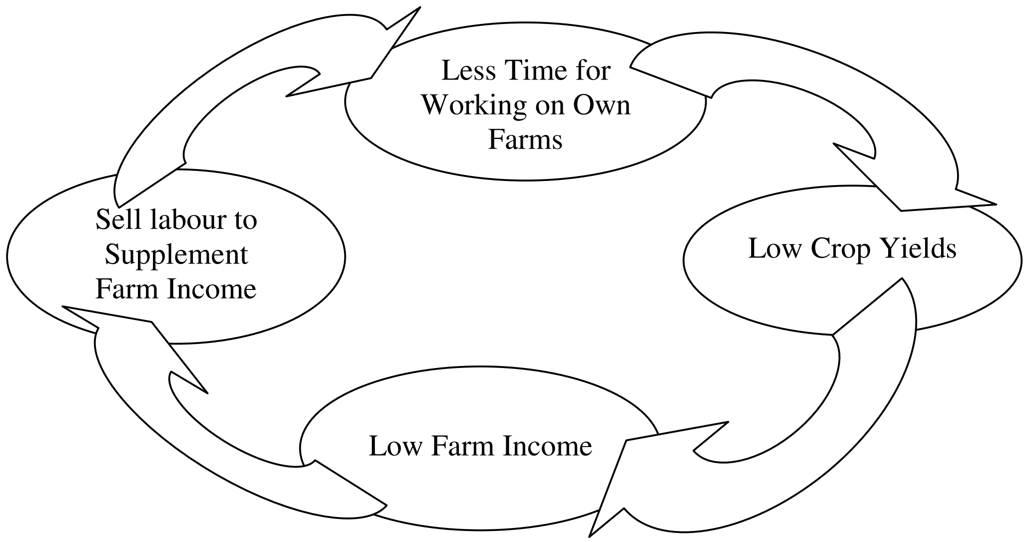

Figure 5.8: Rural Farm Labourers' Predicament

The observed difficulty facing the households' attempts to improve their livelihoods calls for a different way of bridging the income gap caused by low farm revenue. The problem of low yields for households with very small farms is exacerbated by the fact that they normally sell most of their crops (especially maize and rice) soon after harvesting when the prices are usually low. Thus, efforts to help households with small farms should include providing them with soft loans and ensuring that they get good prices for their crops. This could be done by reviving farmer cooperatives which have almost collapsed in recent years. The cooperatives would not only improve producer prices but would also provide a route through which the government can provide soft loans to farmers. The provision of soft loans would enable farmers to spend more time on their farms and hence increase yields. Moreover, the loans would help farmers to increase their farm sizes. Since the present study has found that increasing farm size is crucial for the producers of potential feedstocks for producing biofuels to move out of poverty, then the probable expansion of farm sizes that is likely to be associated with the improved access to credit services will contribute significantly towards the efforts to alleviate poverty among small-scale farmers in the country.

5.3.2 Supporting Off-farm Income Generating Activities

About 37% of the farmers interviewed during the survey conducted for the present study are actively participating in different types of off-farm income generating activities. The most common off-farm income generating activities are: formal employment, production of local brew, carpentry, charcoal making, operating small businesses and masonry. On the other hand, the most common farming activities include growing crops such as sugarcane, rice and maize. The present study found it interesting to determine the relationship between the two main sources of income, *i.e.* farm and off-farm income generating activities. This section provides a brief discussion of the results of the assessment of the relationship between farm and off-farm income generating activities.

The assessment revealed a positive correlation between the amounts of income obtained from farm and off-farm income generating activities. The positive correlation, between the amounts of income obtained from farm and off-farm sources, might be attributed to the fact that off-farm income could be used to finance various farm operations. For example, land preparation and weeding. These farm operations can be facilitated through hiring tractor services and labour by using the income obtained from off-farm activities. The increased ability to hire labourers and to pay for tractor services means that farmers with higher off-farm incomes are likely to have larger farms and hence higher farm incomes as well. Likewise, incomes from farming activities could be used to support off-farm activities by acting as start-up capital and/or widening the capital base for those activities and hence increase the income likely to be obtained from non-farm income sources. Thus, it is plausible to argue that the provision of a conducive environment for undertaking off-farm income generating activities would contribute significantly towards the improvement of the performance of the agriculture sector and hence the efforts to alleviate poverty in rural areas in general.

Among the possible ways of creating more off-farm income generating opportunities for rural households would be to introduce small biofuels production plants in rural areas. The construction of such plants would enhance farm performance by providing reliable markets for crops which could be used as feedstocks for biofuels production and of even more importance as far as non-farm income generation is concerned, as described in the previous section, the plants would also increase off-farm employment opportunities.

5.4 Variations of Profit and Incomes for Sugarcane Farmers

5.4.1 Average Farm Profit Variations with Farm Size

This section provides results of the assessment of the relationship between average farm profit, *i.e.* profit per hectare, and farm size among producers of potential feedstocks for producing biofuels. As described in the previous chapter, the analysis started with the estimation of average farm profits for each of the respondents interviewed during the survey conducted for the present study. The average farm profit figures were then plotted against farm size categories to find out how average farm profit varies with farm size. A similar approach was used by McNinch (2000) in his study on the profitability of beef cattle in Canada. The results of the assessment of the relationship between average farm profit and farm size are presented in figure 5.9.

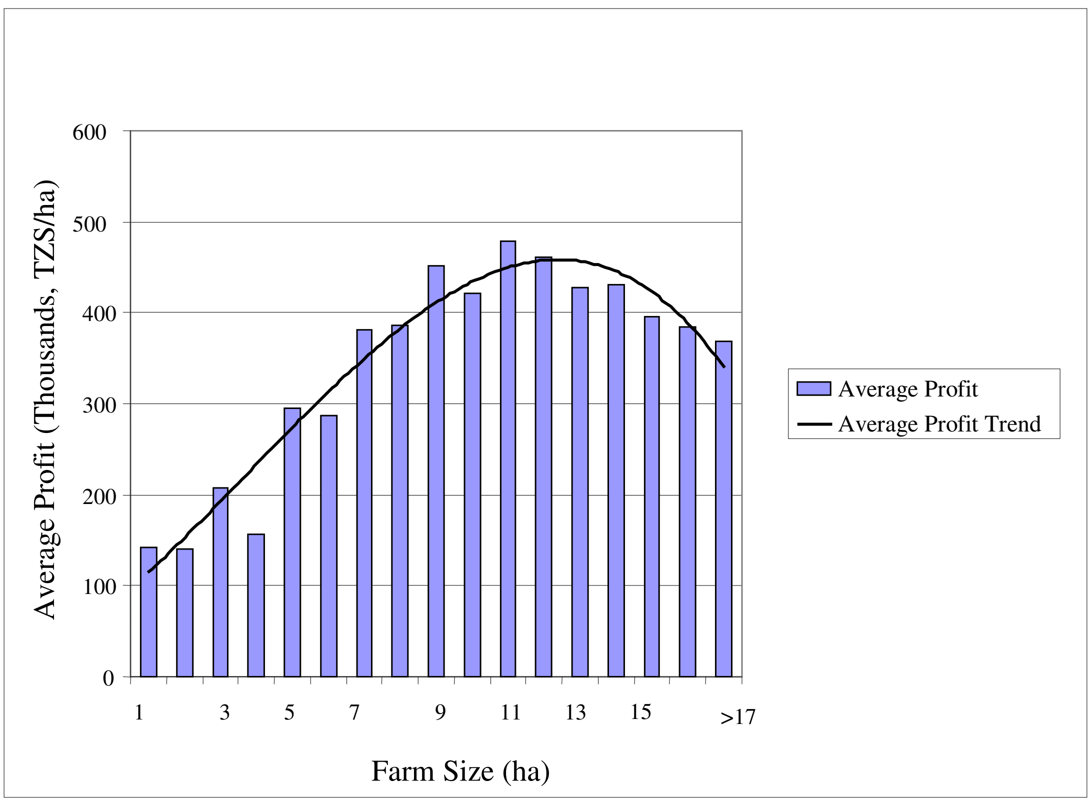

Figure 5.9: Variations of Average Profit with Farm Size

Figure 5.9 shows that the average profit per hectare increases sharply at small farm sizes. The average farm profit increases continuously from one to thirteen hectares. Beyond thirteen hectares, the average farm profit starts to decline. The increase in average farm profit that is associated with increases in farm size when moving from very small to relatively large farms could be attributed to the decline in average production costs that is normally associated with increases in farm size at low farm sizes. The decrease in average production costs with increasing farm size could be attributed to the fact that costs for some farm operations such as bird and wild animals scaring for rice, wild animals scaring for maize, watchmen for sugarcane, and supervision of hired labour for all crops do not change with small changes in farm size[52].

Since profitability per unit area among producers of potential feedstocks for biofuels production increases with increasing farm size, for farms of less than thirteen hectares, then it can be argued that operating at a small scale denies the farmer the benefits of increased profitability that is associated with increases in farm size[53]. Therefore, it is plausible to argue that, although a very large farm size is not a prerequisite for optimality, the policy advocated levels, in Tanzania, of 0.5 to 2.5 hectares for field crops are just too small and economically unjustifiable. A similar argument was raised by Temu (2002). Moreover, the policy advocated sizes are lower than the minimum size, *i.e.* 2.8 hectares, required for an average household deriving livelihood from sugarcane farming to move out of poverty. Thus, promoting such sizes (0.5-2.5 ha) is totally against the country's efforts to pull its people out of absolute poverty. The analysis and findings presented in this section are quite significant as, if adopted, would provide a plausible basis for deciding how much land should be allocated to each household in new rice and sugarcane projects in the country.

[52] The number of man-days required for tasks such as bird and wild animal scaring does not change with small changes in farm size. This is also true for supervision of hired labour where the number of supervisors does not change with small changes in the number of hired labourers.
[53] We recognise the possibility of a positive correlation between farm size and other factors which might also influence profitability. However, the narrow variation in things like education for the interviewed heads of households, access to extension services, and the use of fertilisers and improved seeds emphasises the plausibility of our argument that farm size is likely to be the main reason behind the observed variation in profitability among the producers of potential feedstocks for producing biofuels.

5.4.2 Variations of Per Capita Incomes with Farm Size

This section presents the results of the assessment of the variation of per capita incomes with changes in farm size among sugarcane farmers. As described in the previous chapter, the assessment started with the estimation of the profit obtained from sugarcane farming for each household. This was then divided by the respective household sizes to get the income per capita values. Then the income per capita values were compared to the national poverty line to determine whether the household was above or below the poverty line. Moreover, the established variation between the per capita incomes and farm size enabled the present study to determine the minimum farm size required for a household to be above the poverty line. A similar approach has been used by Reddy (2003) in his study on the profitability of sugarcane farming in Fiji. The results of the assessment of the variations of the per capita incomes, and the differences between per capita incomes and the poverty line for various farm size categories are provided in figure 5.10.

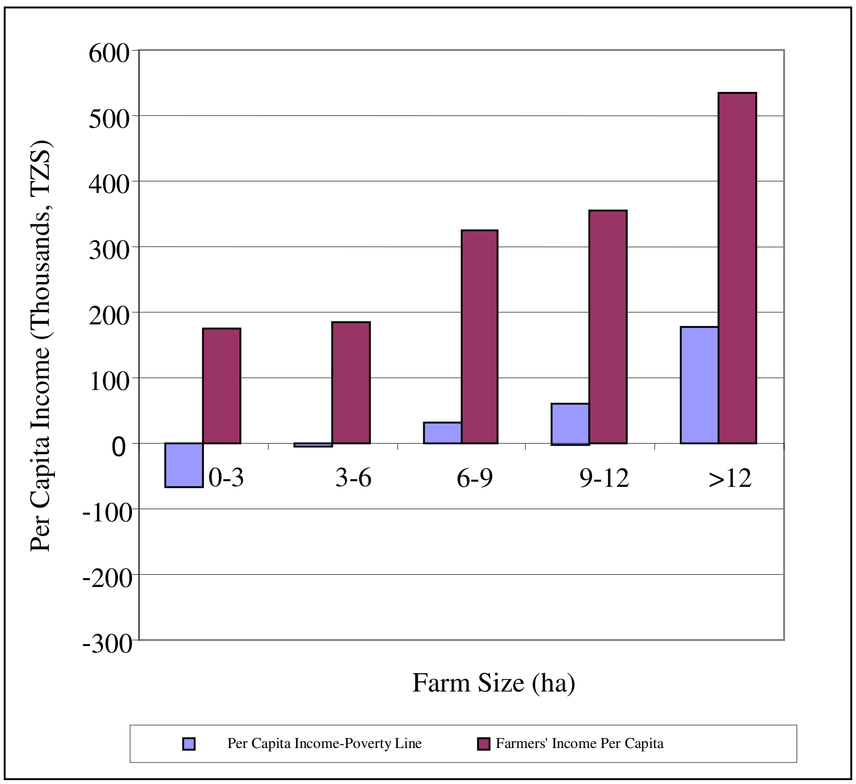

Figure 5.10: Variations of Per Capita Incomes with Farm Size

Figure 5.10 shows that the per capita incomes, from sugarcane farming, for farmers who have farms which are less than three hectares are lower than the poverty line.

Furthermore, the figure shows that a household requires at least three hectares to have income per capita which is above the poverty line. Thus, for sugarcane farming to be a useful tool in poverty alleviation efforts, farmers should be encouraged and supported to increase their farm sizes to at least three hectares. The most appropriate support would be to enhance the sugarcane farmers' access to credit services.

5.5 Tanzanian Biofuels' Contribution to the World Market

As described in the background, the economics of biofuels production and use depend on: (i) the cost of feedstocks, which varies among countries, depending on land availability and quality, agricultural productivity, and labour costs; (ii) processing costs, which depend on plant size and location; (iii) the cost of fossil petrol, which depends on world oil prices. Consequently, countries like Tanzania which have abundant arable land and cheap labour are well placed to produce biofuels at lower costs than developed countries where in most cases land is scarce and labour is relatively more expensive.

The results of the estimation of the costs of producing biofuels provided in section 5.1 support the argument provided in the previous paragraph, *i.e.* the costs of producing ethanol and biodiesel in the country are likely to be lower than the costs of producing those fuels in developed countries. For instance, the cost of producing ethanol by using sugarcane as a feedstock which has been estimated to be TZS 351 (US$ 0.276) per litre is lower than the cost of producing ethanol by using the same feedstock in the USA which is estimated to be US$ 0.390 per litre (Von Lampe, 2006). Similarly, the cost of producing biodiesel by using jatropha as a feedstock which has been estimated to be TZS 648 (US$ 0.510) is lower than the cost of producing biodiesel in the European Union and the USA which are estimated to be US$ 0.607 and US$ 0.549 per litre respectively (Von Lampe, 2006). This means that it would be more economical for developed countries to import biofuels from countries such as Tanzania.

Furthermore, the results provided in section 5.1 show that the country has a potential of producing about 4010 and 1726 million litres of ethanol and biodiesel respectively. The local annual demands for ethanol and biodiesel are estimated at 568 and 886 million litres respectively. Therefore, the country has a potential of exporting about 3442 and 840 million litres (per year) of ethanol and biodiesel respectively. The export of biofuels would help to ease the problem of declining world prices for the traditional exports of the country, such as cotton and coffee. This (export of biofuels) will have a significant contribution towards the country's efforts to alleviate poverty[54].

It is important to point out that the country would be able to benefit from the export of biofuels only if the developed countries would open up their markets for ethanol and biodiesel produced in developing countries. This argument is based on the fact that currently producers of biofuels in developed countries enjoy strong support from their respective governments. For instance, producers of biofuels in the USA are supported through motor fuel excise tax credits, small ethanol producers tax credits and import duties on fuel ethanol imports[55] (Shapour *et al.,* 2006). Likewise, producers of biofuels in the European Union enjoy strong support in the form of tax reductions. According to Frondel and Peters (2005), the tax reductions provided to biofuels producers in various European countries in 2005 were as follows: Germany (0.47€/l), France (0.33€/l), Italy (0.29€/l), Czech Republic (0.10€/l), Spain (0.29€/l) and United Kingdom (0.28€/l). The strong support enjoyed by producers of biofuels in developed countries would give them an unfair advantage against producers of ethanol and biodiesel in developing countries. Thus, as pointed out previously, for developing countries to benefit more from the large market for biofuels in developed countries, there should be a critical review of the support provided to biofuels producers in developed countries.

Notwithstanding the protectionism of developed countries, there is a large potential for developing countries to export ethanol and biodiesel to developed countries. For instance, despite the import duty levied on fuel ethanol by the USA, still the country imported about 604.8 million litres of ethanol from Brazil, Costa Rica, Jamaica and El Salvador in the year 2004 (Severinghaus, 2005). Thus, countries such as Tanzania can also manage to export ethanol and biodiesel to developed countries. Our main argument here (against protectionism), is that the import duties levied on biofuels by countries such as the USA erode the profit that would have otherwise benefited millions of small-scale farmers who would be producing feedstocks for biofuels production in developing countries.

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[54] A detailed discussion on the potential impact of biofuels production on poverty alleviation has been provided in section 5.2.

[55] In the year 2005, the import duty levied on fuel ethanol (by the USA) was about US$ 0.15 per litre.

5.6 Performance of Producers of Feedstocks for Biofuels Production

5.6.1 Descriptive Analyses Results

5.6.1.1 Farm Households Characteristics

Table 5.13 provides socio-economic characteristics of the heads of the households interviewed during the survey of producers of potential feedstocks for producing biofuels. The table shows that almost half of the interviewed households' heads were aged between 30 and 50 years. Households' heads aged less than 30 years constitutes 11.2% of the total number of respondents. It could be further noted that interviewees aged more than 50 years accounts for 37.5% of the total number of interviewees. The small proportion of respondents aged below 30 years could be attributed to several factors. One of the most likely reasons is the rural urban migration which in most cases involves the youth.

The present study also assessed the levels of education of the producers of potential feedstocks for biofuels production. The results of this assessment, presented in table 5.13, show that about 80% of the respondents reported to have attained some form of formal education. This is close to the national literacy level which is 78% (URT, 2006). Furthermore, the table shows that only 10.5% of those who reported to have acquired formal education had attained more than seven years of schooling. This implies that most of the respondents who reported to have got formal education had achieved a maximum of seven years of schooling. The large proportion of respondents who had attained only seven years of formal education could be attributed to the fact that the compulsory primary education in Tanzania lasts for seven years.

Furthermore, table 5.13 shows that female household heads constitute only 21% of the total number of farmers interviewed during the survey undertaken for the present study. The national average for female headed households in rural Tanzania is 17.5% (URT, 2006). Thus, the gender distribution of the interviewees of the present study reflects the rural households heads distribution of the entire country.

Moreover, the table shows that farmers whose farms were less than three hectares account for 41.6% of the total number of interviewees. The large proportion of respondents who had farms which were less than three hectares is not surprising. This is because the national average farm size is less than one hectare (URT, 2006).

Table 5.13: Socio-economic Characteristics of Household Heads

A: Households heads' age distribution:		
Age Category	Number	Percent
Below 30	30	11.2
30-40	65	24.3
40-50	72	27.0
50-60	45	16.9
Above 60	55	20.6
Total	267	100.0
B: Households heads' levels of education:	Number	Percent
No formal education	40	15.0
Adult education	12	4.5
Primary education	187	70.0
Secondary education	28	10.5
Total	267	100.0
C: Gender of the respondent:	Number	Percent
Male	211	79.0
Female	56	21.0
Total	267	100.0
D: Average household size	6.0	
E: Average farm size and farm size distribution		
Average farm size	4.80 ha	
Farm Size Categories	Number of Farms	Percent
Below 3 ha	111	41.6
3-6 ha	82	30.7
6-9 ha	43	16.1
9-12 ha	12	4.5
Above 12 ha	19	7.1
Total	267	100.0
F: Annual off-farm income		
Source of Income	Number of Farmers	Average Annual Income(TZS)
Formal employment	19	1,054,086
Local brewing	6	1,000,000
Carpentry	3	710,000
Charcoal making	4	234,000
Small business	58	933,103
Masonry	8	1,064,700
Average Annual Income	98	936032
G: Annual farm income by farm size category		
Farm Size Category	Average Farm Size (ha)	Average Annual Income(TZS)
Below 3 ha	1.82	857925
3-6 ha	4.16	1197793
6-9 ha	7.35	2033936
9-12 ha	10.42	2378460
Above 12 ha	16.91	3848973
Total Sample Average	4.8	1432884

Source: Own computation

Table 5.13 shows that the average farm size among the respondents is 4.8 ha. This is very high if compared to the national average of 0.7 ha (URT, 2006). The relatively larger farms among the respondents could be attributed to the commercial orientation of the farmers targeted by the present study. Their commercial orientation implies that their production plans are not only determined by the need to fulfil subsistence requirements, which is likely to be the major determinant of farm size for the majority of smallholders in the country, but also other objectives such as profit or revenue maximisation. These additional requirements are likely to be the main driving force behind the relatively larger farm sizes among producers of potential feedstocks for producing biofuels. Moreover, the respondents produce sugarcane, amongst other crops. Sugarcane is produced for sell to nearby sugar factories which also support the farmers in various ways. The support offered by the factories, which include provision of land preparation services, seed-cane, and in some few instances fertilisers on credit terms, might be among the reasons for the observed relatively larger farms in the study area.

Furthermore, table 5.13 shows that the average annual income from the various off-farm activities undertaken by the producers of potential feedstocks for producing biofuels ranges from TZS 234000 for charcoal making to TZS 1064700 for masonry. Also the table shows that operating small businesses is the most common source of off-farm income. Operators of small businesses constitute 21.7% of the total number of respondents and 59% of those who participate in the non-farm income generating activities. The average annual income from off-farm activities is TZS 936032. Moreover, the table shows that the average off-farm income is lower than the average farm income, which is TZS 1432884 per year. The difference between the two sources of income could be attributed to the fact that most farmers consider farming to be their primary activity and off-farm activities to be secondary. Thus, in most cases farmers concentrate most of their efforts on farming.

Furthermore, the table shows that off-farm income generating activities account for 39.5% of the total household income. Thus, it is plausible to argue that off-farm income generating activities constitute an important source of livelihoods for producers of potential feedstocks for producing biofuels. Since off-farm income sources have been found to have a significant contribution to the total household income, then poverty alleviation efforts in rural areas should not only focus on the improvement of the performance of farming activities, but should also seek to provide a conducive environment for the operation of non-farm income generating activities.

5.6.1.2 Availability of Extension Services in the Study Area

This section presents the results of the assessment of the availability of extension services for producers of potential feedstocks for producing biofuels. During the survey, the respondents were asked whether they had contacted extension agents for issues related to their day-to-day crop production activities. Furthermore, they were asked whether they had attended training workshops and/or received any extension materials. The results of the analysis of the farmers' access to various types of extension services are provided in figure 5.11.

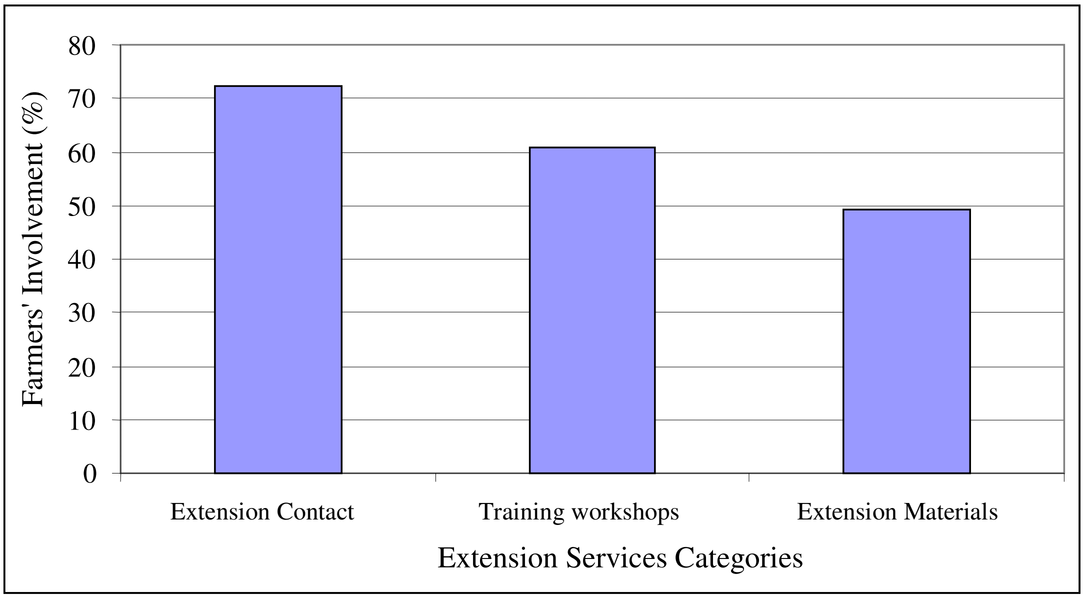

Figure 5.11: Farmers' Access to Various Types of Extension Services

Figure 5.11 shows that a little more than 70% of the producers of potential feedstocks for producing biofuels reported to have had contact with extension agents. This implies that the study area has a reasonable extension service network. Moreover, the figure shows that 60% of the respondents had attended training workshops on various issues related to crop production. Furthermore, figure 5.11 shows that about 50% of the interviewed farmers reported to have received various extension materials. The relatively high proportion of farmers who had attended training workshops and/or received extension materials could be attributed to the fact that most of the producers of potential feedstocks for biofuels production are members of sugarcane farmers association. The association organises regular training workshops for its members. It also distributes some booklets containing information on appropriate husbandry practices for sugarcane.

5.6.1.3 Availability of Credit Services in the Study Area

This section provides a brief discussion on the results of the assessment of the availability of credit services for producers of potential feedstocks for producing biofuels. About 71% of the respondents reported to have had applied for credit during the last three growing seasons. Despite the high proportion of farmers reporting to have applied for credit, respondents cited high interest rates as a big problem in the study area. The interest rates charged by the various sources of credit ranges from 15 to 25%. The fact that farmers thought that the interest rates charged were high, and yet most of them applied for credit can be attributed to the fact that applying for credit helps to ensure that their sugarcane is bought by the factory.

The need for 'a guarantee' arises from the fact that there are many incidences where the sugar factory, due to various reasons, fails to harvest their cane leading to enormous losses to the farmers. Normally the sugar factory and other credit services providers recover their loans when the farmers' cane is harvested by the sugar factory. Thus, in most cases farmers who have applied for credit would be assured of their cane being harvested by the sugar factory as it is in the factory's interest to harvest their cane so as to recover its money. The high incidences of unharvested cane reported by the respondents should be taken as an additional incentive for introducing new uses for the crop. Among the most appealing alternative uses for sugarcane is using it as a feedstock for producing ethanol. The introduction of ethanol production would ensure a reliable market for the crop.

5.6.1.4 Problems Encountered by Producers of Feedstocks for Biofuels

Figure 5.12 presents a summary of the main problems encountered by producers of potential feedstocks for biofuels production in their day-to-day farming activities. The figure shows that there are eleven main obstacles which have been reported by the interviewed farmers. In order to establish the significance of each of the eleven problems, the farmers' responses were divided into four categories[56], and percentages were computed for each category.

Regarding the land shortage problem, about 60% of the respondents reported it as an important obstacle to their farming activities. This might sound strange for an area with abundant arable land. The high percentage of respondents considering land shortage as an important problem could be attributed to factors such as the limitation on the distance from the factory at which sugarcane could be grown profitably, and the inability to erect structures to control floods. Transport costs in the country are fairly high. The high transport costs mean that the profitability of sugarcane production decreases with increasing distance from the factory. Consequently, most of the farmers scramble for land which is close to the factory. Moreover, there are some areas which are close to the factory but are considered to be unsuitable for sugarcane farming due to the floods during the long rain season. Thus, generally the 'land shortage' problem has a lot to do with the high transport costs which could be attributed to high fuel prices and poor field roads conditions. Therefore, the most appropriate solution for this problem is to reduce transport costs by improving field roads and reducing fuel costs by producing own fuel in the form of biofuels.

It can be further noted, from figure 5.12, that about 40% of the interviewed producers of potential feedstocks for producing biofuels think that low soil fertility is an important problem in the area. Given the low prevalence of fertiliser use among the producers of potential feedstocks for biofuels production and the relatively high average yields[57], the farmers' perception that the land is reasonably fertile might be credible.

Furthermore, figure 5.12 shows that the number of respondents who consider shortage of hired labour to be an important problem account for less than 20% of the interviewees. The low percentage of farmers who consider shortage of hired labour to be a significant problem might be attributed to the large number of people who derive their livelihoods from labour selling. The large number of people who rely on labour

[56] The categorisation was based on farmers' perceptions regarding the severity of the problems.
[57] The average sugarcane yield (for small-scale farmers) in the study area is 61.82 Tonnes/ha. This is close to the world average yield for this crop which is 65 Tonnes/ha.

selling for their livelihoods means that farmers are not likely to encounter any problems in finding hired labourers to work on their farms. It is worthwhile pointing out that in some crucial times, for instance harvesting, the demand exceeds the supply of hired labour in the area. This fact is not clearly reflected by the farmers' responses regarding labour availability in the study area because harvesting for the widely grown crop, *i.e.* sugarcane, is done by the sugar factories. The factories deal with this problem by ferrying labourers from other parts of the country.

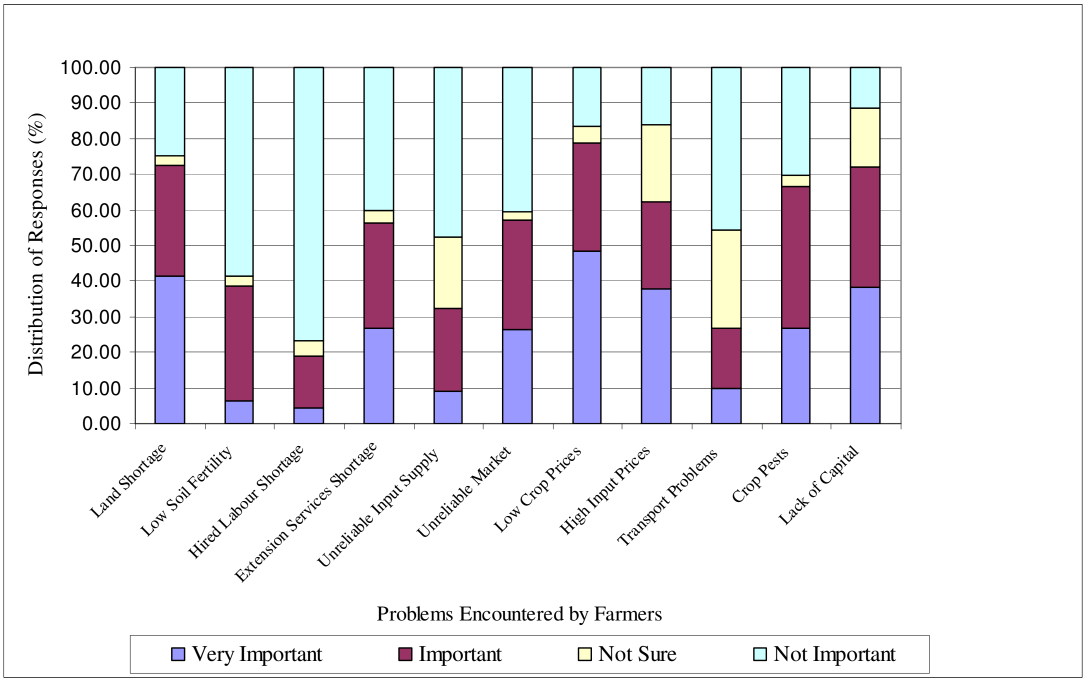

Figure 5.12: Distribution of Ranks of Problems Encountered by Farmers

Producers of potential feedstocks for producing biofuels were also asked whether they had encountered any problems in accessing extension services. Figure 5.12 shows that about 60% of the respondents consider the extension services provided to be inadequate. This is a bit surprising as the present study found that there are several sources of extension services in the area. The sugar factories are among the important sources of extension services in the study area. Moreover, small-scale sugarcane farmers, who account for a significant proportion of the producers of potential feedstocks for producing biofuels, have an association which provides extension services. The provision of extension services for other potential feedstocks for biofuels production is done by village and ward extension agents who are employed by the local government.

Given the abundance of sources of extension services, the insufficiency of those services which has been reported by the farmers might be attributed to the fact that most extension agents are poorly supported and inadequately motivated. The poor motivation implies that extension agents are unlikely to do their work as expected.

Figure 5.12 shows that only 30% of the respondents consider unreliable input supply to be an important problem. The low percentage of farmers reporting unreliable input supply as a significant obstacle can be attributed to the fact that most of the producers of potential feedstocks for biofuels production practice low external input agriculture. Most farmers in the study area do not use agrochemicals and fertilisers, they also make use of their own seeds. Thus, in a way they are the suppliers of most of the inputs they need to produce the various crops they grow. The fact that most farmers have decided to be suppliers of most of the inputs required for the production of the various crops they grow might be attributed to high input prices in the study area. This argument is based on the fact that about 60% of the respondents reported high input prices among the key problems in their day-to-day farming activities. The high input prices can be attributed to the removal of agricultural input subsidies towards the end of the 1980s[58].

The present study also tried to assess the farmers' perceptions regarding the availability of markets for their major crops. The survey conducted in the area revealed that apart from sugarcane, which is bought by local sugar factories, farmers depend on small traders for selling other crops. This makes the market for maize and rice very unreliable, as when the production of those crops in the most accessible parts of the country is high, the traders rarely set foot in remote areas. Thus, it is not surprising to have about 60% of the respondents reporting unreliable markets for their crops among the main problems in their farming activities.

Furthermore, figure 5.12 shows that almost 80% of the respondents reported low crop prices as a significant obstacle. This is likely to be a big problem for maize and rice. This is because the prices of these crops are normally low during the harvesting period.

[58] Having noted the impact of the removal of subsidies on the use of inputs such as fertilisers and improved seeds, the government of the United Republic of Tanzania has decided to gradually start subsidising the prices for some inputs.

Since most of the small-scale farmers cannot afford to store their crops, then they normally sell most of their harvest soon after harvesting. Regarding the price for sugarcane, farmers believe that the factory is taking advantage of being the sole buyer for their cane to pay low prices. This problem can be reduced by introducing alternative uses for sugarcane. Among the promising alternative uses for the crop is using it as a feedstock for producing ethanol. The introduction of ethanol production would help to break the monopoly of the sugar factories and hence improve producer prices for sugarcane farmers.

Figure 5.12 shows that about 25% of the respondents mentioned harvest transport problems among the key obstacles for their farming activities. The low proportion of farmers considering difficulties in transporting their crops as an important problem could be attributed to the fact that transport services for sugarcane are offered by the sugar factories which buy their cane. Furthermore, transport for other crops, such as maize and rice is normally done by hired labourers who use bicycles. Since there are many hired labourers, it is very unlikely that farmers would face problems in transporting crops from their farms. It is also important to note that small maize and rice traders normally buy those crops at the farmers homes. Consequently farmers do not need to take their crops (maize and rice) to a designated marketplace.

It can be noted further, from figure 5.12, that about 65% of the interviewed producers of potential feedstocks for biofuels production consider damages caused by crop pests to be an important problem. Although some animals such as wild pigs destroy most of the crops grown in the study area, the most affected crops are maize and rice. Moreover, the respondents reported outbreaks of army worms as one of the most serious problems. The large proportion of farmers reporting damages caused by crop pests among the main problems can be attributed to the fact that although there is always some assistance from the crop protection section of the local government, in most cases the chemical supplies to control crop pests are not timely delivered and consequently farmers incur enormous crop losses.

Figure 5.12 shows that almost 70% of the respondents reported to have encountered problems in financing their farming activities. The large proportion of respondents encountering problems in financing their farming activities can be attributed to the high interest rates charged by the various providers of credit services. The high interest rates compel farmers to think twice before they decided to apply for credit. Notwithstanding the high interest rates, as pointed out in previous sections, farmers do apply for credit as a strategy to make sure that their cane is harvested by the factory. Thus, for the credit services to have a meaningful contribution to the improvement of the performance of the producers of potential feedstocks for biofuels production, the interest rates charged should be low enough to make the use of credit to finance farming activities economical.

5.6.2 Transport Costs Variations with Sucrose Content

This section provides a brief discussion of the results of the assessment of the variation of transport costs with changes in sucrose content. A graphic presentation of the variations of the transport cost-producer price ratios with changes in sucrose content is provided in fugure 5.13.

Figure 5.13 shows that the average transport costs, expressed as a percentage of sugarcane producer prices, decrease continuously with increasing sucrose content. The transport cost (expressed as percentages of producer prices) ranges from 40% for sugarcane with sucrose content of less than 5% to 12% for sugarcane with sucrose content of more than 13%. The results suggest that farmers would benefit siginifcantly if they would be able to increase the quality of their cane (measured by sucrose content).

Furthermore, the figure shows that the transport cost-producer price ratio has been declining slightly from the 2002/03 to the 2004/5 season. The decline in the ratio implies that there has been a relatively higher increase in sugarcane producer prices than the transport costs. The high transport cost-producer price ratio and the sharp decline in the ratio with increasing sucrose content implies that there is a large incentive for farmers to improve the sucrose content of their cane. Since the average sucrose content is high for sugarcane harvested towards the end of the dry season (September) than that harvested in the beginning of the dry season (June), farmers could improve their cane's sucrose content by strategic selection of the planting time.

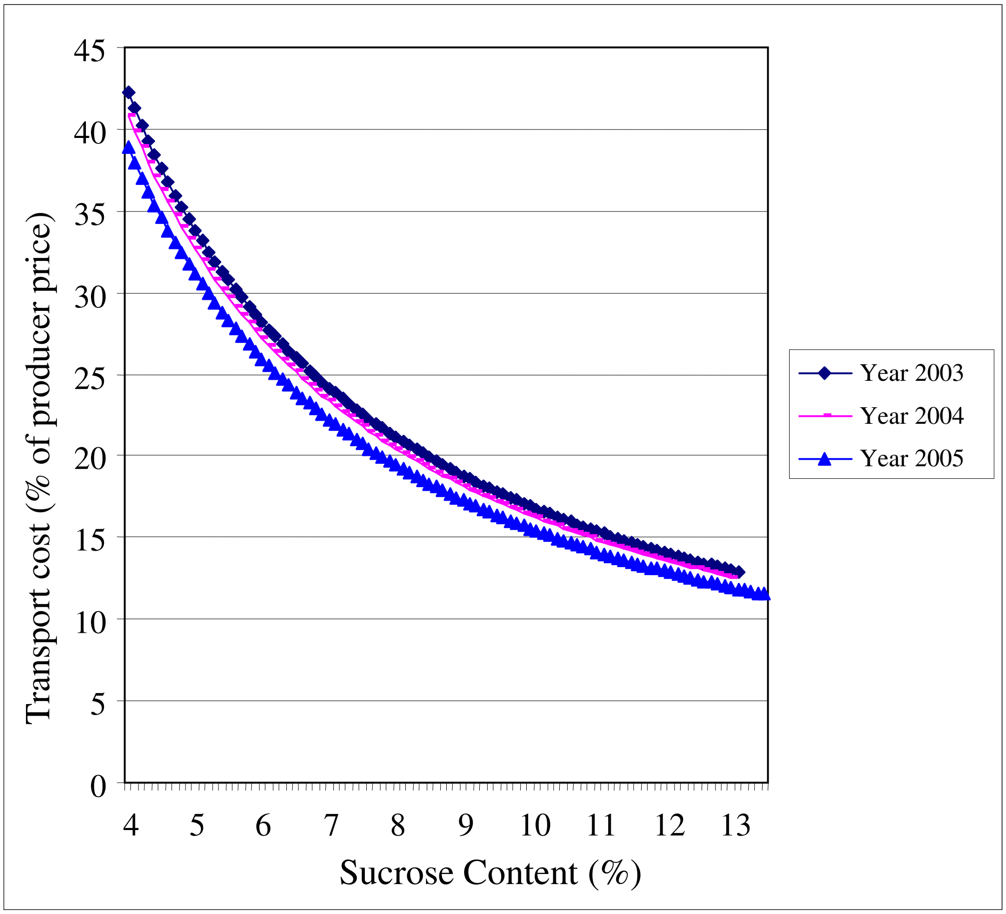

Figure 5.13: Variations of Transport Costs-Producer Prices Ratios

5.6.3 Production Efficiency Analysis Results

This section provides a brief discussion of the results of the assessment of production efficiency among the producers of potential feedstocks for producing biofuels in Tanzania. As pointed out in chapter four, the analysis focuses on sugarcane outgrowers. The focus on sugarcane producers is based on the fact that the crop has a high potential for being used as a feedstock for producing ethanol. Moreover, the outgrowers produce other crops, such as maize, and rice, which could also be used as feedstocks for producing biofuels.

The economics of biomass ethanol production and use depend on a number of factors specific to the local situation. These factors include: (i) the cost of feedstocks, which varies among countries, depending on land availability and quality, agricultural productivity, and labour costs; (ii) processing costs, which depend on plant size and location; and (iii) the prices of fossil fuels. Having dealt with the other determinants of the feasibility of producing biofuels in the previous sections, this part focuses on the efficiency of the producers of potential feedstocks for producing biofuels.

5.6.3.1 Distribution of DEA Technical Efficiency Scores

The present study made use of DEA to measure the efficiency of sugarcane outgrowers in Tanzania. In addition to sugarcane, the outgrowers also produce maize, and rice. Thus, the ability of DEA to handle multi-outputs situations made it a natural choice for the present study. The frequency distribution of DEA technical efficiency scores for sugarcane outgrowers is provided in table 5.14.

Table 5.14: Frequency Distribution of DEA Technical Efficiency Scores

Efficiency Score (%)	Number of Farmers	Percent
20.0-30	11	4.1
30.1-40	41	15.4
40.1-50	57	21.3
50.1-60	38	14.2
60.1-70	26	9.7
70.1-80	28	10.5
80.1-90	20	7.5
90.1-100	46	17.2
Average Score: 60.6		

Source: Own computation

Table 5.14 shows that about 40% of the sugarcane outgrowers have technical efficiency scores which are less than 50%. Furthermore, the table shows that the average technical efficiency score for the sugarcane outgrowers is 60.6%. The low average efficiency score implies that there is a wide room for improving efficiency among the sugarcane outgrowers. Improving efficiency would be important because, as pointed out in the previous section, productivity is among the key determinants of the feasibility of producing ethanol.

5.6.3.2 DEA Technical Efficiency Scores - Farm Size Relationships

This section presents the results of the assessment of the relationship between efficiency and farm size among sugarcane outgrowers. As mentioned previously, efficiency has been estimated by using DEA. A detailed description of the relationship between the DEA technical efficiency scores and farm size categories is provided in figure 5.14.

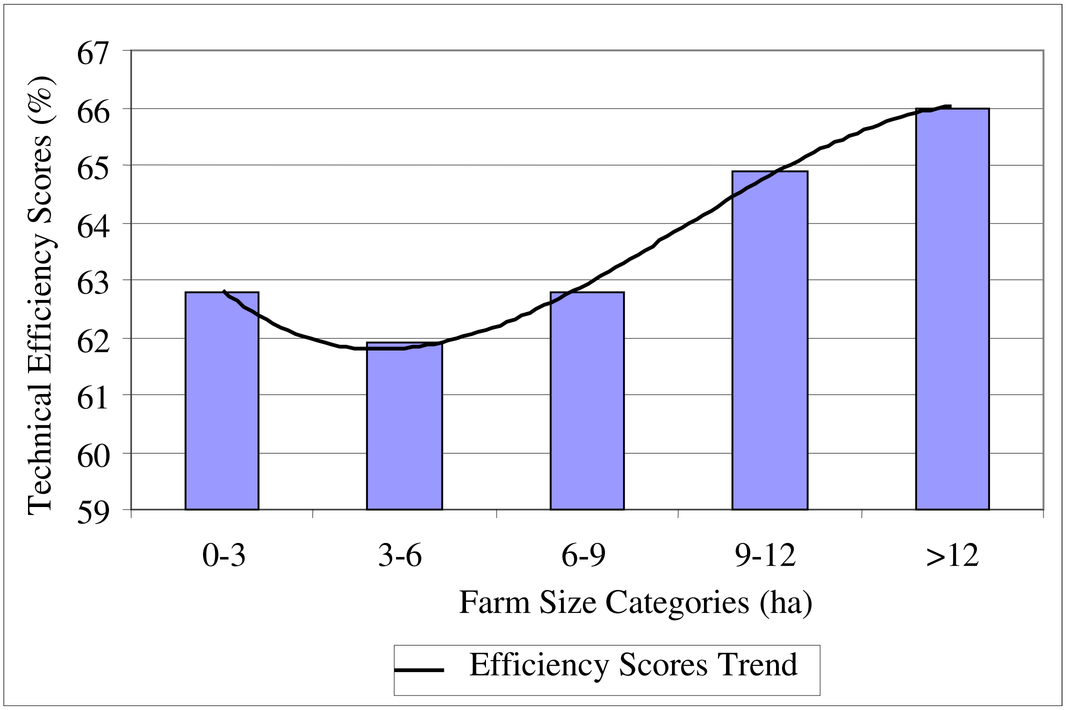

Figure 5.14: DEA Technical Efficiency Scores Vs Farm Size Categories

Figure 5.14 shows that very small farmers (with farms measuring less than three hectares) are relatively more efficient than those who have farms measuring between three and six hectares. Furthermore, the figure shows that farms which have areas of more than nine hectares have higher DEA technical efficiency scores than the other farm size categories. A similar farm size-efficiency relationship has been reported by Heltberg (1998).

The observed tendency of declining farm efficiency when moving from very small farm size to relatively large size could be attributed to changes in the land-labour ratio which forces the household to make use of hired labour when farm size increases. The need to start hiring labour comes with another requirement of supervising the hired labourers which might cause a decline in productivity of family labour and hence the entire average labour productivity. On the other hand, the higher efficiency scores for farms with areas of more than nine hectares could be attributed to improvements in supervision of hired labourers. Large farms which hire many labourers are likely to employ field officers or hired labourers' supervisors. The employment of hired labour supervisors is likely to increase the productivity of hired labour and hence improving the efficiency of the farm as a whole. Furthermore, since the number of supervisors does not change with slight changes in the number of hired labourers, farmers who employ many hired labourers are likely to benefit from scale economies in hired labour supervision[59].

5.6.3.3 DEA Technical Efficiency Scores and Farmers' Education Levels

The present study also tried to determine the relationship between farm productivity and the farmers' levels of education. This is in essence an attempt to determine the influence of the farmers' levels of education on farm efficiency. The education levels of the respondents have been divided into four different categories. The first category includes farmers who have no any form of formal education, the second group is made of farmers who have attended adult education classes, the third category includes farmers who have attended the compulsory seven years of primary education, and the last group is made of farmers who have attained post primary education. Figure 5.15 provides a description of the relationship between DEA technical efficiency scores and the levels of education among the sugarcane outgrowers.

Figure 5.15 shows that the average DEA technical efficiency score for farmers who have not attended any form of formal education is more or less equal to the average value for farmers who have attended adult education classes. The equality of technical efficiency levels for those groups might be attributed to the fact that the knowledge obtained from the adult education classes (reading and writing) is not likely to make a big difference in a production setting dominated by traditional farming techniques. The fact that there is little use of fertilisers, herbicides, and other agrochemicals implies that

[59] Increasing the number of hired labourers from say 10 to 20 would not necessarily require an increase in the number of hired labourers' supervisors.

having a knowledge of reading is not likely to have a significant contribution to farm productivity.

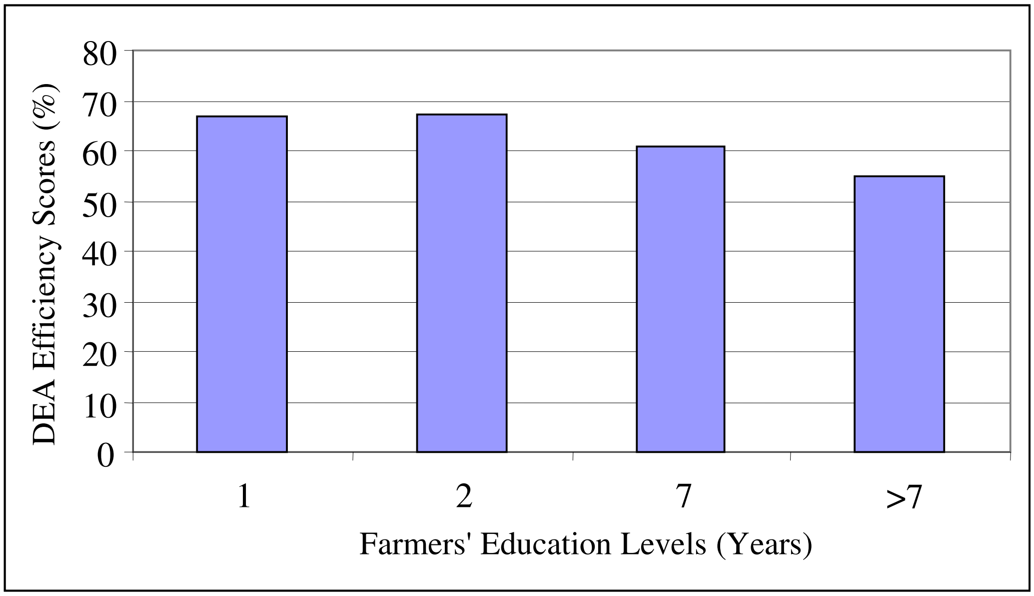

Figure 5.15: DEA Farm Efficiency Indices Vs Farmers' Educations Levels

Furthermore, the figure shows that there is a slight decrease in the average DEA technical efficiency scores between the third and fourth education categories. The decline in technical efficiency when the farmer attains post primary education can be attributed to the fact that almost all farmers who have attained post primary education are not full time farmers. Most of them are either government employees or have other off-farm economic activities as their main sources of livelihoods. Thus, in most cases they have less time for their farms.

5.6.3.4 DEA Technical Efficiency Scores - Farmers' Experience Relationship

This section provides a brief discussion on the results of the assessment of the relationship between efficiency and farming experience. This is in essence an attempt to determine the influence of farming experience on farm performance. The results of the assessment of the relationship between DEA technical efficiency scores and farming experience are provided in figure 5.16.

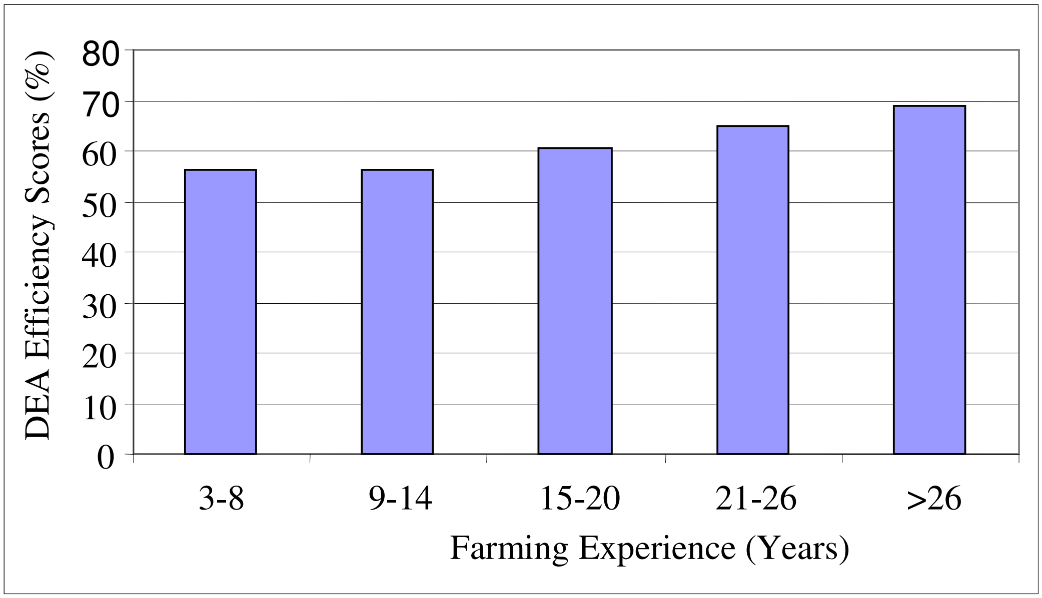

Figure 5.16: DEA Technical Efficiency Scores Vs Farming Experience

Figure 5.16 shows that there is a slight increase in the DEA technical efficiency scores with increasing farming experience. The figure shows that farmers with farming experience of more than twenty six years have the highest avearage DEA technical efficiency score. The increase of the DEA technical efficiency scores with increasing farming experience can be attributed to the fact that the knowledge of appropriate husbandry practices is likely to increase with increasing farming experience. Thus, the high technical efficiency scores, for the more experienced farmers, reflect the high yields resulting from good farm management.

Despite the positive relationship between the DEA efficiency scores and farming experience, the figure shows that the difference in efficiency between the least and the most experienced farmers is rather small. This can be attributed to the fact that the use of hired labour is very common in the study area. The use of hired labour means that even farmers who are less experienced are likely to benefit from the farming experience of the labourers they employ. Thus, hiring labour helps to bridge the gap in farming knowledge between the least and most experienced farmers.

6.0 Policy Recommendations and Executive Summary

6.1 Policy Recommendations

Providing appropriate policy recommendations for developing countries is not an easy task, and requires some practical down to earth experience in the field. This is because economic theory alone is not sufficient to cope with some problems which are specific to these countries. Nonetheless, an attempt has been made to develop some recommendations which could help policy makers in formulating strategies for improving the performance of the agriculture sector and hence enhance the contribution of the sector towards the efforts to alleviate poverty in Tanzania.

As pointed out in the first chapter, the main objective of the present study is to explore the feasibility of producing biofuels and the potential contribution of biofuels production towards the country's efforts to alleviate poverty among small-scale farmers. The results of the analysis aimed at determining the feasibility of producing biofuels in Tanzania have revealed that the country has a high potential of producing ethanol and biodiesel. The established high ethanol and biodiesel production potential makes it reasonable to recommend deliberate efforts, by the government, to attract investments in biofuels production in the country. Moreover, the present study found that tax incentives reduce significantly the minimum world oil prices required for ethanol and biodiesel produced in the country to be able to compete with the traditional fossil fuels. The observed responsiveness of the threshold world oil prices to support measures such as tax incentives makes it plausible to recommend the use of such measures to attract investments in the production of ethanol and biodiesel in Tanzania.

The present study also tried to determine the probable impacts of biofuels production on the livelihoods of small-scale producers of sugarcane and jatropha. The results show that the use of sugarcane and jatropha for producing ethanol and biodiesel respectively would have a significant impact on the incomes of the producers of those crops. Furthermore, the results show that the production of biofuels would also benefit the rural poor who usually depend on working as hired labourers to supplement the incomes obtained from the sale of their own crops. The high potential impacts of introducing biofuels production on the incomes of sugarcane and jatropha farmers makes it plausible to recommend the incorporation of ethanol and biodiesel production in the government's list of strategies to alleviate poverty in the country. Moreover, the high potential impact of biofuels production on the incomes of small-scale sugarcane and jatropha farmers emphasises the significance of the recommendation to attract investments in ethanol and biodiesel production which was made previously.

The present study also attempted to determine the relationship between profitability and farm size among the producers of potential feedstocks for producing biofuels. The results show that farm profitability increases continuously up to thirteen hectares from where it starts to decrease. The observed low farm profitability at very small farm sizes, coupled with the increase in profitability up to around thirteen hectares makes it reasonable to recommend a policy reorientation in favour of relatively larger farms. More emphasis should be directed at creating favourable environment for increasing farm sizes so as to ensure a smooth transition from an agriculture sector dominated by very small farms to a sector that will be made of relatively larger farms. Since the majority of farmers in Tanzania have very small farms[60], then there is a need to encourage and support them to increase their farm sizes. The most appropriate support is ensuring that credit is made available to farmers at reasonable terms. Moreover, farmers should be encouraged to move from subsistence to commercial farming, which seems to be a prerequisite for improving the Tanzanian agriculture sector. In the light of this recommendation, new national/regional agricultural projects should make sure that the land allocated to each household enables it to take advantage of the increase in profitability that is associated with increasing farm size for small farms[61]. The recommendation to encourage and support farmers to increase their farm sizes has not only emanated from the observed increase in profitability with increasing farm size for small farms, but also from the fact that farmers who had farms which were less than three hectares were found to have per capita incomes, from farming activities, which were lower than the poverty line. Thus, by increasing their farm sizes, farmers would not only increase farm profitability, but would also increase their chances of moving out of absolute poverty. As pointed out previously, moving from subsistence to commercial farming is crucial for enhancing the contribution of the agriculture sector towards the efforts to alleviate poverty. Thus the production of biofuels, which would provide a

[60] The average farm size in Tanzania is estimated to be 0.7ha (URT, 2006).
[61] The term "small farms" as used here refers to all farms which are less than thirteen hectares.

reliable market for small-scale producers of crops which can be used to produce ethanol and biodiesel, and hence set the shift from subsistence to commercial farming in motion, would contribute significantly to poverty alleviation in the country.

The present study also tried to identify the main problems encountered by the producers of potential feedstocks for biofuels production in their day-to-day farming activities. Among the main problems identified is high input prices. Since high input prices ranked high in the list of key obstacles mentioned by farmers, then the government should increase the efforts to tackle the problem. The problem can be tackled by strengthening farmers' associations and entrust them with the task of supplying farm inputs. This recommendation is based on the fact that inputs supplied by farmers' associations were found to be cheaper than those supplied by private traders. The large input price differential between farmers' associations and private traders could be attributed to fact that while the farmers' associations supply inputs on "no profit no loss" basis, private traders have profit maximisation at the centre of their input supply operations. Unfortunately, however, the farmers' associations are unable to meet the input requirements for all farmers. Thus the government should increase the ability of such associations to procure inputs by providing seed money. This would enhance their ability to provide input supply services to small-scale farmers in rural Tanzania and hence ease the problem of high input prices.

Shortage of extension services is another problem that has been reported by a significant proportion of respondents. Consequently, it is plausible to recommend improvements in the provision of extension services. The extension services can be improved by promoting the linkage between farmers, researchers and extension personnel. This will facilitate the flow of information from the researchers to the farmers and vice versa, which is important for the development of relevant technologies. An efficient extension system will ensure proper communication between farmers and researchers, which is important for the developed technologies to reach the end users, and for the researchers to have a clear knowledge of farmers' needs. To achieve this target, the government should enhance the support provided to extension agents and agricultural researchers.

Furthermore, the results of the analysis of the main problems encountered by the producers of potential feedstocks for producing biofuels have revealed that unreliable markets is among the main obstacles. This problem can be reduced by introducing ethanol and biodiesel production in the country. In addition to helping to ease the problem of unreliable markets, the use of crops as feedstocks for producing biofuels would also increase the demand for crops such as sugarcane and jatropha. The increase in demand for the crops which can be used as feedstocks for producing biofuels would possibly lead to improvements of producer prices for those crops. Thus the introduction of biofuels production would also help to ease the problem of low crop prices which was reported by a substantial proportion of farmers.

Moreover, the present study found that lack of capital is among the main problems encountered by the producers of potential feedstocks for biofuels production. The significance of the problem of lack of capital among the interviewed farmers makes it plausible to recommend deliberate efforts to ensure that farmers have access to credit at reasonable terms. Since, among the credit services providers, farmers' associations were the most preferred source of credit, then the government should enhance the support provided to those associations. In this case the most appropriate support would be to boost the capital bases of saving and credit associations operated by farmers in the country. Supporting such associations would enable them to serve more farmers and hence ease the problem of lack of capital among the producers of potential feedstocks for biofuels production.

Lastly, the exploration of the main problems encountered by the producers of potential feedstocks for producing biofuels revealed that land shortage is among the main obstacles. A close scrutiny has revealed that the main reason for the "land shortage" problem is the poor rural infrastructure which compel farmers to use land that is as close to the market as possible. The need to use land that is close to the market results to stiff competition for land that is close to sugar factories, and hence the reported land shortage problem. Thus to ease the "land shortage" problem, the government should invest more in rural infrastructure improvement projects.

6.2 Executive Summary

6.2.1 Background and Objectives

Tanzania is among the countries which depend entirely on imports for their oil needs. Consequently, the recent increases in world oil prices have led to rapid increases in the country's expenditure on oil imports. For example, the value of the country's oil imports increased from US$ 400.3 million in 2003 to US$ 1.1 billion in 2005. The expenditure on oil imports in 2005 was almost equal to 50% of the total foreign exchange reserves of the country. Thus, it is clear that the country is spending a significant proportion of its meagre foreign exchange reserves on oil imports. It is with this concern in mind that, just recently, the Tanzanian government started to think about the possibility of displacing petrol and diesel fuels with liquid biofuels. Unfortunately, however, the government has not yet backed its interest on biofuels with detailed economic analyses on the feasibility of producing ethanol and biodiesel in the country. Though there are several studies which provide an overview of the country's potential in producing biofuels, there is not any study which has conducted a detailed empirical analysis of the feasibility of producing biofuels in Tanzania. Thus, the present study is an attempt to contribute towards the knowledge base regarding the feasibility of producing biofuels in the country. The production and use of biofuels would not only help to reduce the country's expenditure on oil imports and augment the Tanzanian government's efforts to alleviate poverty among small-scale farmers, but would also contribute significantly towards the worldwide efforts to reduce the emission of greenhouse gases that are blamed for causing global warming.

General Objective

The general objective of the present study is to explore the potential of producing biofuels and the prospective influence of biofuels production on poverty alleviation among small-scale farmers in Tanzania.

Specific Objectives

1. To explore the potential of producing biofuels in Tanzania.
2. To determine the potential contribution of biofuels production towards the efforts to pull small-scale farmers out of poverty.
3. To examine the relationship between profitability and farm size among producers of potential feedstocks for biofuels production.

4. To identify the main problems encountered by producers of potential feedstocks for producing biofuels.
5. To determine the efficiency of the producers of potential feedstocks for biofuels production.

6.2.2 Data and Methodology

Data were collected through an intensive survey of small-scale producers of crops which could be used as feedstocks for producing biofuels. A total of 267 farmers, from 23 villages, were interviewed. These (the primary data) were supplemented by secondary data which were extracted from reports and other documentary materials. The data collected include: input requirements (quantities) and their respective prices for the various crops which can be used as feedstocks for producing biofuels, prevailing prices for those crops, investment costs for biofuels plants of various capacities, fossil fuel prices, prices for other products, like sugar, which would be competing for feedstocks with biofuels. Data concerning the demand for petroleum products in the country were obtained from the Tanzanian Petroleum Development Company (TPDC).

The present study estimated the costs of producing biofuels from various feedstocks. The study focussed on sugarcane, maize, cassava, sorghum, jatropha and oil palm. The estimated costs were then compared with their respective threshold production costs to find out whether ethanol and biodiesel produced in the country could compete with the traditional fossil fuels. After estimating the costs of producing biofuels, a linear programming model was used to determine the quantities of sugarcane, maize, cassava, sorghum, jatropha and oil palm which can be produced for use as feedstocks for producing biofuels. Moreover, the potential impact of biofuels production on the profitability of the crops which would be used as feedstocks for producing biofuels was estimated. This entailed the estimation of the potential returns from using the various crops as feedstocks for producing biofuels and comparing them with what the farmers get when those crops are used for other purposes. Also the present study estimated the potential impact of biofuels production on the acreages under the various crops which can be used for producing biofuels. The estimation of the impact of biofuels production on the acreages for various crops which can be used to produce ethanol and biodiesel enabled the present study to come up with a rough estimate of the number of new employment opportunities that would be created by producing biofuels in the country.

Furthermore, the present study assessed the performance of the producers of potential feedstocks for producing biofuels. Technical efficiency and average farm profit were used as indicators of farm performance. The present study used DEA to measure technical efficiency. Moreover, the present study tried to determine the influence of farm size, levels of education and farming experience of the interviewed heads of households on farm profitability and efficiency.

6.2.3 Results, Conclusions and Policy Recommendations

Several principal findings emerged from the analyses conducted to test the hypotheses formulated to address the objectives of the present study. The present study started with estimations of the costs of producing ethanol and biodiesel by using various feedstocks. The estimated costs were then compared with their respective threshold production costs to find out whether ethanol and biodiesel produced in the country could compete with the traditional fossil fuels. The estimates of the production costs for ethanol are: 351, 570, 676 and 584 TZS/l for sugarcane, maize, sorghum and cassava respectively. At the same time the threshold ethanol production cost has been estimated to be 597 TZS/l. A quick comparison of the estimates of ethanol production costs and the threshold production cost shows that ethanol produced by using sugarcane, maize and/or cassava as feedstocks can easily compete with petrol. Thus it is appropriate to conclude that ethanol can be produced competitively in Tanzania.

Furthermore, the results show that the production costs for biodiesel are 601 and 648 TZS/l when using palm oil and jatropha as feedstocks respectively. These are slightly higher than the threshold production cost for biodiesel, which is estimated to be 580 TZS/l. A comparison of the estimates of the biodiesel production costs and the landed price for fossil diesel shows that the differences between those estimates are TZS 21 (US$ 0.02) and TZS 68 (US$ 0.05) when using palm oil and jatropha as feedstocks respectively. The small differences between the estimated biodiesel production costs and the fossil diesel landed price makes it reasonable to conclude that there is a realistic possibility of producing biodiesel profitably in the country.

Having estimated the average costs of producing biofuels from various feedstocks, the present study also estimated the amounts of ethanol and biodiesel that can be produced in Tanzania. The estimation of the quantities of ethanol and biodiesel that can be produced in the country was based on the estimates of the quantities of the various crops that can be produced for use as feedstocks for producing biofuels. The results show that the country can produce about 4010.10 and 1726.80 million litres of ethanol and biodiesel respectively per year. The annual demand for petrol and diesel in Tanzania were estimated to be 375 and 789 million litres respectively. Thus it is clear that the country can produce enough biofuels to meet the local demand. Given the high potential of producing biofuels in the country the present study recommends deliberate efforts to attract investments in biofuels production in the country.

Moreover, the present study assessed the effects of support measures, such as tax incentives, on the threshold world oil prices for biofuels produced by using various feedstocks in the country. The results show that providing tax incentives for biofuels producers would lower significantly the world oil prices at which biofuels produced in the country can compete with fossil fuels. For instance, complete VAT exemption has been found to reduce the world oil prices required for ethanol to be able to compete with fossil petrol from US$ 40 to 25 a barrel when using sugarcane as a feedstock; from US$ 65 to 45 a barrel when using maize/cassava as feedstock; and from US$ 75 to 55 a barrel when using sorghum as a feedstock. Regarding the threshold world oil prices for biodiesel production, the results show that supporting biodiesel producers by providing tax incentives would decrease the world oil prices at which the fuel can compete with fossil diesel from US$ 60 to 50 and US$ 65 to 55 a barrel when using oil palm and jatropha as feedstocks respectively. The sensitivity, of the minimum world oil price that is required for biofuels produced in the country to be able to compete with fossil fuels, to tax incentives makes it plausible to conclude that such measures can be used to attract investments in biofuels production in the country. It can be concluded further that tax incentives would be a very useful tool for supporting biofuels producers in the unlikely event of a drastic decrease of world oil prices.

The present study also estimated the potential impact of biofuels production on the incomes of small-scale sugarcane and jatropha producers in the country. This was aimed at determining the potential contribution of biofuels production to the country's poverty alleviation efforts. The results show that the use of sugarcane for producing ethanol would increase the net returns for small-scale sugarcane growers by 28%. In the case of jatropha, which at the time of data collection was produced in small quantities for producing soap, its use for biodiesel production would increase the net returns for small-scale producers of the crop by 53%. Since at the time of data collection there was a limited production of jatropha in the country, the present study also tried to determine the potential impact of using the crop as a feedstock for biodiesel production on the returns to land in the Tanzanian central plateau where the crop would be grown. The results show that the production of jatropha for producing biodiesel would increase the returns per hectare (compared to the returns from the other crop which is widely grown in the area considered, *i.e.* sorghum) by almost 90%. Moreover, the results show that the use of sugarcane and jatropha for producing biofuels would create about 1.8 million new employment opportunities for small-scale farmers in rural Tanzania. Also the results show that the production of biofuels would reduce the proportion of the rural poor living on less than one dollar a day by 31%. Therefore, it is plausible to conclude that the production of biofuels would contribute significantly in pulling small-scale sugarcane and jatropha farmers out of absolute poverty. The high potential impact of biofuels production on the incomes of small-scale farmers emphasises the significance of the recommendation to attract investments in ethanol and biodiesel production which was made previously.

Furthermore, the present study examined the relationship between profitability and farm size among sugarcane outgrowers. The analysis involved estimating the average profit (profit per hectare) for each of the farm households interviewed during the survey conducted for the present study. Then the variation in average profit with changes in farm size was established. The results show that the average profit increases with increasing farm size up to thirteen hectares from where it starts to decline. Given the observed profitability-farm size relationship, it can be concluded that: i) farm size is among the important determinants of profitability; ii) the relationship between farm size and profitability is not fixed, *i.e.* the effect of increasing farm size on farm profitability depends on the prevailing farm size. Whereas increasing farm size from one to two hectares is almost certainly going to increase average farm profit, increasing farm size from thirteen to fourteen hectares will at best result in no change in average farm profit. Thus it can be concluded further that very small farms can increase their profitability by increasing their respective farm sizes. Furthermore, the increase in profitability (with increasing farm size) up to thirteen hectares and the subsequent slight decline beyond that size makes it plausible to conclude that the optimal farm size for sugarcane outgrowers is around thirteen hectares.

The profit estimates obtained during the assessment of the farm size-profitability relationship were used to determine the minimum farm size required for an average household to move out of poverty. The results show that almost all households which have farms which are less than three hectares have per capita incomes which are lower than the poverty line. Thus it is plausible to conclude that for sugarcane farming to be able to pull small-scale farmers out of poverty, farmers with small farms should be encouraged and supported to increase their farm sizes to at least three hectares.

The present study also tried to identify the main problems encountered by producers of potential feedstocks for producing biofuels. The results revealed that there were seven main problems which were reported by at least 50% of the respondents. The main obstacles which were reported by farmers and the corresponding proportions of respondents reporting them are: land shortage (72%), shortage of extension services (56%), unreliable markets (58%), low crop prices (78%), high input prices (62%), crop pests (65%), and lack of capital (71%). The large proportions of farmers reporting lack of capital, unreliable markets, low crop prices and high input prices make it reasonable to conclude that they are among the main problems encountered by the producers of potential feedstocks for biofuels production in their day-to-day farming activities.

Lastly, the present study assessed the efficiency of sugarcane outgrowers in Morogoro. The decision to assess the efficiency of sugarcane producers was based on the fact that production efficiency is likely to influence feedstock costs and hence the feasibility of producing ethanol in the country. The results of efficiency estimations show that the average efficiency score among the sugarcane outgrowers is 60.6%. The low average efficiency score for the sugarcane outgrowers makes it plausible to conclude that there is widespread inefficiency among sugarcane outgrowers.

7.0 References and Appendices

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7.2 List of Appendices

Appendix 1: Farmers Questionnaire

A. Farm Household Characteristics

Questionnaire number:……………………………

1. Date: ……………… Interviewer's Name……………………………………

2. District …………………………………… Division ____________
Village ____________

3. Farmer's name ____________ Age: ______

4. Farmer's Gender:
   1 = Male ( )
   2 = Female ( )

5. Farmer's marital status:
   1 = Single ( )
   2 = Married ( )
   3 = Divorced ( )
   4 = Widow ( )
   5 = Temporary separated ( )

6. Household size ……………………………

7. Household composition

Age category (Years)	Sex (Gender)	
	Male	Female
0-9		
10-14		
15-65		
Above 65		

8. Farmer's years in sugarcane farming: ____________

9. Farmer's (household head) Level of education:
   1 = No formal education ( )
   2 = Adult education ( )
   3 = Primary education ( )
   4 = Secondary education ( )
   5 = Other (specify) ( ) ……………………………………………

B. Crop Production Information

10. Do you own the entire land you are currently using for crop production activities?
   1 = Yes ( )
   2 = No ( )

11. What is the total size of land that is owned by the household? .... (Acres)
12. How was the land owned by the household allocated to the different crops during the last three growing seasons?

Land Allocation to various crops in the last three seasons			
	Acreage		
Crop↓	2004/2005	2003/2004	2002/2003
Sugarcane			
Maize			
Rice			
Other crops			
Total			

13. How was the land (owned by the household) obtained?
1 = Inherited ( )
2 = Bought ( )
3 = Given by village government ( )
4 = Accessed free land ( )

14. If you bought land, then when was it bought .... and what was the price per acre (TZS) ....

15. What is the average size of land (in acres) that has been used for crop production activities in the last three seasons?

2004/2005		2003/2004		2002/2003	

16. If you do not own the entire land you are using for farming, then whose land do you use for crop production activities?
1 = Relative's land (free use) ( )
2 = Hired (monetary payments) ( )
3 = Hired (payments in produce form) ( )

17. If you hired land for crop production in the last three years, then in what form did you pay for the land you hired?
1 = in cash ( )
2 = in Produce form ( )

18. If you paid in cash, then what was the rent for hiring one acre of land? Provide Values in TZS for the last three years:

2004/2005		2003/2004		2002/2003	

19. If payments were in produce form then how much rice/maize was required per acre?

2004/2005		2003/2004		2002/2003	

20. Which crops did you grow on hired land during the last three seasons?

Hired land allocation to various crops in the last three seasons			
	Acreage		
Crop↓	2004/2005	2003/2004	2002/2003
Sugarcane			
Maize			
Rice			
Other crops			
Total			

21. What major food and cash crops have you grown in the last three seasons? And on average what was the quantity obtained for each crop?

Season→	2004/2005			2003/2004			2002/2003		
Cash crops	Acreage	Yield (T)	Rend	Acreage	Yield (T)	Rend	Acreage	Yield (T)	Rend
Sugarcane									
Rend = % sucrose content									

Season→	2004/2005		2003/2004		2002/2003	
Food crops	Acreage	Yield (Bags)	Acreage	Yield (Bags)	Acreage	Yield (Bags)
Rice						
Maize						

C. Household Income

Income From Farming Activities

22. Out of the various crops produced, which ones did you sell? Provide amounts and average prices for the last three seasons

Season→	2004/2005			2003/2004			2002/2003		
Crop↓	Amount (T/bag)	Price per T/sack	Total income	Amount (T/bag)	Price per T/sack	Total income	Amount (T/bag)	Price per T/sack	Total income
Sugarcane									
Paddy									
Maize									
Other crops									
Total									

Income From Off-Farm Activities

23. Apart from crop farming activities, what other activities bring income into your household? And how much did you get from those activities last season (2004/2005)?

Source of income	Average monthly income	Average Annual Income
Formal employment		
Brewing and selling local brew		
Carpentry		
Selling charcoal / firewood		
Small business		
Brick making		
Masonry		
Lumbering		
Others (specify)		
Total		

24. What problems do you encounter in your off-farm income generating activities?

Source of income	Main problems
Formal employment	
Brewing and selling local brew	
Carpentry	
Selling charcoal / firewood	
Small business	
Brick making	
Masonry	
Lumbering	
Others (specify)	

D. Labour And Other Input Use Information

25. What is the average labour requirement (man days per acre) for the various operations?

Average Labour Requirements for Various Farm Operations (per acre)				
Crop→	Sugarcane	Rice	Maize	Total
Land Preparation				
Planting				
Weeding				
Agrochemicals Application				
Harvesting				
Transporting				
Bird Scaring				
Other				
Total				

26. If hired labour was used, indicate the average cost per operation per acre for sugarcane production for the last three seasons

Sugarcane									
Season	2004/2005			2003/2004			2002/2003		
Operation/activity↓	Size (acre /T)	Unit cost	Total cost	Size (acre / T)	Unit cost	Total cost	Size (acre / T)	Unit cost	Total cost
Land Preparation									
Planting									
Weeding									
Fertilization									
Harvesting									
Transporting									
Other									
Total									

27. If hired labour was used, indicate the average cost per operation per acre for maize production for the last three seasons

Maize									
Season	2004/2005			2003/2004			2002/2003		
Operation/activity↓	Size (acre / T)	Unit cost	Total cost	Size (acre / T)	Unit cost	Total cost	Size (acre / T)	Unit cost	Total cost
Land Preparation									
Planting									
Weeding									
Fertilization									
Harvesting									
Transporting									
Other									
Total									

28. If hired labour was used, indicate the average cost per operation per acre for rice production for the last three seasons

Rice									
Season	2004/2005			2003/2004			2002/2003		
Operation/activity↓	Size (acre / T)	Unit cost	Total cost	Size (acre / T)	Unit cost	Total cost	Size (acre / T)	Unit cost	Total cost
Land Preparation									
Planting									
Weeding									
Fertilization									
Harvesting									
Transporting									
Bird Scaring									
Other									
Total									

Other expenses in production operations (apart from labour charges)

29. What other expenses (apart from labour) did you incur in producing sugarcane in the last three seasons? *{Cost for tractor services, harvest transport, equipment hire e.g. sprayers etc.}*

Sugarcane									
Season	2004/2005			2003/2004			2002/2003		
Operation/activity↓	Amount	Unit cost	Total cost	Amount	Unit cost	Total cost	Amount	Unit cost	Total cost
Tractor Services									
Equipment hire									
Transporting									
Other									
Total									

30. What other expenses (apart from labour) did you incur in producing maize in the last three seasons? *{Cost for tractor services, harvest transport, equipment hire e.g. sprayers etc.}*

Maize									
Season	2004/2005			2003/2004			2002/2003		
Operation/activity↓	Amount	Unit cost	Total cost	Amount	Unit cost	Total cost	Amount	Unit cost	Total cost
Tractor Services									
Equipment hire									
Transporting									
Other									
Total									

31. What other expenses (apart from labour) did you incur in producing rice in the last three seasons? *{Cost for tractor services, harvest transport, equipment hire e.g. sprayers etc.}*

Rice									
Season	2004/2005			2003/2004			2002/2003		
Operation/activity↓	Amount	Unit cost	Total cost	Amount	Unit cost	Total cost	Amount	Unit cost	Total cost
Tractor Services									
Equipment hire									
Transporting									
Other									
Total									

32. Did you purchase fertilizers or any other agrochemicals during the last three growing seasons?
    1 = Yes ( ); 2 = No ( )

33. If the answer for question 32 is 'yes', then where did you buy those inputs?
    1 = Input suppliers within the ward ( )
    2 = Input suppliers in Morogoro town ( )
    3 = From farmers' associations ( )
    4 = From MSE/KSE ( )
    5 = Other (specify) ( ) ....

34. If the answer for question 32 is 'no', then what were the reasons for not buying those inputs?
    1 = Not available ( )
    2 = Expensive ( )
    3 = Not necessary ( )
    4 = other (specify) ( ) ....

35. Indicate amounts and prices for the inputs used in sugarcane production in the last three seasons.

Crop→	Sugarcane								
Season→	2004/2005			2003/2004			2002/2003		
Operation/activity↓	Amount	Unit price	Total cost	Amount	Unit price	Total cost	Amount	Unit price	Total cost
Fertilizer									
Seed cane									
Herbicides									
Insecticides									
Labour									
Land									
Other									
Total									

36. Indicate amounts and the respective prices for the inputs used in rice production in the last three seasons

Crop→	Rice								
Season→	2004/2005			2003/2004			2002/2003		
Inputs↓	Amount	Unit price	Total cost	Amount	Unit price	Total cost	Amount	Unit price	Total cost
Fertilizer									
Seeds									
Herbicides									
Insecticides									
Labour									
Land									
Other									
Total									

37. Indicate amounts and the respective prices for the inputs used in maize production in the last three seasons

Crop→	Maize								
Season→	2004/2005			2003/2004			2002/2003		
Inputs↓	Amount	Unit price	Total cost	Amount	Unit price	Total cost	Amount	Unit price	Total cost
Fertilizer									
Seeds									
Herbicides									
Insecticides									
Labour									
Land									
Other									
Total									

E. Investment

38. Indicate the number, acquisition price, year of acquisition and expected life span of the following items:

Item	Number	Year	Economic life	Acquisition cost	Total cost
Hoe					
Machete					
Sprayer					
Bicycle					
Car					
Tractor					
New land					
Others					
Total					

F. Agronomic Practices

39. Do you burn your farm before harvesting sugarcane?
   1 = Yes ( )
   2 = No ( )

40. What method do you use to control weeds?
   1 = Chemical control (use of herbicides) ( )
   2 = Cultural control (flooding, mulching) ( )
   3 = Mechanical control (hoeing) ( )

41. What method do you use to enhance soil fertility?
   1 = Use of organic fertilizers ( )
   2 = Use of inorganic fertilizers ( )
   3 = Use of both organic and inorganic fertilizers ( )
   4 = None ( )

G. Access To Institutions:
A) Credit Services

42. Do you have access to credit facilities?
1= Yes ( ); 2 = No ( )

43. If you have access to credit facilities, then what are the sources of credit?
1= Bank ( )
2= MSE ( )
3= MOA ( )
4 = Traders ( )

44. Have you applied for credit from any agency in the last three years?
1 = Yes ( ); 2 = No ( )

45. In what form did you receive the credit?
1 = in kind ( ) ; 2 = Cash ( )

46. If in kind what inputs/services did you obtained?

Input/service	2004/2005			2003/2004			2002/2003		
	Amount	Crop	Total value	Amount	Crop	Total value	Amount	Crop	Total value
Land preparation									
Fertilizers									
Harvesting									
Transport									
Other									
Total									
Crops: 1 = Sugarcane; 2 = Maize; 3 = Rice; 4 = Other crops									

47. If in cash, what was the amount (in TZS) received during the last three growing seasons?

2004/2005		2003/2004		2002/2003	

48. What was the interest rate for the credit?

49. What was the repayment procedure for the credit?
1= Cash ( )
2 = In kind ( )
3 = Both cash and in kind ( )

50. What was the repayment period?

51. If you have not applied for credit, then provide reason(s) for not applying for credit.
1 = Not available (lack of credit facilities) ( )
2 = High interest rates ( )
3 = I have enough own funds ( )
4 = High risk (crop failure) ( )
5 = Other (specify) ....

52. Has credit restriction affected your sugarcane /rice/maize production in any way?
1 = yes ( )
2 = No ( )

53. If yes, How?
1= Use less amount of inputs ( )
2 = Restrict expansion of farm size ( )
3 = Others (Specify) ( ) ....

....

B)Extension Services

54. Do you have access to extension services?
1 = Yes ( )
2 = No ( )

55. If yes, how many times did the extension agent(s) visited you in the last growing season? ....

56. Have you participated in any farmer training workshop in the last three years?
1 = Yes ( )
2 = No ( )

57. Have you received any extension material, such as leaflets, in the last three growing seasons?
1 = Yes ( )
2 = No ( )

H. Farmers' Perceptions Regarding Various Constraints To Farming

58. Provide ranks for the influence of the following factors on crop production (Answer: 1 = Very important, 2 = Important, 3 = Not sure, 4 = Not important)
Shortage of land ( )
Low soil fertility ( )
Shortage of hired labour ( )
Shortage of extension services ( )
Unreliable input supply ( )
Unreliable market ( )
Low output prices ( )
High input prices ( )
Difficulties in transporting crops ( )
Damages caused by crop pests ( )
Lack of capital to purchase inputs ( )
Other (specify) ( ) ....

....

THANK YOU VERY MUCH FOR YOUR COOPERATION

Appendix 2: Food and Biofuels Demands Constraints for Various Scenarios

Constraints	Scenarios		
	Scenario 1	Scenario 2	Scenario 3
Minimum area for sugarcane for sugar	Imposed	Not imposed	Not imposed
Minimum area for oil palm for palm oil	Imposed	Not imposed	Not imposed
Minimum area for oil palm for Biodiesel	Imposed	Imposed	Not imposed
Minimum area for maize for food	Imposed	Not imposed	Not imposed
Minimum area for rice for food	Imposed	Not imposed	Not imposed
Minimum area for cassava for food	Imposed	Not imposed	Not imposed
Minimum area for cassava for ethanol	Imposed	Imposed	Not imposed
Minimum area for Jatropha	Imposed	Imposed	Not imposed
Minimum area for maize for ethanol	Imposed	Imposed	Not imposed
Minimum area for sorghum for ethanol	Imposed	Imposed	Not imposed

Source: Own formulation

Appendix 3: Results for Various Activities for the Scenarios Considered

Activities	Amounts for Various Activities (tonnes)		
	Scenario 1	Scenario 2	Scenario 3
Sugarcane for sugar	4,942,350.00	0.00	0.00
Sugarcane for ethanol	27,640,499.00	35,237,400.00	35,237,400.00
Maize for food	14,464,301.00	13,824,399.00	9,849,600.00
Maize for ethanol	5,000,000.00	5,000,000.00	0.00
Rice for food (in zone1)	76,004.00	0.00	0.00
Sorghum for food	4,840,749.00	4,840,749.00	6,800,000.00
Sorghum for ethanol	769,250.00	769,250.00	0.00
Cassava for food	580,000.00	0.00	0.00
Cassava for ethanol	464,000.00	464,000.00	0.00
Oil palm for palm oil	720,000.00	1,672,000.00	1,920,000.00
Oil palm for biodiesel	120,000.00	120,000.00	0.00
Jatropha	5,040,000.00	5,040,000.00	0.00
Labour hired in January (Man-days)	88,675,012.00	87,131,250.00	68,031,250.00
Labour hired in May (Man-days)	68,453,700.00	87,162,500.00	12,562,500.00
Labour hired in October (Man-days)	18,650,414.00	25,224,744.00	0.00
Objective Function (TZS)	1.06331E+13	1.0845E+13	1.22166E+13

Source: Own computation

Appendix 4: Results for the Various Constraints Imposed in the Model

Constraints	Scenario 1		Scenario 2		Scenario 3	
Name	Amount used	Slack (% of constraint)	Amount used	Slack (% of constraint)	Amount used	Slack (% of constraint)
Land availability (ha)						
Zone 1	570000	0	570000	0	570000	0
Zone 2	11700000	0	11700000	0	11700000	0
Zone 3	1200000	0	1200000	0	1200000	0
Zone 4	8000000	0	8000000	0	8000000	0
Labour availability (Man-days)						
January	306250000	0	306250000	0	306250000	0
February	207378721	32	208556505	31.8	199764668	34.7
March	287500000	0	287500000	0	287500000	0
April	284375000	0	284375000	0	284375000	0
May	307812500	0	307812500	0	307812500	0
June to September	197189403	84	212364795	82.9	141038265	88
October	310625000	0	310625000	0	257041581	17
November	106835621	65	105707704	65.7	100274234	67.5
December	178987061	41	176198125	42.5	175328125	42.8
Minimum areas for various crops (ha)						
Sugarcane for sugar in zone 1	79947	0	--	--	--	--
Oil palm for palm oil in zone 3	450000	260	--	--	--	--
Oil palm for biodiesel in zone 3	75000	0	75000	0	--	--
Maize for food in zone 2	8433581	181	--	--	--	--
Maize for ethanol in zone 2	3086419	0	3086419	0	--	--
Maize for food in zone 3	495000	0	--	--	--	--
Rice for food in zone 1	42940	0	--	--	--	--
Cassava for food in zone 2	100000	0	--	--	--	--
Cassava for ethanol in zone 2	80000	0	80000	0	--	--
Cassava for food in zone 3	100000	0	--	--	--	--
Cassava for ethanol in zone 3	80000	0	80000	0	--	--
Sorghum for ethanol in zone 4	905000	0	905000	0	--	--
Jatropha in zone 4	1400000	0	1400000	0	--	--

Source: Own computation

-- not applicable

Appendix 5: Shadow Prices for the Constraints Imposed in the Model

Constraints	Scenario 1		Scenario 2		Scenario 3	
Name	Value	Shadow Price	Value	Shadow Price	Value	Shadow Price
Land availability (ha)						
Zone 1	570000	3138202	570000	3138202	570000	3252659
Zone 2	11700000	532946	11700000	532946	11700000	563656
Zone 3	1200000	549495	1200000	549495	1200000	609300
Zone 4	8000000	249844	8000000	249844	8000000	278264
Labour availability (Man-days)						
January	306250000	1320	306250000	1320	306250000	1320
February	207378721	0	208556505	0	199764668	0
March	287500000	0	287500000	0	287500000	0
April	275671300	0	284375000	0	284375000	0
May	307812500	1320	307812500	1320	307812500	1320
June to September	197189403	0	212364795	0	141038265	0
October	310625000	1320	310625000	1320	257041581	0
November	106835621	0	105707704	0	100274234	0
December	178987061	0	176198125	0	175328125	0
Minimum areas for various crops (ha)						
Sugarcane for sugar in zone 1	79947	-544916	--	--	--	--
Oil palm for palm oil in zone 3	450000	0	--	--	--	--
Oil palm for biodiesel in zone 3	75000	-167380	75000	-167380	--	--
Maize for food in zone 2	8433581	0	--	--	--	--
Maize for ethanol in zone 2	3086419	-351320	3086419	-351320	--	--
Maize for food in zone 3	495000	-16549	--	--	--	--
Rice for food in zone 1	42940	-1956716	--	--	--	--
Cassava for food in zone 2	100000	-372190	--	--	--	--
Cassava for ethanol in zone 2	80000	-420578	80000	-420578	--	--
Cassava for food in zone 3	100000	-388739	--	--	--	--
Cassava for ethanol in zone 3	80000	-437127	80000	-437127	--	--
Sorghum for ethanol in zone 4	905000	-179150	905000	-179150	--	--
Jatropha in zone 4	1400000	-81999	1400000	-81999	--	--

Source: Own computation

-- not applicable