Identifying optimal locations for large scale Jatropha cultivation for biodiesel production in Tanzania's semi arid regions

By

Elmah Zvanyadza Mudede

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Supervisor: Dr Helen K Watson
School of Environmental Sciences
Faculty of Science and Agriculture

UNIVERSITY OF
KWAZULU-NATAL

Abstract

Rapidly increasing concerns about energy security coupled with detrimental environmental impacts posed by the dependence on fossil fuels, and an urgent need for rural development in Africa are key drivers for the search for fuel alternatives. The international effort into the development of criteria and indicators for sustainable bioenergy production clearly recognizes that bioenergy production must not be at the expense of biodiversity and food security. Owing to its multi-purpose capabilities i.e. its ability to rehabilitate eroded lands, drought resistance as well as its biophysical and maintenance requirements, Jatropha was selected as a potential candidate for the production of biodiesel. Jatropha is not new to the people of Tanzania, the study area of the project. Research has shown that, its associated social, environmental and economic benefits are crucial to economic development of the country. At present, all of Tanzania's petroleum based products are imported; about 90% of the energy consumed is derived from biomass; road, rail and electricity networks are underdeveloped. Environmental degradation is also a concern in the country.

The aim of the study was to identify three optimal locations for large scale Jatropha cultivation for biodiesel production in Tanzania's semi arid regions. Geographical Information Systems was used to overlay several remotely sensed data from previous research namely semi arid regions delineations, agro-ecological sub-zones that had Jatropha potential as well as the administrative zones of Tanzania. The unavailable and/unsuitable areas were verified against literature and this enabled the areas that were under cultivation, were housing biodiversity or were generally constrained to be filtered out from the study area. The three largest, available and potentially suitable areas that the study identified for large scale Jatropha cultivation occupied about 7.6 million hectares. Assuming an optimal seed yield and an oil content of 35%, these areas are capable of producing about 14.4 million litres of Jatropha oil per annum. Targeting a SADC fuel import substitution of 10%, these 14.4 million litres of Jatropha oil that the three areas will meet about 83% of the country's energy needs. Owing to the state of electricity generation in Tanzania, these three areas are able to generate about six

percent of electricity and this can contribute to some extend to the country energy needs.

From the analysis it was clear to note that the production of biodiesel for blending or for electricity generation is going to be economically viable from the three selected regions. The available and suitable areas that were not consolidated within the three selected regions can be used for small scale Jatropha cultivation and their produce can be fed to large scale commercial oil production or they can use the biodiesel to produce their own electricity. Jatropha will have to be irrigated to enhance a viable economic yield; infrastructure will need to be constructed to areas that are not served by roads and railway lines. All of this bodes well for enhancing rural development. The government has already had the foresight to establish the National Biofuels Task Force which will need to monitor investors to ensure no enforced human displacement and/or exploitation in areas where the large scale farms are to be established.

PREFACE

The work described in this dissertation was carried out in the School of Environmental Sciences, University of KwaZulu-Natal, Durban under the supervision of Dr Helen K. Watson.

This study represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any other University. Where use has been made of the work others, it has been duly acknowledged in the text.

Signed: ______________________________ Date: _______________________

DECLARATION 1-PLAGIARISM

I, **Elmah Zvanyadza Mudede** declare that

1) The research reported in this thesis, except where otherwise indicated, is my own work.
2) This thesis has not been submitted for any degree or examination at any other university.
3) This thesis does not contain other person's data, pictures, graphs or other information, unless specifically acknowledged as being source from other persons.
4) This thesis does not contain other person's writing unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
    a) their work have been rewritten but the general information attributed to them has been referenced
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5) This thesis does not contain text graphics or tables copied and pasted from the Internet unless specifically acknowledged, and the source being detailed in the thesis and in the Reference sections.

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DECLARATION 2-PUBLICATIONS

Details of contributions to publications that form part and/or include research presented in this thesis

Watson, H.K., 2008: *Work Package 1, "Land Use Change and Impacts,"* Progress Report, Internal COMPETE meeting, Bamako, Mali, 28 November 2008, www.compete-bioafrica.net

Signed: ______________________________ Date: _______________________

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List of Abbreviations

BFP	biofuels feedstocks production
cm	centimeters
g	grams
ha	hectare
km	kilometer
kg	kilogram
kg/h	kilograms per hour
kg/l	kilograms per litre
kg/m^3	kilograms per cubic metre
km^3/yr	cubic kilometers per year
l/yr	litres per year
m^3	cubic metres
m.a.m.s.l	metres above mean sea level
mm	millimeters
MAP	Mean Annual Precipitation
MW	Megawatts
Mt	Metric tonnes
NTFPs	non timber forest products
$p.km^2$	people per square kilometer
pa-	per annum
SSA	Sub Saharan Africa
t/ha/yr	tonnes per hectare per year

List of Acronyms

ADB	Africa Development Bank
AEZ	Agro-ecological Zones
ARI-Mlingano	Alternative Resource Institute-Mlingano
ASDP	Agricultural Sector Development Programme
ASDS	Agricultural Sector Development Strategy
COMPETE	Competence Platform on Energy Crop Agroforestry Systems for Arid and Semi arid Ecosystems
DESA/DSD	Department of Economic and Social Affairs-Division of Sustainable Development
DMEWR	Department of Minerals, Energy and Water Resources
ECDO	Expertise Centrum voor Duurzame Ontwikkeling
EIA	Energy Information Administration
ESRI	Environmental Systems Research Institute
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FAO/IIASA	Food and Agriculture Organization/International Institute for Applied Systems
FAO/UNESCO	Food and Agricultural Organization United Nations Educational, Scientific and Cultural Organization
GDP	Gross Domestic Product
GNP	Gross National Product
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
HDI	Human Development Index
HEDON	Household Energy Network
IEA	International Energy Agency
IGBP	International Geosphere Biosphere Project
IIED	International Institute for Environment and Development
IMF	International Monetary Fund
INCRAF	International Centre for Research in Agroforestry

IUCN	International Union for Conservation Nature
KAKUTE	Kampuni ya Kusambaza Teknolojia (a Kiswahili acronym meaning Technology Promotion Company)
LEAT	Lawyers Environmental Action Team
NBST	National Bureau of Statistics of Tanzania
NGO	National Governmental Organization
NIMP	National Irrigation Master Plan
NMEC	National Environmental Management Council
NPPT	National Population Policy of Tanzania
SADC	Southern African Development Community
SADC TIIR	Southern African Development Council Trade, Industry and Investment Review
SEI	Stockholm Environmental Institute
TaTEDO	Tanzania Traditional Energy Development Organization
TNHBS	Tanzania National Housing Budget Survey
UK	United Kingdom
UNDESA	United Nations Department of Economic Affairs
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNEP-WCMC	United Nations Environment Programme World Conservation Monitoring Centre.
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFPA	United Nations Population Fund
URT	United Republic of Tanzania
USA	United States of America
USABAQ	United States Advisory Board on Air Quality
WBCSD	World Business Council for Sustainable Development
WCMC	World Conservation Monitoring Centre
WCPA	World Commission on Protected Areas
WDPA	World Database on Protected Areas
WFB	World Food Programme
WWF	Wild Wildlife Fund

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Chapter 1
Introduction

1.1 Introduction

The chapter details the rationale for the study, i.e. why biofuels are being touted as one of the most promising and sustainable alternatives to fossil fuels. It briefly traces the origin of biodiesel and assesses Jatropha as a biodiesel feedstock. The reasons for interest in Sub-Saharan Africa (SSA) as a promising source of biofuels feedstock are briefly discussed as well as the motivation for why this study focuses on semi arid regions of Tanzania. To date, Jatropha in Tanzania is grown on a small scale basis thus the chapter motivates why focus on large scale cultivation. In ending, the aim, objectives as well the structure of the thesis is presented.

1.2 Motivation for the Study

World over, countries currently depend on fossil fuels for their major energy needs. Duncan and Youngquist (1999: i) state, “In all human history, no substance has changed economies, social structures, and lifestyles so rapidly and profoundly as oil.” Ramadhas *et al*., (2003) also share the same sentiments and assert that the soaring industrialization and motorization of the world has led to an abrupt rise in the demand for the oil and several petroleum based products. Petroleum based products are not only obtained from limited and finite reserves, but they are also concentrated in certain regions of the world. Many such regions for example Saudi Arabia, Iraq, Iran and recently Russia are geopolitically unstable (Bahgat, 2003; Johnson, 2007; Lovett, 2007). The new reserves for oil, natural gas, coal and thermal energy that are still being found in Africa (e.g. Nigeria and Angola) remain under-exploited as its countries lack both capital resources and a favorable political and economic environment that private investors seek (Stockholm Environmental Institute (SEI), 1999).

Despite the constraints that fossil fuels are associated with, they continue to be used abundantly because they are a convenient form of energy after processing (Ghosh *et al*., 2007). The emissions from the burning of the fossil fuels and its associated products like petroleum and diesel have added to greenhouse gases which are contributing to the greenhouse gas effect. In its Energy on Climate Change Report, World Energy Council (WEC) (2007) stated that, energy related emissions (including energy used in transportation) account for over two thirds of the anthropogenic greenhouse gas emissions. The consequent global warming is expected to have significant effects to the world's climate.

The 21st century rise in the price and demand of petroleum and petroleum based products has triggered a growth in the interest in alternative fuels. Biofuels are touted as one of the most promising and sustainable such alternatives. Biomass energy or bioenergy refers to energy in solid, liquid or gaseous form as well as electric power or chemical products. They are derived from material that is obtained directly from plants or indirectly from plant derived industrial, commercial or urban wastes, or agricultural or forestry residues (Department of Economic and Social Affairs/Division of Sustainable Development (DESA/DSD), 2007). Biomass energy provides the desired form of energy and energy services such as heat, light and locomotive power (Kartha *et al*., 2005). Fuelwood and charcoal have been known and used for millennia by human kind. They are still being recognized as bioenergy feedstocks. However, their importance to today's world energy needs has been slightly shifted by the demand for biofuels such as ethanol, biodiesel, biogas and biogel and these are obtained from: (i) natural vegetation, (ii) dedicated energy crops, (iii) true borne oil seeds, (iv) agriculture wastes and (v) residues from industries and homes (Von Braun, 2007).

Liquid biofuels occur in several forms and the most important ones are pure plant/vegetable oil, bioethanol and biodiesel, the latter being the subject of this study. Biodiesel, generally known to be obtained from esterification of plant oils has been around for more than a century and its use in diesel engines is not new (Strong *et al*., 2004; Johnson, 2007). It is ranked second after ethanol on the list of global primary biofuels feedstocks (DESA/DSD, 2007). It first gained momentum when the use of steam engines in the forging of iron, grinding of grain and in textile industries had become too expensive late in the 18th century (United States Advisory Board on Air Quality (USABAQ), 2006). The first fuel inventor Dr Rudolf Diesel (1858-1913), ran an engine on fuel that was obtained from peanut butter oil at the World Exhibition that was held in Paris in 1900 (Bryant, 1976). The premature engine failure that this fuel gave, reduced the momentum that biodiesel had gained but Dr Diesel left a legacy that, the diesel engine could be fed with vegetable oils and would considerably help in the development of agriculture in countries that would use it (USABAQ, 2006; Shahid and Jamal, 2007; Cummins, 2008).

Although the journey to biodiesel use had decreased by the early 20th century as the diesel engines were now adapted to burn the cheap and widely available petroleum distillate, the United States of America (USA), continued to use diesel oil from vegetables in emergency situations in the 1930s and 1940s (Ma and Hanna, 1999). However, the 1970s oil crisis that is similar to the contemporary situation, stimulated scientists and engineers to investigate other fuel alternatives (Shahid and Jamal, 2007). The continued escalation of petroleum prices over the past decade; the fossil fuel limitations and the associated environmental concerns have triggered a more focused interest on research into the use of biodiesel from plant oils as an alternative fuel feedstocks today (Johnson, 2007).

Biodiesel can be produced from a variety of feedstock i.e. oil (rapeseed, oil palm, hemp, algae, canola, flax, mustard and Jatropha), animal fats, and/or waste vegetable oil (United Nations Department of Economic Affairs (UNDESA), 2007). Jatropha has become an agricultural and economic celebrity; with the discovery that it may be the ideal candidate for biodiesel production at the same time provide promises for sustainable development. It is a drought resistant plant thus cultivating it on waste or degraded lands can rehabilitate them (Achten *et al*., 2007). On a field observation station in India, Ghosh *et al*., (2007) observed that, besides being hardy plants that grow on eroded soils, they were the only plants that withstood cyclones and successive droughts when all other plants perished on the study site. The fact that their seeds are poisonous is an additional positive characteristic in that if planted as a hedge, it will keep domestic animals out of the fields and homes (Martinez-Herrena *et al*., 2005). As will be discussed further in Chapter Three, it is a fact that the 35-40% and the 55-60% of oil that the seeds and kernel produce respectively can be extracted with oil presses for example (Benge, 2006).

Degraded or abandoned lands, eroded lands, marginal lands and waste lands are terms that are interchangeably used in literature to define various lands where Jatropha cultivation is feasible. Abandoned land is land where former land use has been stopped. Hennenberg and Fritsche (2008) maintains that land may be abandoned due to market forces but such land may be having a higher value for natural regeneration which is preferable to bioenergy production from a carbon balance point of view. Schroers (2006) cited in Hennenberg and Fritsche (2008) defines marginal lands as an area where a cost effective production is not possible under given side conditions, cultivation techniques, agricultural policies as well as macro economic and legal conditions. Waste lands are characterized by natural physical and biological conditions that are per se unfavorable for land associated human activities (Olderman *et al*., 1990). Defining degraded and abandoned lands is, therefore, an important step when considering land for bioenergy production because the cultivation of biomass on these lands has the potential to safeguard against the negative indirect land use change effects. In this study, the term eroded land shall be used to specify all lands that are either waste, degraded, abandoned or are marginal

India is endowed with a variety of seed bearing trees that are distributed throughout the county. It has well established large and small scale Jatropha plantations, eroded lands of between 50 and 150 million ha and substantial areas of those lands have already been planted up (Euler and Gorriz, 2004; Singh and Nimbkar, 2007). The government of India has begun large scale cultivation of Jatropha and these have rehabilitated some substantial areas of eroded soils. Jatropha cultivation is expected to make eroded lands become more useful and more yields are expected to be produced when both rain fed and irrigation facilities are considered (Ghosh *et al*., 2007). The small scale farming practices are expected to improve people's livelihoods as electricity is going to be generated from Jatropha oil.

An experience with liquid biofuels production is already significant in South America, North America, Europe and some other countries in Asia besides India. The European Union (EU) presently needs to obtain 5.75% of its transport sector fuel from biofuels by 2010 (Takavarasha *et al*., 2005; Lovett, 2007). The EU does not have enough available and suitable land to produce fuels that will meet the demand; the balance will have to be met by importing from biofuels producing nations. The International Energy Agency (IEA) (2008) suggests that the growing global demand will favor an international trade in bioenergy and biofuels and investments in emerging and developing countries.

Recent research has shown that there is greater potential for biofuels production in Africa. Gnansounou *et al*., (2007) maintains that there have been a lot of initiatives of developing a number of energy crops in Africa. Several small scale projects using Jatropha oil to produce electricity are NGO driven. Ethanol production, for example, has long been introduced in Kenya, Malawi, Zimbabwe and South Africa but these have not had a significant impact on the global biofuels market. One of the barriers to advancement and global coverage of the produce was the lack of clear policies and inadequate institutional capacity and awareness. Biofuels production can play a significant role in improving lives and livelihoods of people in Africa but one need not to oversimplify one of the greatest challenges that this continent has, i.e. the need to come up with effective policies and strategies that will guarantee its countries are secure both in food and fuel. However, the international effort into the development of criteria and indicators for sustainable bioenergy production clearly recognizes that it should not be at the expense of biodiversity and food security (Rajagopal, 2008). Johnson (2007) suggests that, in order to preserve the credibility of bioenergy as an environmentally sustainable source of energy, and in view of possible future bioenergy international trade, sustainability concerns have to be addressed first. Research has articulated upon the quest for a bioenergy sustainability criteria but questions as to the best sustainability criterion and for which practices still needs to be considered (Fritsche *et al*., 2006; Rajagopal, 2008).

The dependence on biomass by SSA is by far the greater than in any other world region and most of it is being consumed via traditional means. Biomass accounts for more than 61% of primary energy consumption and more than 71% if South Africa is excluded (Johnson and Rossillo-Calle, 2007). A comparison that was made with reference to the large areas of unused pasture and agricultural land that are currently undergoing a decline in productivity in SSA showed that, comparing it to all other world regions, the greatest bioenergy potential lies in its lands (Smeets *et al*., 2004). The cultivation of Jatropha as a biodiesel plant in SSA countries` eroded lands could ease the plights of rural livelihoods of these nations as are working towards meeting an increase in the demand for energy and at the same time reducing the effects of the rise in oil prices on their economies. To southern African countries land portions, which currently neither pose threats to biodiversity conservation nor are under permanent crop cultivation, bioenergy production could give a potential face lift to the economic and agricultural sectors (Takavarasha *et al*., 2005; Lovett, 2007).

1.3 Motivation for the Study Area

Paradigm shifts in bioenergy production research has diverted attention from the popularly known biomass energy producing nations like the United Kingdom (UK) and the United Sates of America (USA). One of them is being conducted by COMPETE, a South-South-EU cooperation which focuses on SSA. COMPETE stands for Competence Platform on Energy and Agroforestry Systems for Arid and Semi-arid Ecosystems-Africa.[1] One of its aims is to enhance sustainable use of renewable natural resources and at the same time stimulate sustainable bioenergy implementation in arid and semi arid regions of SSA. This project forms part of the research under work package one whose main objective is to identify land in SSA where intensification of, or conversion to bioenergy use will not have detrimental environmental and/or socio-economic impacts (Watson, 2008a). This study focused on the semi arid regions of Tanzania in view of the need to cultivate bioenergy crops on land that is not in conflict with food crop cultivation.

Tanzania is a developing country in east Africa and it borders the Indian Ocean between Kenya and Mozambique. It has a climate which is quite heterogeneous ranging from being

[1] www.compete-bioafrica.net

tropical along the coast to being temperate in the highlands (World Fact Book (WFB), 2008). The topography of the country has plains along the coast; central plateaus as well as highlands in the north and in the south. According to Maselli *et al*., (2008), the landcover of the country is quite complex and heterogeneous. The National Population Policy of Tanzania (NPPT) (2006) note that about 50% of the country's total area is covered by forests and woodland, 40% is covered by grassland and only between six to eight percent is cultivated.

The economy of the Tanzania is mainly dependent on agriculture. More than 40% of the country's GDP is obtained from it, 85% of exports emanate from it and it employs more than 80% of the country's workforce (WFB, 2008). This strong economic growth is attracting biofuels investors into the country. As will be substantiated in section 2.9, Tanzania has a low GDP when compared to that of developing countries and relative to this is the scarcity of foreign currency (United Republic of Tanzania (URT), 2008). Poverty is still acute and is a common phenomenon to the rural areas where about 80% of its population lives. According to International Monetary Fund (IMF) (2008), over reliance on rain fed agriculture in Tanzania rural areas for income and livelihood is still dominant but productivity continues to be affected by concurrent droughts. The rural small holder farmers also lack market linkages, engage in unsustainable large and small scale irrigation practices, lack inputs, have limited capital and have a limited access to financial services. These consequences have worsened their poverty situation.

Ninety one percent of the total energy consumed in Tanzania is derived from biomass (Johnson and Rosillo-Calle, 2007; Household Energy Network (HEDON), 2007). Biomass contributes 95% of the total energy. Tanzania's energy is composed of renewables and wastes, oil, hydro, gas and coal. Electricity is mainly generated from oil, hydropower and coal and it contributes about 0.6% of the total energy consumption (URT, 2008). The country is a net importer of all its petroleum requirements (Foester *et al*., 2005). The 21.73 billion m^3 proven gas reserves and 1,200 Mt of coal it has, if tapped, could solve the country's energy problems and exporting them will increase its foreign currency (URT, 2008). A heavy reliance on wood based biomass and use of inefficient wood-to-energy conversion technologies are listed among the major contributors of high rates of deforestation as well as poor indoor air quality in Tanzania (Lyimo, 2006). Environmental degradation arising from illegal human activities related to agriculture (e.g. livestock keeping), settlement along slopes of mountains or on top of mountain ranges, in river valleys and around water sources is a concern in Tanzania too. Growing Jatropha on degraded lands is expected to alleviate environmental degradation as well as reduce poverty and health problems (Van Eijick and Romijin, 2006).

The transport sector of Tanzania is primarily road based and the importation of all fuel requirements together with the costs of delivering the petroleum products continues to increase the vulnerability of Tanzanian economy and its livelihoods to the changes that exists in the world oil market (DESA/DSD, 2007). Biofuels can offer a significant potential to boost economic growth, relieve the country of foreign exchange constraints and well as reduce the country's foreign currency spending on the transport sector (IMF, 2008).

Energy crops such as sugarcane, Jatropha and oil palm have been ranked first, second and third in their potential of biofuels production in Tanzania (Shuma, 2008). Sugarcane was ranked high because it is already being grown and used in the production of bioethanol and also because of the benefits in terms of employment generation and foreign exchange savings. Jatropha scored high because, when compared to other oil producing crops that are in the country like sunflower, cashew, coconut and oil palm, Jatropha does compete with other uses in its consumption. Jatropha is commonly grown on a small scale basis by farmers in Tanzania albeit not for biodiesel production. Attention has been paid to this individual plant due to the advantages it has, i.e. noted above it is capable of producing seeds which can be processed into oil and seed cake and it does not require a lot of watering and nutrients. The plant can also prevent soil erosion in poor soils, thereby reclaiming land and the oil does not compete with food production. The plant has several uses which shall be explained in Chapter Three. There is currently no large scale Jatropha cultivation in the country but SunBiofuels` intentions in Jatropha production are in the Wami wetlands

(Sawe, 2008). The cultivation of Jatropha for bioenergy purposes in an environmentally sound manner is expected to promote sustainable development within Tanzania but the risks of potential negative impacts need not be oversimplified.

The semi arid regions of Tanzania were chosen to avoid conflicts on land that might otherwise be used for food production and for biodiversity conservation. Jatropha is currently grown where food crops are being grown in Tanzania, thus the semi arid regions were chosen as they will have fewer limitations that can be placed on them by land evaluation. Wijgerse (2008) suggests that the possibility of Jatropha in semi arid regions, the energy content, the multi-purpose applications, and the social and economic capabilities arising from its initiation makes it an ideal candidate for bioenergy production for developing countries. Low profit margins, low yields and unrealistic expectations of, for example, the food versus fuel crisis, are amongst the potential demerits of Jatropha cultivation for bioenergy purposes on a large scale basis.

Based on the motivation for the study and the study area, the following aim and objectives for the project have been established.

1.4 Aim and Objectives

The study aimed to identify optimal locations for large scale Jatropha cultivation for biodiesel production in Tanzania's semi arid regions.

In order to achieve this aim, the following objectives were met:-

1) Compile an inventory of the favorable biophysiographic characteristics for Jatropha.

2) Assess whether the areas that were identified by COMPETE as available and suitable for bioenergy crops in Tanzania's semi arid regions are ideal for large scale Jatropha cultivation.

3) Determine whether these areas are adequately served by roads/railways and rivers to irrigate for better yield and a potential labor force.

4) Select the three most favorable areas for large scale Jatropha cultivation.

1.5 Structure of the Thesis

The thesis is divided into six chapters. The introduction, motivation of study, motivation of study area together with the main aim and objectives of the study are outlined in Chapter One. The description of the study area, with specific emphasis on the geographical location, terrain, climate, agro-ecology, biodiversity and natural resources, hydrogeomophology, socio-economics and energy situation, are presented in Chapter Two. Chapter Three discusses the ecology of Jatropha as well as the biomass energy conceptual framework. Chapter Four itemizes the data sources used as well as the methodology and data analysis steps the study took. Chapter Five singles out the results that were obtained. Lastly, the conclusion and recommendations for further research are provided in Chapter Six.

Chapter 2
Description of the Study Area

2.1 Introduction

This study focused on Tanzania's semi arid regions. In order to comprehend their potential value to the country for large scale Jatropha production, the chapter describes these regions within the context of the country as a whole. The chapter is divided into several sections. The first section gives an overview of the geographical location, terrain and climate of the country. This is followed by a brief description of the protected areas and natural resources. An outline of the agriculture and environmental issues, the socio-economics and the energy situation of the country is also outlined. In ending, the current state of Jatropha cultivation in the country and a general overview of the semi arid regions is provided.

2.2 Geographical Location of Tanzania

The United Republic of Tanzania (URT)[2] forms the eastern corner of Africa between parallels 1°S and 12°S and meridians 30°E and 40°E (Food and Agricultural Organization (FAO), 2007). The country consists of the Tanzania mainland and the islands Zanzibar, Pemba and Uguja. The total area of Tanzania mainland and islands is 945 087 km² and 6.2% of this area is covered by inland waters (World Business Council for Sustainable Development (WBCSD), 2007; WFB, 2008). The country extends from Lake Tanganyika in the west, to the Indian Ocean in the east; Lake Victoria in the north, to Lake Nyasa and Ruvuma River in the south. It borders Uganda and Kenya to the north, Rwanda and Burundi to the north-west, Democratic Republic of Congo to the west, Zambia to the south-west, and Mozambique to the south (Figure 1).

Zanzibar, the largest coral island off the coast of Africa, covers an area that is approximately 1 650 km² and is separated from the coast of the mainland Tanzania by a channel, which is about 30 km wide and 90 km long. Pemba also found some 40 km north-

[2] The United Republic of Tanzania includes islands thus the term Tanzania will be used in the thesis.

west of Zanzibar, is an island of about 70 km length and approximately 980 km² of area. These two islands are both low-lying. They will not be described in further detail as this study focused on the semi arid regions in mainland Tanzania.

Figure 1: Detailed Map of Tanzania (Geology.com, 2007)

Francis *et al*., (2005) laments that, if there is a per capita decline in land for agriculture versus a trend in populations increase, then degraded lands may need to be reclaimed for productive use. Jatropha is one of the crops that can grow on such lands while reclaiming them. As is noted in the introduction, Watson (2008a) identified land that is potentially suitable for bioenergy crop cultivation in SSA arid and semi arid regions, including Tanzania's semi arid regions which were used as the basis of the project (Figure 2).

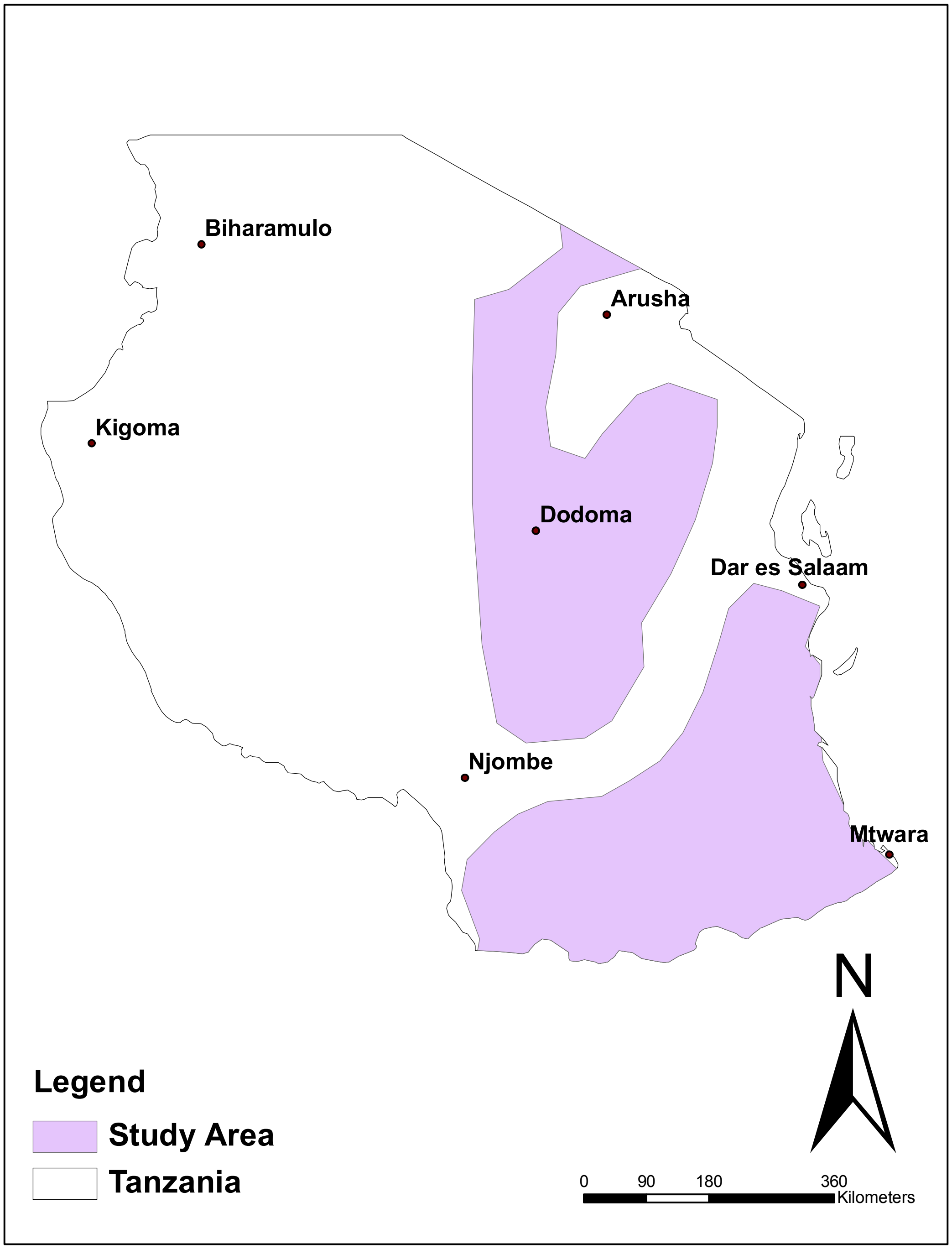

Figure 2: Study Area (Watson, 2008a)

2.3 Terrain/Relief

Extremes of topographical relief of the African continent lie within Tanzania (*Refer to Appendix 1*). The spectacular landscape is made up of mainly three physiographic regions, i.e. the islands and coastal plains to the east, an inland saucer shaped plateau and the highlands (URT, 2008). The country houses the highest and lowest places in Africa i.e. the summit of Mt Kilimanjaro (5 895 m.a.m.s.l) forming the north-eastern border adjacent to Kenya and the floor of Lake Tanganyika (358 m.a.m.s.l) (Morgan, 1969; Basalirwa *et al*., 1999). Tanzania`s mainland is generally flat and low along the coast, but the greater part of it is composed of the saucer shaped plateau. The plateau has plains and arable land, scattered hills and low lying wetlands and averages 1 200 m.a.m.s.l (Berry and Berry, 1969). In the north-east and south-west are groups of isolated mountains which vary in height. To the west lie the Southern Highlands and the Ruwenzori Mountains and these combine together with small mountains that are found in the east to form the major source of most of the country's rivers. The western part consists of plateaus which are indented by the western rift valley (Silayo, 2003).

2.4 Climate and Seasonality

Tanzania's climatic conditions are diversified due to the extreme variations in relief, as outlined in section 2.3. The alpine desert like climatic conditions are found on the top slopes of Mt Kilimanjaro and these are permanently covered by snow. On the tropical coastal areas, the weather is influenced by two monsoon winds (Agricultural Sector Development Programme (ASDP), 2005). The north-east monsoons that blows southwards (December-March) brings the hottest weather, and the south-east monsoon winds that blows northwards (March-September) brings intermittent rains. Mean annual temperatures range from 24-34ºC while mean annual rainfall varies from 400 to 2 500 mm (FAO Forestry, 2007). Two rainfall regimes that are common in Tanzania are the unimodal and the bimodal rains. The unimodal seasonal rains (December-April) are experienced over the southern, south-western, central and western parts of the country. The bimodal regime with a long rainy season (*Masika)* (March-May) and a short rainy season *(Vuli)* (October-December) occurs over the northern parts of the country (Basalirwa, 1999; Majule, 2004).

The dry season has duration of between 4 and 6 months (May-November) and this affects the greater central, south-west and southern parts of Tanzania (Jackson, 1970).

2.5 Soils of Tanzania

A soil classification according to the World Reference Base for Soil Resources (WRB), based on the FAO-Unesco Soil Classification System, shows that there are 19 dominant soil types in Tanzania. Cambisols have the most dominant coverage followed by Acrisols, Leptosols and Vertisols respectively (ARI-Mlingano2, 2006). Their percent coverage's as well as potential use have been presented on Table 1. The remaining soil groups have their coverage's in the country of below 5% (ARI-Mlingano2, 2006). Research has shown that, since the country gained its independence, the fertility of the soils of the wetlands and dry lands have declined due to increased population and the change in land management policies (ASDP, 2005). The degradation of both the soils and the physical land areas of especially the semi arid regions of Tanzania have been reported and this is highlighted in section 2.9.1.

Table 1: Soil Types and their Land use in Tanzania (ARI-Mlingano2, 2006)

Soil Type	Area (%)	Land use
Cambisols	35.6	Mixed arable farming and grazing
Acrisols	8.6	Rainfed agriculture and irrigated crops production
Leptosols	8	Forestry, nature conservation and extensive grazing
Vertisols	5	Not suitable for the have 30% more clay horizons to a depth of 100 cm

2.6 Agro-ecologic Zones of Tanzania

Agro-ecologic zones are physical regions, which are sufficiently large to be mapped at the scale of 1: 2 000 000 and are sufficiently uniform in climate, physiography and soil patterns for generalized descriptions and evaluation of the agricultural potential and constraints to be meaningful (De Pauw, 1984). Based on climate and elevation data, Tanzania has four major agro-ecological zones namely the Lowland zone, the Highland zone, Plateau zone and the Semi desert zone. Table 2 shows precipitation and elevation of three of the sub-zones of each of the major agro-ecological zones. The Semi desert zone (MAP of 625 mm) receives rainfall with varied intensity (FAO Forestry, 2007).

Table 2: Tanzania Agro-ecological Zones Characteristics (ARI-Mlingani2, 2006)

Agro-ecological Zones	**Sub-zone**	**MAP (mm)**	**Elevation (m.a.m.s.l)**
Lowland	Wet	1 800	500
	Moist	1 000-1 800	1 000
	Dry	750-1 000	1 000
Highland	Moist highlands	1 000-1 800	1 200-2 100
	Dry highland	625-1 000	1 500-2 100
Plateau	Moist	1 000-2 000	900-1 500
	Dry	625-1 000	900-1 500

Physiography was also used as basis for categorizing agro-ecological zones for crop suitability rating by the ARI Mlingano Agricultural Research Institute (ARI-Mlingano1, 2006). It used the agro-ecological zonation work of De Pauw (1984) and seven major agro-ecological zones that were obtained were named as; the coastal plains; the eastern plateaux and mountain blocks; the highlands and plateaux; the volcanoes and rift depressions; the plains of the central plateaux; the Rukwa-Ruaha rift zone alluvial fans; the inland sedimentary sediments; the Ufipa plateau and the western highlands. These regions have sub-zones and they were denoted by the following regions respectively C, E, H, N, P, R, U and W (*Refer to Figure 3*).

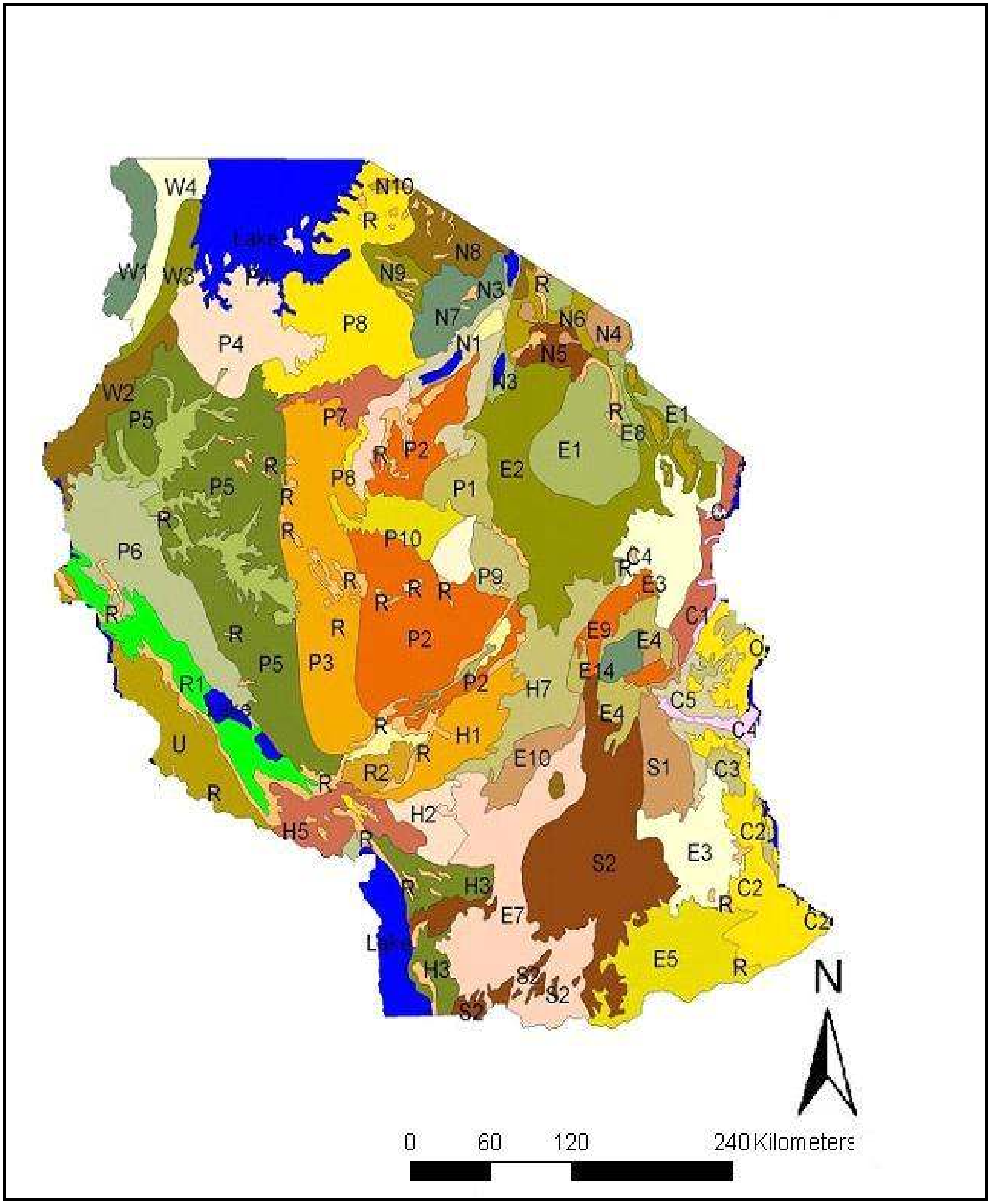

Figure 3: Agro-ecological Sub-zones of Tanzania (ARI-Mlingano1, 2006)

2.7 Biodiversity and Natural Resources

Biological diversity is made up of a diversity of plants, animals and other living organisms in all their forms and levels of organization, a diversity of genes, species and ecosystems, as well as the evolutionary and functional processes that link them (Matlock, 2008). Tanzania has a rich biodiversity (National Environmental Management Council (NMEC), 2006). The vast array of ecosystems noted in the previous section provides food, water, medicine and raw materials to the industries and livelihoods. Over 25% of the total land area is gazzetted as Protected Areas and here wildlife is either completely or partially protected in National Parks (NPs), Conservations Areas (CAs), Game Reserves (GRs), Game Controlled Areas (GCAs) and Wildlife Management Areas (WMAs) (Rural Energy Act (REA), 2005; Lawyers Environmental Action Team (LEAT), 2008).

The forests and woodlands that amount to about 33, 5 million ha are scattered on public lands of the country and they lack proper management. Of these total reserves, 13 million ha are gazzetted as forest reserves, 8 000 ha are gazzetted under plantation forestry and about 1, 6 million ha are under the water catchment management (URT, 2008).

The Wetlands of International Importance or Ramsar sites are areas that have been categorized as having both local level and international significance and this designation is in relation to the zoology, botany, and hydrology that the areas have (The Ramsar Bureau, 2008). Tanzania houses four such sites namely the Malagarasi-Moyovozi Wetlands, the Lake Natron basin, the Kilombera Valley flood plain and the Rufiji-Mafia-Kilwa Marine. The country is home to three of the sixty nine biosphere reserves that Africa holds (United Nations Educational, Scientific and Cultural Organization (UNESCO), 2002; Butler; 2006). There are six biodiversity hotspots in the country and one of them, the East Arc Mountain Forests is recognized as one of the twenty world`s “biodiversity hot spots”. About 25% of the plant species that are found in these forests are endemic. Figure 4 below shows the country’s key biodiversity areas as well as the biodiversity hot spots areas. The biodiversity is important to the surrounding regions and the country as a whole in that, about 40% of the household consumption of forest and woodland products are obtained from them. The East Arc Mountains are also a major catchment area for main water sources that human beings and industry need and about 70% of the country’s hydro-electric power is sourced from its waters (NMEC), 2006). There are six world heritage sites in the country and two of them namely, The Ngorogoro Conservation Area (828 800 ha) and The Selous Game Reserve (4 480 000 ha), are under Natural World Heritage Site Criteria II, IV and the IUCN management category IX (UNESCO, 2008). They are of importance because the study area extends into them.

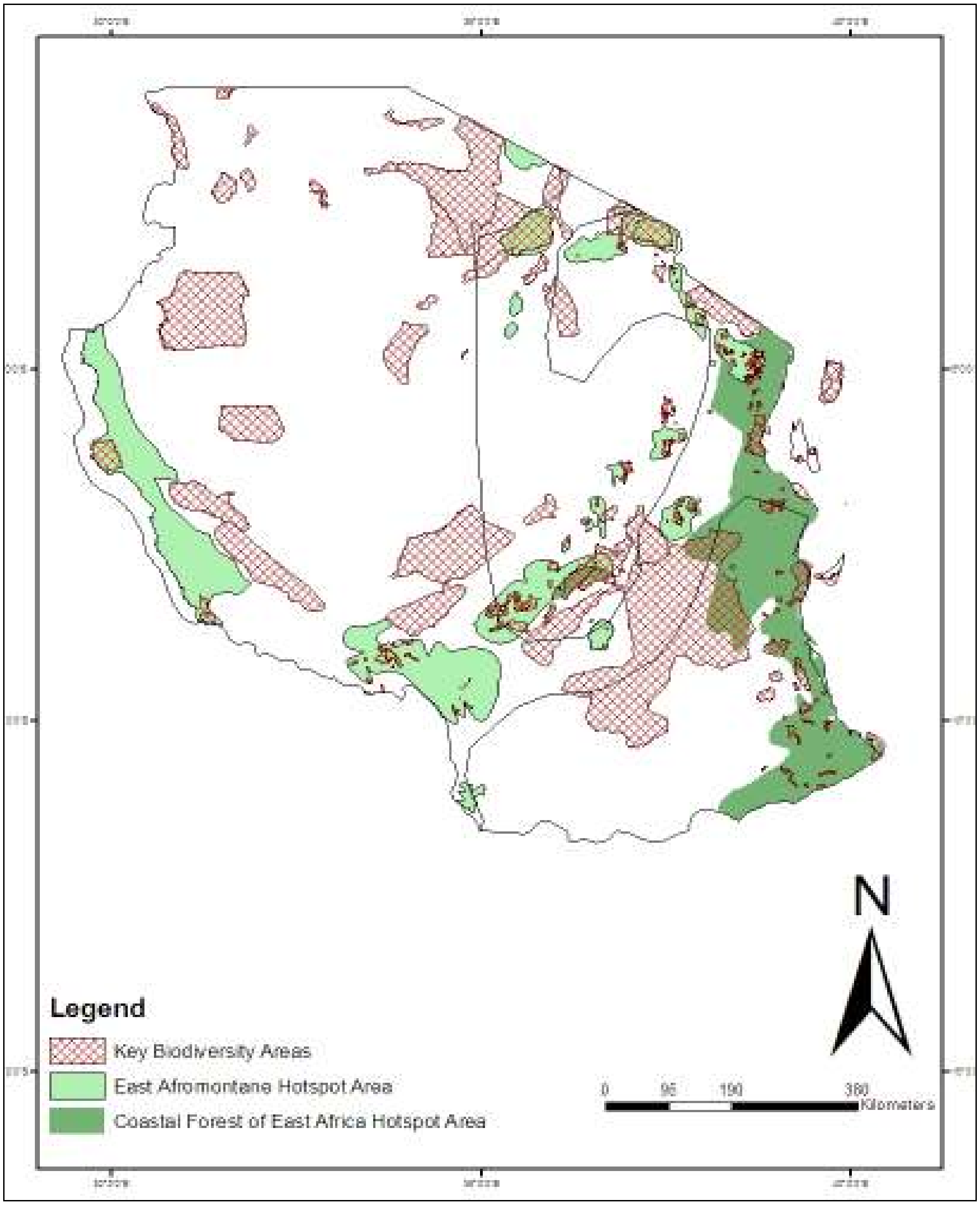

Figure 4: Key Biodiversity Areas and Biodiversity Hotspots of Tanzania

According to Butler (2006) Tanzania is a home to 1 008 plant species; 316 mammals; 1 056 known bird species; 335 reptiles, 116 amphibians and 331 species of fish. Of all these species, nine percent are endemic and about six percent are threatened. Amphibians show a high diversity and have their endemism in the coastal forests and in the East Arc Mountains. Reptiles are widely distributed and are not affected greatly by habitat change (ASDP, 2005). About 239 plant species, 34 mammals and 37 bird species are found on the list of threatened species of the country (Butler, 2006).

Marine resources vary between fish stocks, coral reefs, sandy beaches, mangroves, marine grasses to salt deposits. The fish reserves are concentrated in the three large lakes (Victoria, Tanganyika and Malawi), the Indian Ocean coastline, the rivers and in wetlands. The potential yield of fish from natural waters has an annual estimate of 730 000 Mt and the present catch is estimated at 350 000 Mt (URT, 2008).

2.8 Hydro-geomorphology and Irrigation Potential

Jatropha requires water for optimal growth levels to be attained and especially during the initial establishing phase. As this study focuses on its cultivation in semi arid regions, optimal growth levels will need watering in the first years of cultivation (Watson, 2008b). The current hydro-geomorphology and irrigation scenarios are looked at so as to assess the viability of irrigated Jatropha cultivation and problems that it can face.

Renewable water resources of the country amount to about 89 km^3/yr (Turton and Henwood, 2002). About 30 km^3 is groundwater and four km^3/yr of the groundwater are considered to be overlapping between surface water and groundwater. As Figure 5 shows, Tanzania can be divided into five basic hydrological basins i.e. areas draining into the Indian Ocean mainly the Rufiji River and its tributaries; the Pangani and Ruvuvu River basin; the Malagarasi basin draining into Lake Tanganyika; the Lake Victoria basin draining via the Nile into the Mediterranean Sea and two inland drainage systems:- one draining into Lakes Eyasi, Manyara and Natron in the north and the other draining into Lake Rukwa in the south-west (Kauzeni *et al*., 1993; AQUASTAT 2005). A notable exception is the Great Ruaha river which originates in the Mbeya mountains and flows north-east to the centre of the country before turning south-west and eventually feeding into the Rufiji River.

Figure 5: Major Water Sources within Tanzania (*adapted* from Sweet Maria's, 2009)

About 5.7% of the total land area is covered by the three lakes Victoria (68 800 km²), Tanganyika (329 900 km²) and Malawi (30 800 km²). These are shared with neighboring countries and Tanzania owns 51%, 41% and 18% respectively of the total area of these three lakes (AQUASTAT, 2008). Lake Tanganyika forms part of the Nile River therefore the country is a member country of the Nile Basin Initiative. The Kagera River basin covers the upper part of the of the Nile basin until it enters into Lake Victoria, thus it involves Burundi, Rwanda, Tanzania and Uganda. The shares the Congo River with Angola, Burundi, Cameroon, the Central African Republic, Congo, the Democratic Republic of Congo, Rwanda and Zambia. It also forms part of the Zambezi Watercourse Commission and shares it with Angola, Botswana, Malawi, Mozambique, Namibia, Zambia, and Zimbabwe (AQUASTAT, 2008). It is signatory to the SADC Protocol on Shared Water Course Systems of 1995 and this covers all water including agricultural, domestic, industrial and navigational. The protocol seeks to maintain and achieve a close cooperation between member states and most of the principles it follows are derived from the main international water rules and conventions (Turton and Henwood, 2002).

There are about 21 small scale earth fill type dams that were constructed mainly on seasonal rivers in the Tabora region for keeping water for irrigation and domestic supply purposes in the 1970s (WFB, 2008). These dams currently suffer from serious sedimentation and further dam construction in the country is restricted by hydrological and topographic conditions. The smaller Charco[3] dams that are scattered all over the country provide water for irrigation, domestic and livestock purposes.

Stockle (2001) maintains that the agricultural sector remains as the major consumer of fresh water, with world average usages totaling 71% and regional variations ranging from 88% in Africa to less than 50% in Europe. According to the 2002 National Irrigation Master Plan (NIMP) data based on water resource potential, irrigation potential and socio-economic potential, irrigation potential is estimated to be 2.1 million ha in Tanzania and the potential is higher in the following regions, (1) Mara, Mwanza and Kagera, (2) Arusha and Kilimanjaro, (3) Morogoro and Mbeya and (4) Iringa (AQUASTAT, 2005). The total water withdrawal of Tanzania in 2002 was estimated to be 5 142 million m^3. According to Turton and Henwood (2002) when compared to the SADC region water withdrawal rates, Tanzania (1.17 km^3/yr) is ranked second after South Africa whose withdrawal rate stands at 13.31 km^3/yr. In Tanzania, agriculture consumes the greatest share of water about; 4 624

[3] Charco is a local term in the country that is used to describe dams that are constructed far away from settlement areas and are used to store water mainly for livestock. They are constructed in flat areas adjacent to gently sloped areas (catchment) to ease runoff collection (Mbilinyi *et al*., 2005)

million m³ (almost 90%); with 4 417 million m³ used for irrigation and 207 million m³ used for livestock purposes (AQUASTAT, 2008).

According to AQUASTAT (2008) the total area that is equipped for irrigation is 183 988 ha. There were 1 428 inventoried irrigation schemes (including water harvesting schemes) in the country and of these inventoried schemes, 1 328 were small holder schemes, 85 were privately owned and 15 were government-managed schemes. Small holder farmers utilize surface irrigation and water is distributed via lined and unlined canals as well as furrows and basins. The large scale farmers use sprinkler irrigation mainly, and drip irrigation methods are not used in the country. Gravity-fed irrigation schemes account for over 99% of the irrigated area while the rest uses pumps for water abstraction. According to AQUASTAT (2005) and Agricultural Sector Development Strategy (ASDS) (2005) data, the main types of irrigation that are dominant are:

- **Modern irrigation practices** (35 847 ha): These are formally planned and designed schemes with full irrigation facilities and usually they have a strong element of management by government and other external agencies. They are dominant in the Kilimanjaro, Morogoro and Mbeya regions.

- **Traditional irrigation schemes** (122 630 ha): These have been initiated and operated by farmers themselves, with no interventions from external agencies. They include schemes based on traditional furrow irrigation for the production of fruit and vegetables in the highlands and simple water diversion schemes on the lowland for paddies.

- **Improved traditional irrigation schemes** (25 511 ha): these are traditional irrigation schemes on which at some stage, there was intervention by an external agency, such as the construction of a diversion structure.

- **Water harvesting schemes** (7 900 ha): These are water harvesting and flood recession schemes on which sub-subsistence farmers have introduced simple techniques to artificially control the availability of water to the crops.

- **(Ex) Parastatal Large Irrigation Estates** (25 464 ha): These irrigation estates are in the process of being privatized as there are still to be strategic privatization procedures to be adopted by the government of Tanzania

Most irrigation facilities are beneficial in that when food production is increased, food prices are reduced, there is higher employment opportunity and it can lead more rapid economic development. However, irrigation and water resource development can have social and environmental impacts and the sources of environmental impacts ranges from construction of irrigation projects; water supply and operation of irrigation projects as well irrigated agricultural management (Stockle, 2001). These may not need to be underestimated when setting up the large scale Jatropha cultivation in the semi arid regions.

2.9 Overview of Agriculture Sector of Tanzania

Agriculture is the main source of livelihood for more than two thirds of Tanzanians (National Adaptation Programme of Action (NAPA), 2006). As noted in the introduction, it is the main contributor of the country's economy providing 46% of the GDP, 75% of the exports and 80% of the employment sector. About 30% of the sector's GDP comes from livestock production and this is spread across beef, milk and poultry, and small stocks production as 40%, 30% and 30% respectively (SADC TIIR, 2007). As is noted in the introduction, cultivated land as a percentage of total land area varies between six and eight percent (NPPT, 2006). The sector is dominated by small holder farmers and their farms average between one and three hectares. They use traditional farming methods and small amounts of their produce are made ready for the market (Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), 2005). Medium scale farmers do mixed farming for commercial purposes and large scale commercial farmers grow cash crops for export purposes (AQUASTAT, 2008). A variety of staples grown include maize, sorghum, millet, rice, wheat, pulses, cassava, potatoes, bananas and plantains. The major export crops are coffee, cotton, cashew nuts, tobacco, sisal, pyrethrum and tea, fruits, vegetables and flowers.

The oil crops range from oil palm, cashew nut, sunflower, peanut, sesame, cottonseed, soy beans, castor to Jatropha. The study focused on Jatropha because it has long been known to the majority of the Tanzanians although its utilization was limited to use as a protection hedge. Because it is not palatable to livestock, it is grown around homesteads, gardens and graves (Foester *et al*., 2005). As noted earlier in the introduction, Tanzania has a large potential for biofuel production. Its agricultural and livestock policy categorizes oil seeds as industrial (*not used for human consumption*) or edible oil seeds (*produce edible oil for human consumption*) (GTZ, 2005). Research and extension services for oil seeds crops have been inadequate causing an insufficient performance of the oilseed sub-sector. The private sector is important for growing and processing of oil seeds but there is need for government attention to be directed towards assisting the sector to accelerate the growing. Sawe (2008), notes that this acceleration will have to be done through design of proper policy support base and provision of adequate technical knowhow in Tanzania.

Up until the present none of the existing policies have given support for growing and exploiting potential biofuels crops such as Jatropha and palm trees. Instead, Jatropha is grown by small holder farmers and promoted by local NGOs for non-transport applications such as fuel for cooking and feedstock for soap making. There are over eight institutions that are working on biofuels and some specifically on Jatropha activities. These include the government ministries; public and private companies; NGOs; community based organizations; and research and training institutions. The seeds were not used otherwise and it was not until 2000 that the McKnight Foundation of the USA through HPI-Tanzania gave funds to develop the sub-sector in order to promote the rural marginalized women in Arusha and Manyara regions. The aim of the project was to help reduce biodiversity loss while increasing livelihood security and income of rural women. The subsector development plan was initiated as the Alternative Resources Income Project for Monduli women (ARI-MONDULI). The project spanned between June 2000 to December 2004 and

HPI contracted KAKUTE Ltd to help in the management of the day-to-day activities of the project (Foester *et al*., 2005). The project managed to introduce Jatropha crop through the provision of seeds, cuttings together with technical assistance, training, extension, production and marketing.

KAKUTE Ltd managed to develop a Jatropha chain from scratch and it established a contract arrangement whereby, the company offers the seeds and seedlings to small groups of women in the form of a soft loan and deducts this when the women sell the seeds back to KAKUTE Ltd after harvesting (Foerster *et al*., 2005; Van Eijick and Romijin, 2006). Strategic collaboration with the Manyara and the Arusha women groups have been developed by KAKUTE Ltd and the sale outlets that are in Arusha are aimed at developing a Jatropha soap market chain for Tanzania as so far it is the Jatropha soap that has penetrated the market. There KAKUTE Ltd is planning to diversify into renewable energy technologies and it is in the process of signing of the memorandum of understanding with large companies like Pamoja Inc of USA, PROKON BV of Germany, D1 Oils of the UK and Diligent Tanzania to enhance the development of this industry.

A foreign based company, SunBiofuels is finalizing the acquisition of an 8 000 ha estate south-west of Dar es Salaam for large scale Jatropha cultivation (Africa News Network, 2008). It has not ventured into the option but it plans to grow about 5 500 ha of the crop in the next 10 years on lands that receives enough rainfall and has physiographic factors that are non-limiting. Areas that it is targeting are in the Wami wetlands. The rainfed sites that it envisages should receive above 750 mm and if the rainfall is 650-800 mm the trees will be have to be irrigated during the first year (Schafer, 2008). The cultivation of Jatropha on semi arid regions on a large scale will reduce risks arising from the use of lands that otherwise have to be used for food crop cultivation or have biodiversity in them.

D1 Oils is based in several regions in Tanzania and its objectives are to initiate Jatropha cultivation on a large and small scale commercial basis for biodiesel production for the transport sector (Chagache, 2003; GTZ, 2005). It is in the process of selecting suitable communities to establish 10 000 ha land for energy crops for producing biodiesel for the transport sector. Diligent Tanzania is active in the northern region of Tanzania and there are other companies that are active in Jatropha in Lindi and Bangamoyo/Pangani area. The University of Dar es Salaam is conducting research on biodiesel production from vegetable oil and is also conducting engine tests on pure biodiesel and biodiesel/diesel blends.

2.9.1 Environmental Issues

The National Environmental Policy identified six major problems, which require urgent attention in Tanzania. These are:- (i) loss of biodiversity and wildlife habitats; (ii) deforestation; (iii) land degradation; (iv) deterioration of aquatic ecosystems; (v) lack good quality water; and (vi) environmental pollution (LEAT, 2008). The destruction of coral reefs is also threatening marine habitats and wildlife is threatened by illegal hunting and trade especially ivory. The best agricultural lands of Tanzania are densely populated and the high population pressure is the underlying root cause of the soil fertility decline problems (Roy and Nabhan, 1999). Other major causes of soil degradation are divided into natural and direct causes. The natural causes include high intensity rains; fragile semi arid climates; inherent low nutrient content soils; strong leaching characteristics and poor soil structure. The direct causes are poor agricultural practices, deforestation and overgrazing (Roy and Nabhan, 1999; LEAT, 2008).

2.9.2 Land and Land Tenure Policy Framework: An Overview

Kartha *et al*., (2005:21) defines a bioenergy project as, "a particular application for bioenergy in a specific locality" and a bioenergy program as, "a large scale initiative to create the conditions conducive to bioenergy activities that support development particularly in rural areas." The bioenergy project and the development of bioenergy programs in an area is land intensive and, therefore, it relies on land tenure systems. Land tenure systems determine whether the chosen biomass feedstock can be provided sustainably to a given bioenergy project over a long time.

The importance of land tenure and land reform to rural development of Tanzania in particular has formed major debates for decades for SSA and beyond (Limbu, 1995). Land has been, and still is, state property thus it can not be purchased. In their land use planning and resource assessment case study in Tanzania, Kauzeni *et al*. (1993), note that there exists direct (silent) conflict and a sharp difference in the way land use is planned at rural village level and at higher level (district, regional and national). They maintain that land use and land resource management continues to be dominated by traditional practices, which depend mainly on experience, customs, beliefs, traditional laws and local knowledge while at a higher level, planning is carried out by official expert government land use planners who have physical planning skills. They also argue that there exists a void that remains unfilled between both parties and this is usually a factor that is worth considering even for land suitability for bioenergy purposes.

Limbu (1995) also asserts that the post independence (1961-1967 period) government policies especially in the 1970s were inappropriate, unstable and were based on *ad hoc* decisions. The policies emphasized improved peasant farming through extension services, the provision of credit and marketing structures as well as large scale agriculture in selected areas under government support (ASDS, 2005). The Arusha Declaration Policy of Self Reliance of 1967 gave the government of Tanzania the management and investor rights virtually in all sectors. It established state owned farming enterprises, nationalized most of the large scale commercial farms, promoted collective farming and established systems of national pricing of agricultural commodities (ASDS, 2005). These policies were later on seriously affected by the severe droughts in the 1973/74 and 1984 period and the world oil crisis of 1973 and 1979. The 1978/79 war with Ugandan Iddi Amin also led to diversion of the resources that were meant for the agricultural sector in Tanzania (Limbu, 1995).

The government led privatization and demonopolysation[4] of agricultural parastatals through structural adjustment programmes and with the help of a coalition of donors in the 1980 is still continuing and focuses much on the decentralization and empowerment of local communities so that they become more responsible for and more responsive to local development problems and opportunities (ASDS, 2005). One of the policy strategies was the Kilimo cha Kufa n Kupona (Do or Die Agriculture) of 1983 and this emphasized the increase in agricultural production.

The Tanzania Development Vision 2025 looks forward to reducing poverty significantly by 2025 and this will be achieved by emphasizing basic food security, improving income levels and expanding export earnings (Vedeld and Kengera, 2006). The Poverty Strategy Reduction Paper's (PSRP) describes strategies to be implemented through the Rural Development Strategy (RDS) and the ASDS. The latter identified agricultural development as the most critical of all sectors due to its potentials as (i) a major contributor to the country's GDP; (ii) a major income source; and (iii) employer for the majority of rural Tanzanians (Vedeld and Kengera, 2006).

Like any other developing countries, the price uncertainties of the world oil prices continues to negatively impact on the cost of production and service delivery in the agriculture economy of Tanzania. Inflation grew from 8.6% during the year ended January 2008 to 13.5% at the end of December 2008 (National Bureau of Statistics of Tanzania (NBST), 2009). Van Eijick (2006) suggests that growing and production of biofuels in Tanzania could supplement income to households in communities of the country and could also provide an alternative energy source.

2.10 The Socio-economic Environment

2.10.1 Demography of Tanzania

[4] Demonopolysation entails a reduction in the control over a market of a certain commodity i.e. having lesser power to rule over the decision of a body which is identified to run affairs of organization e.g. parastatals of Tanzania.

The processes of biofuels production require division of labour therefore the state of population distribution and growth rates of the country are worth assessing. The population of Tanzania increased from 23.1 million people in 1988 to 34.6 million in 2002 and this growth rate averaged 2.9% per annum (Figure 6) (Tanzania SENSA, 2003; NPPT, 2006). Over the 1967 to 2002 period, the population almost tripled and based on this growth rate, the county's population is projected to reach 63.5 million by 2025 (NPPT, 2006). An analysis of the populations distribution by region, on the past censuses including the 2002 National Population and Housing Census has shown that, about two thirds of the population is concentrated in one quarter of the total land area.

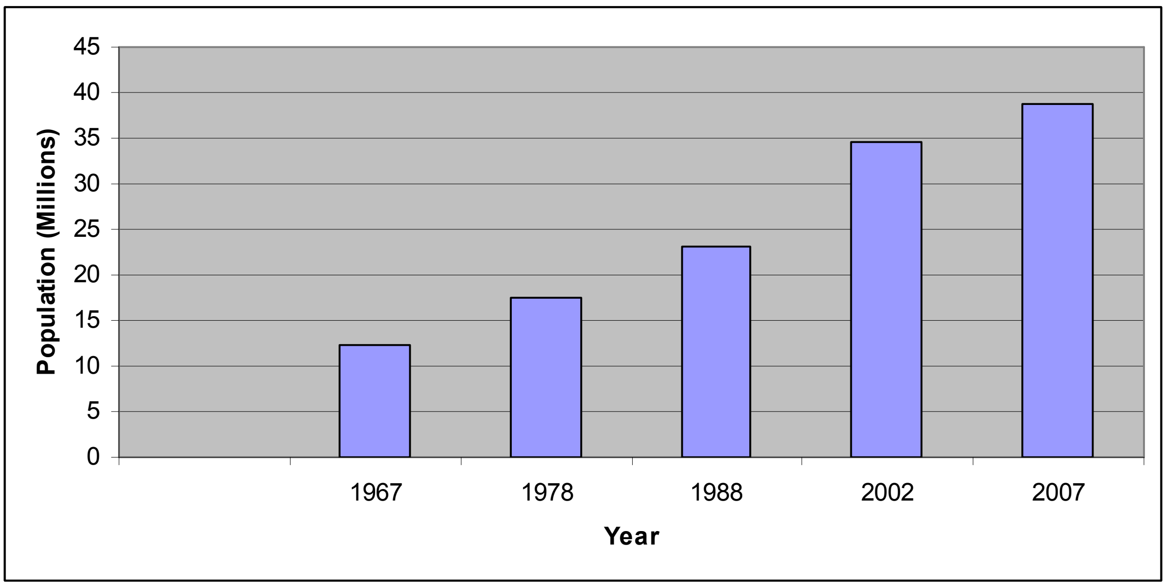

Figure 6: Tanzania Population Census Statistics (*adapted from* Tanzania SENSA, 2003; PRB, 2007)

The number of people per square kilometer of land area varies considerably from region to region and Tanzania has 21 administrative regions. The position and population sizes of these regions are shown in Figure 7. For the whole country, the population density was 39 p.km² in 2002 (Tanzania SENSA, 2003). The Population Reference Bureau (PRB) (2007) estimated that it is 41 p.km². Although this population density portrays an impression that the country is sparsely populated, it is important to note that people are highly concentrated on regions where climatic conditions are favorable, soils are good, and water sources are adequate and reliable. People are particularly concentrated in Dar es Salaam region (1 793 p.km²) and Urban West (1 700 p.km²) (Tanzania SENSA, 2003). Nearly 80% of the people who live in the rural areas depend on land for their subsistence (Maguje, 2004). In major cities like Dar es Salaam, Mbeya, Arusha and Zanzibar, rural urban migration has put burden on public services and social infrastructures (NPPT, 2006).

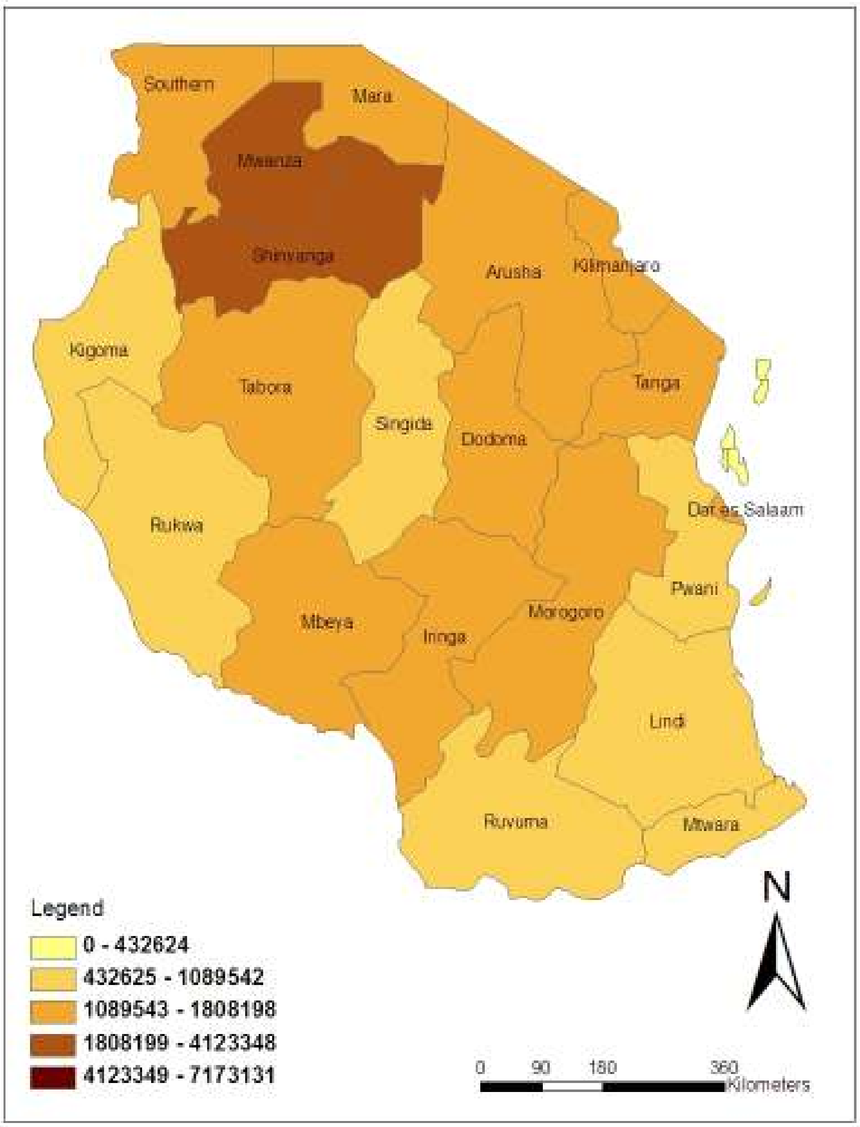

Figure 7: Population of Administrative Regions of Tanzania

2.10.2 Economics

The country's economic growth has been strong since 2000. Increases in GDP have been between 5% and 7% each year (Human Development Report (HDR), 2008). GDP in Tanzania depends strongly on agriculture. As was noted in the motivation for the study, agriculture accounts for 44-46% of the GDP followed by services (18%) and industry (18%) (WBCSD, 2007). Employment ranking during the 1996-2005 period showed agriculture as the highest employer providing for 82% of employment, followed by services (15%) and industry (3%) (HDR, 2008).

2.11 Energy Situation

Tanzania has a number of good energy sources which include solar, wind, biogas, coal reserves, natural gas, hydropower, biofuel, fuelwood and geothermal power. The most exploited source is fuelwood because it is considered to be cheap and accessible to the majority of the poor who live both in rural and urban areas. The major commercial energy sources are petroleum, hydropower and coal. As was previously described in section 1.3, more than 90% of the biomass resources that Tanzania requires come from firewood, farm residues, forest waste and dung and the rural households require about 98% of the total biomass energy that the country produces. The collection of fuelwood for heating and preparation of meals is mostly done by women and children in the rural areas. Urban dwellers depend on wood vendors for they cut the wood from natural forests and make charcoal and transport it to towns by trucks for sale. Coal is preferred by the urban dwellers due to its high energy density, higher efficiency when compared to wood, user friendliness and its easiness to transport and store (Zuzarte, 2007). As is noted in the motivation for the study area and as shown in Figure 8, the contributors to the 2005 total energy were renewable and wastes, followed by oil, hydropower, gas and coal (IEA, 2005).

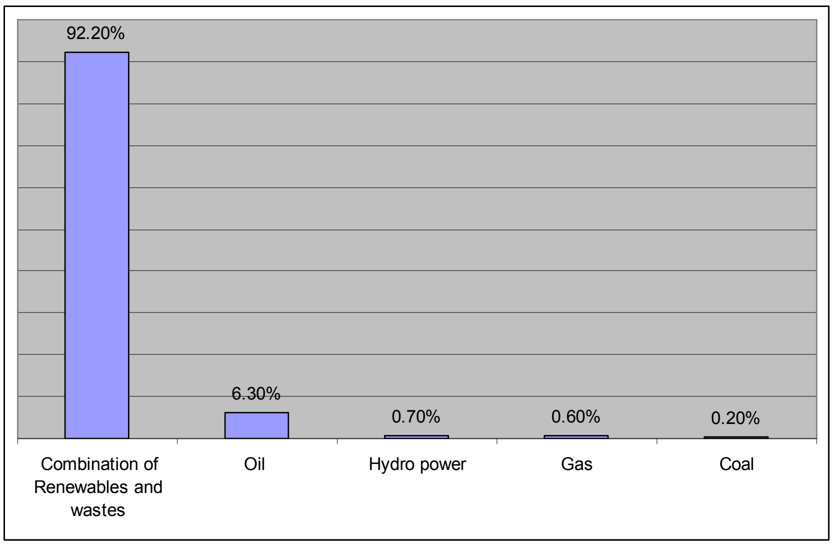

Figure 8: Share of Tanzania Primary Energy Supply in 2005 (IEA, 2005)

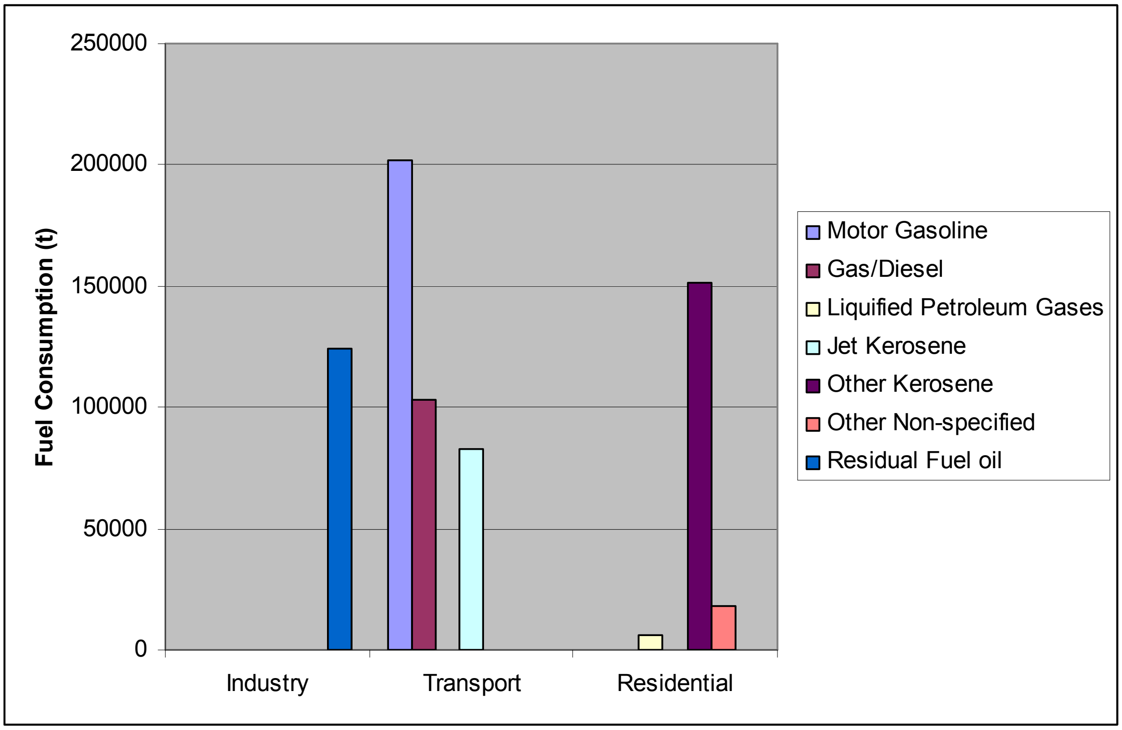

Figure 9: Per Sector Fuel Consumption of Tanzania (IEA, 2005)

Figure 9 shows the fuel consumption of various sectors and the transport sector is the dominant user of petrol, diesel and jet kerosene. The industry consumes mainly residual fuel oils[5] while the residential sector consumes largely other kerosene besides the non specified fuel types and liquefied petroleum gases (includes ethane, ethylene, propane, propylene, butane, butylenes, isobutane and isobutylene).

Electricity plays a minor role in the rural areas where 80% of the populations live. The percentage of urban and rural electrification stood at 39% and 2% respectively in 2005 (Lyimo, 2006). In 2005, 34.2 million people were without electricity (HDR, 2008). Less than 10% of the total population have access to electricity but only one percent of the rural population is connected to the electricity grid (Shuma, 2006; Lyimo, 2006; Johnson and Rosillo-Calle, 2007). The installed electricity generation as shown in Figure 10 comprises

[5] Residual oils are a general classification for heavier oil known as No.5 and No.6 fuels oils that remain after distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations (EIA, 2007).

of a mix of hydropower, fuel oil, coal contributed. In 2005, their contributions were 56%, 37% and 3 % respectively, and only 4% of the total electricity was imported (IEA, 2005). Despite the fact that electricity is lost through distribution losses and vandalism, most of the electricity goes towards lighting residential areas, followed by the industrial sector, non specific uses and transformer functioning. In a strategic niche management analysis for Jatropha biofuels, Van Eijick (2006) found that, cities are constantly affected by power shutdowns and, thus, they use diesel generators as backup source. Oil lamps for lighting homes uses imported kerosene and to a lesser extend candles, batteries, solar electricity and grid electricity. The cultivation of biofuels crops is expected to decentralize the production of both biodiesel and subsequent oil, and these will then be fed into the backup generators and lighting lamps for both the rural and urban areas.

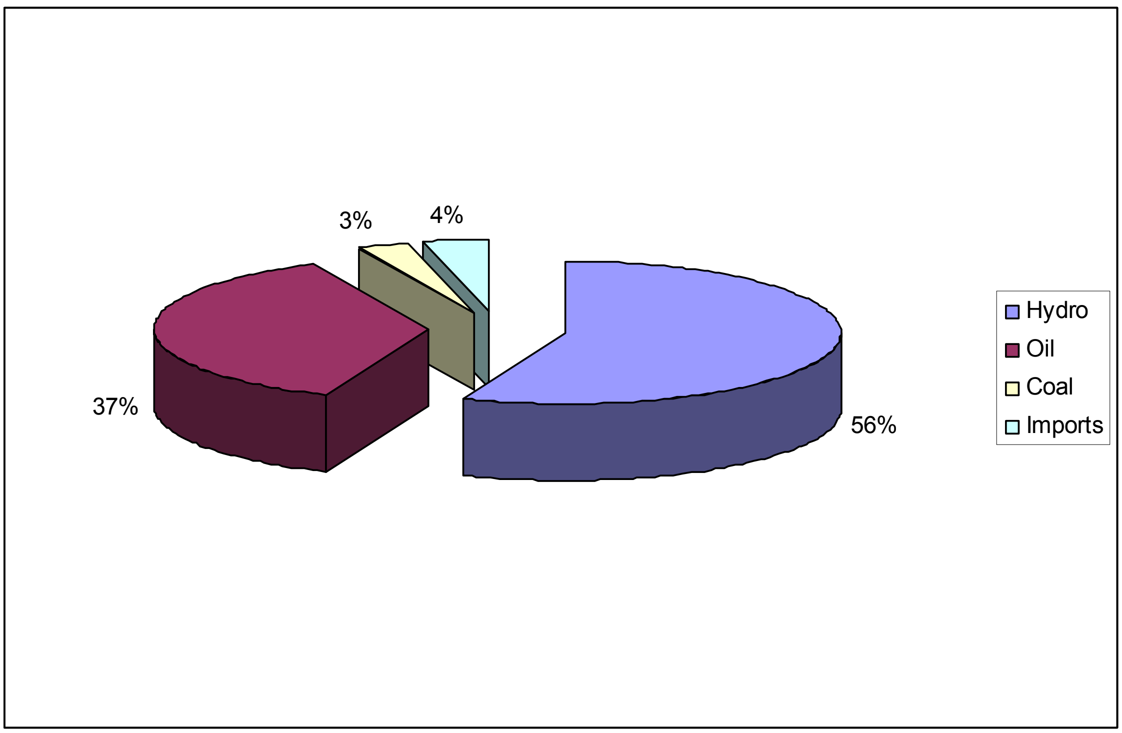

Figure 10: Contributions of Electricity to the National Grid (IEA, 2005)

None of the country's oil reserves merit exploitation, thus, the Tanzanian Petroleum Development Company (TPDC) procures crude oil for refining at the Tanzania Italian Petroleum Refinery (TIPER) in Dar es Salaam. The major share of the consumption of the imported oil and oil products goes towards fueling and maintenance in the transport industry (Fig 9) (IEA, 2005). Chagache, (2003:13) noted that , “due to the higher number of unpaved highways in comparison to paved highways, the country requires locally produced fuel alternatives that can act as extenders or substitute of diesel and paraffin (kerosene) in the rural areas.” The production of biofuels locally can accommodate the rural deprived areas but it is enough to not compromise the demerits of large scale companies, as there is a tendency of produce being marketed outside of production zones. However, this production of biofuels for use at a local level can reduce the amount of money that is used to transport fossil fuel as well as ease the problem of transporting them to the rural areas.

Kerosene, a liquid fuel that is distilled from petroleum, is imported and is used as a cooking fuel in the urban areas and for lighting in the rural areas. Except for kerosene (*referred to as other kerosene in Figure 11),* where 151 000 t of the 155 000 t imported in 2005 was mainly consumed by families and households, the transport sector continues to drain the country of its foreign currency, as it uses it to procure oil from oil rich nations where monopoly and over pricing dominates the market (Lyimo, 2006).

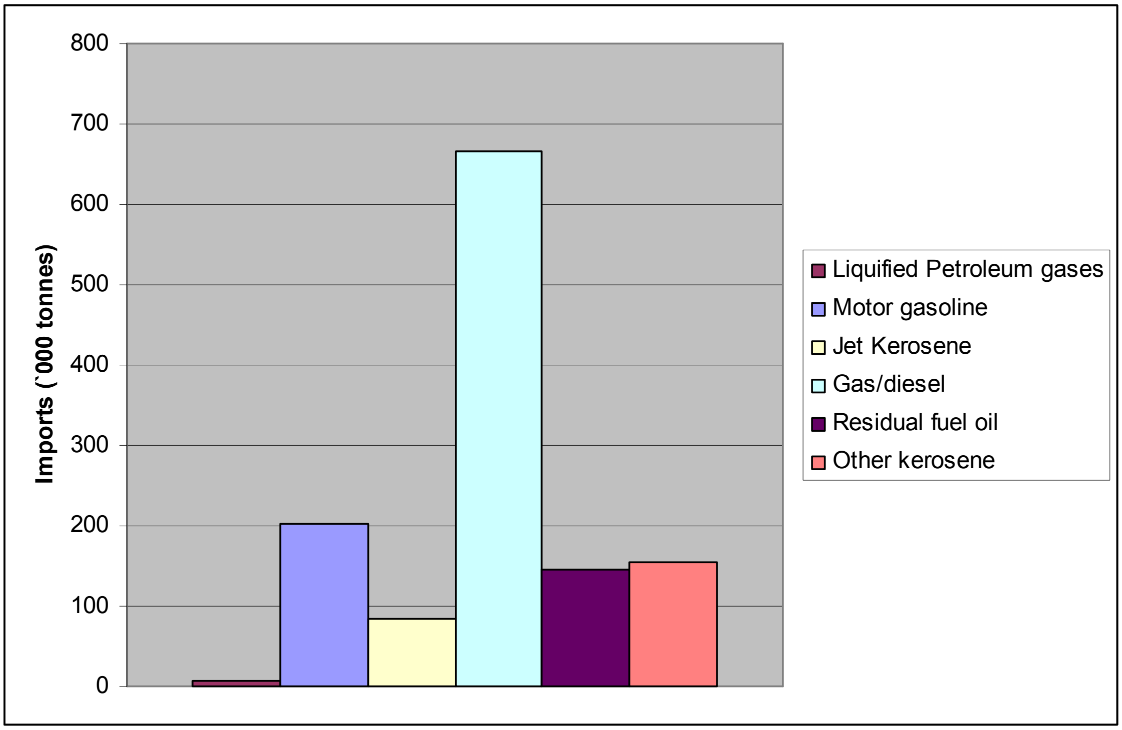

Figure 11: Tanzania Oil and Oil Based Products Imports (IEA, 2005)

According to the IEA (2008), coal reserves in Tanzania are estimated at 1 200 millions tonnes and 304 million tonnes are proven. Of the coal that was produced in 2005, 61% was consumed by the electricity plants and the remaining 39% was consumed by the industrial sector (IEA, 2005). Kauzeni *et al*. (1993:24), laments that "Coal in Tanzania is abundant but plays a minor role as a source of energy due to its poor quality, undeveloped market, peripheral location and poor transport facilities."

The country has a potential for natural gas and proven off shore reserves are estimated at 0.72 trillion cubic feet (Kauzeni *et al*., 1993). There is also a geothermal potential of 150 MW and varying levels of research that have been conducted shows that, the government needs to strategize how small scale geothermal plants can work out for rural electrification through the introduction of mini grid systems (Karekezi *et al*., 2007). The geothermal areas include Lake Eyasi, Lake Manyara, Lake Natron, Mbeya, Musona and the Ngorogoro Crater.

2.12 The State of Renewable Energy Resources

Renewable energy resources currently in use in the country include photovoltaic (PV) equipment, solar thermal, wind pumps and biogas. In order to increase the use of renewable energy technologies, the country has removed all taxes on imported solar and wind equipments since 2005. The country's demand and price for petroleum products are growing at a rate of more than 30% per year (GTZ, 2005). Since petroleum is a finite resource, renewable fuels such as ethanol and biodiesel help reduce dependence on petroleum products. Thus, foreign currency can be reserved for other imports if local production is sustainable.

2.13 Context for Promoting Sustainable Transportation

In view of biofuel production, the Department of Minerals, Energy and Water Resources (DMEWR) (2007) suggests that it is necessary to consider feedstock production areas, which are adequately supported by satisfactory road and rail transport infrastructure. Adequate road and rail transport infrastructure is required to transport biofuels from processing plants to distribution points. Tanzania's transport sector growth of 6.2% in 2004 compared to 5.0% in 2003 was attributed to an increase in the investment in mobile telecommunication; construction and rehabilitation of airports and roads; and an increase in transportation agencies (GTZ, 2005). Road transport is the most dominant with a total coverage of 78 891 km (6 808 km paved; 72 083 km unpaved). This is followed by the railway lines (3 690 km); air (124 airports); pipeline; waterways; merchant marine; ports and terminals, and all these facilitate the movement of goods and populations in the country and out of the country's boundaries (WFB, 2008). An extensive comprehensive road network consisting of 85 000 km connects Tanzania with Kenya, Zambia, Uganda, Burundi and Rwanda is covered by an extensive comprehensive road network (SADC TIIR, 2007). The network consists of trunk (10 300 km); regional (24 700 km); district (20 000 km); urban (2 450 km) and community (27 550 km) roads (GTZ, 2005).

The Tanzania Railway Cooperations (TRC) runs the 2 605 km system linking Dar es Salaam with the central and northern regions, and it also branches to Kigoma on Lake Tanganyika and Mwanza on Lake Victoria. The Tanzania-Zambia Railway Authority (TAZARA) operates 960 km of track and it is mainly used to transport Zambian copper to the Dar es Salaam port and Zambia imports in the opposite direction. Tanzania has principal coastal ports at Dar es Salaam, Tanga, Lindi, Mtwara, Zanzibar and Dar es Salaam is the largest and natural deep water harbour in the country. The main lake ports are Mwanza, Bukoba, and Musoma on Lake Victoria; Kigoma on Lake Tanganyika; and Itungi Port and Mbamba Bay on Lake Malawi.

2.14 Conclusion

The chapter described the geographical location, the terrain and climatic conditions, agriculture and hydrology and natural resources of the study area. The contribution of agricultural sector to the economy and the area extend of biodiversity rich areas in the country provide enough motivation for the study to only focus on the bioenergy crop cultivation on lands that have to be in the semi arid regions. The irrigation types and water resources in the country avail for irrigation of Jatropha to maximize yield, can be a viable option. The fact that there is growing interest in biofuels from several stakeholders means there is need to provide adequate technical knowhow and policy support to ensure all activities are done in a sustainable manner. The next chapter looks at the background to the bioenergy crop Jatropha, its characteristics, and its current status as a biomass feedstock.

Chapter 3
Background to Jatropha

3.1 Introduction

This chapter gives in-depth background characteristics of Jatropha, its biophysical requirements, how to manage and propagate it, its uses as well as its constraints. The bioenergy systems theoretical frameworks as well as the global and SSA bioenergy systems perspectives are also reviewed in this chapter. The chapter concludes by the highlighting the pros and cons of bioenergy systems and their implications for SSA.

3.2 Jatropha

3.2.1 Origin of Jatropha

There are a lot of uncertainties into where Jatropha initially originated from but there is a general consensus in the literature that it originated from South America (Amin, 2001; Jongschaap *et al*., 2007). Its centre is suspected to be Mexico and Central America where it naturally occurs in forests of coastal regions (Openshaw, 2000; Amin, 2001; Benge, 2006). To the tropical and subtropical semi arid and arid regions throughout Africa and Asia, it is claimed that it was distributed by the Portuguese seafarers via the Cape Verde Islands and Guinea Bissau (Heller, 1996). As noted in the introduction, Jatropha is widely grown in India, it grows as a weed in Brazil, Fiji, Honduras, Jamaica, Panama, Puerto Ricco and El Salvador, and in the Philippines, it is widely grown in fence lines.

3.2.2 Botanical Features

The Jatropha plant or physic nut is a shrub or small tree belonging to the family *Euphorbiaceae*, subfamily Crotonoideae and tribe Jatropheae (Mendoza *et al*., 2007). Jatropha is a morphologically diverse genus of 160-175 species of trees, shrubs, rhizomatous subshrubs, or geophytes (Rupert *et al.,* 1970; Dehgan, 1984). The genus name Jatropha is derived from the Greek *jatrós* (doctor), *trophe* (food), which implies medicinal use (Heller, 1996; Henning, 2004). The four most important species are *J. curcas* L*, J. gosstifolia, J. podrika and J. mutifada,* and in this thesis, the species *Jatropha curcas* Linnaeus shall be referred to as Jatropha. The species was on focused because it is the most common species of Jatropha found in Africa. It has been grown by small scale farmers for at least four to five decades in a number of countries where it has mainly been used as a live fence and to a lesser degree for making soap and candles (Sawe, 2008).

The plant has spreading thick branchlets and stubby twigs (*Refer to Figure 12*) (Mendoza *et al*., 2007). It also has a straight trunk and grey or reddish bark which is masked by white patches. When the stems are cut, they produce whitish-yellowish coloured, watery, latex (Henning, 2004). The leaves are deciduous, ovate, acute to acuminate, basally corded, 6-15 cm long and 6-15 cm wide (Heller, 1996; Amin, 2001; Mendoza *et al*., 2007). Jatropha can grow to between three and five metres in height, but under favorable climatic conditions it can grow up to a height of between eight and ten metres (Heller, 1996). Five roots, one central (tap root) and four other peripherals are normally formed from a seed propagated plant (Heller, 1996). According to reports on propagation from cuttings reviewed by Benge (2006) only four lateral roots and at times a pseudo root which can reach between half and two thirds of the length of the normal tap root, are obtained from the cuttings propagated plants. The tap root may stabilize the soil against landslides while the shallow roots are alleged to prevent and control soil erosion caused by wind or water (Achten *et al*., 2008).

Figure 12: Physiography of *Jatropha Curcas*

The Jatropha plant is monoecious i.e. separate male and female flowers can be produced on the same plant and the terminal inflorescences contain unisexual flowers (Foidl *et al*., 1996; Raju and Ezradanam, 2002; Achten *et al*., 2008). Raju and Ezradanam (2002:1395) also state that, "The ratio of male to female flowers range from 13:1 to 29:1 and this ratio diminish with age." The plant is pollinated by insects and, under rainfed conditions, flowers only once during the rainy season. However, Heller (1996) suggests that, in permanently humid regions or under irrigated conditions, Jatropha flowers almost throughout the year. The mature flowers are usually greenish cymes; yellowish and bell shaped (Mendoza *et al*., 2007). Approximately 10 or more fruits can be produced form each fluorescence. The yellow fruits formed are trilocular ellipsoidal in shape and their exocarp remains fleshy until when the seeds are mature (Henning, 2004). When the exorcap is removed, black seeds with an average length of 18 mm and width of 10 mm are obtained. The average weight of individual seeds is 0.73 g (Heller, 1996).

The seeds are potentially an excellent source of protein. According to Makkar and Becker (1997), cited in Makkar *et al*. (1997), with the exception of lysine, their essential amino acid levels exceed those recommended by the FAO for a two to five year old child. Unfortunately, the seeds are not edible to humans or animals because they contain Phorbol esters, typsin inhibitors, lectins, phytates and curcin protein. These compounds are so concentrated that the seeds, oil and seed cake are not edible without detoxification (Heller, 1996; Makkar *et al*., 1997; Benge, 2006). The concentration of the phorbol toxins tends to vary in a variety of cultivars of Jatropha ranging from the non-toxic Mexican varieties that can be roasted for home consumption to the variety that contains 6 mg per seed kernel that is found in India (Heller, 1996; Francis *et al*., 2005). Kingsbury (1964), cited in Makkar *et al*. (1997), reports accidental injestions by humans in Florida, Hawaii and Philippines causing burning and pain in the mouth and throat, vomiting, delirium, muscle shock, a decrease of visual capacity, and a high pulse. Findings from Makkar *et al*. `s (1997) feeding studies with rats and fish using *Jatropha curcas* meal, has shown that seeds from Papantla in Mexico were non-toxic whereas those varieties from the Cape Verde and Nicaragua were toxic.

The life of a Jatropha tree or shrub extends to more than 50 years if it is not attacked by termites (Henning, 2000; Benge, 2006).

3.3 Environmental Constraints to Growth of Jatropha

3.3.1 Altitude

Jatropha mainly occurs from sea level up to 500 m.a.m.s.l. (Amin, 2001) but it is viable for cultivation up to 1 800 m.a.m.s.l. (Foidl *et al*., 1996). Generally speaking, cultivation on surface slopes exceeding 30° triggers soil erosion (Tewari, 2007).

3.3.2 Temperature and Insolation

Temperature exerts a major influence on the amount of water a plant requires, and the rate of physical and chemical reactions that determine its rate of growth and development. Tropical and subtropical areas with a mean annual temperature range of 20-28°C provide optimal growing conditions for Jatropha. While it can withstand severe heat (Amin, 2001), it is susceptible to freezing temperatures (International Centre for Research in Agroforestry (ICRAF), 2003).

3.3.3 Rainfall and Humidity

Jatropha experiences optimal growth where the MAP ranges between 250-1000 mm. Water requirements of Jatropha are dependent on the species variety and origin of the plant. Tropical and subtropical areas with MAP range of 500/600-1 000/1 200 mm provide optimal growing conditions and hence economic yield. Jatropha is however capable of growing over a much wider range of MAP. Daey Ouwens *et al*. (2007) noted that it was not producing well at a MAP of 3 00 mm. In parts of Cape Verde Islands where the MAP is 250 mm Benge (2006) attributed its ability to grow to the high atmospheric temperatures. However Foidl *et al*. (1996), report its growing at a MAP of 3 000 mm. ProBios (2006) found that a MAP of 600 mm was required for Jatropha to produce fruits. As the study focuses on Jatropha cultivation in semi arid areas, areas that have a low MAP will have to be irrigated to improve productivity.

3.3.4 Soil and Fertilization Requirements

Soil characteristics may be divided into physical or chemical properties from an agricultural perspective. Well aerated sandy to loamy soils are the best soils for Jatropha cultivation (Daey Ouwens *et al*., 2007). However, on degraded sandy or gravelly areas and it has a possibility for reclaiming the low potential soils that are found in these areas (Amin, 2001). The term "low potential" soils refers to, "Resource poor or marginal agricultural lands, where inadequate or unreliable rainfall, adverse soil conditions, fertility and topography limit agricultural productivity and increase the risks of land degradation" (Barbier *et al.,* 1997: 892). Heavy clay soils swell and shrink on wetting and drying and consequently impair and reduce root system development (Daey Ouwens *et al*., 2007). In their study on Jatropha as a biofuel crop in Nicaragua, Foidl *et al*. (1996) concluded that, Jatropha grows well on all soils except Vertisols as regions with these are at a risk of water logging. A minimum soil depth of 60 cm was observed to be the optimal soil depth that is currently working for Jatropha plants in India (ProBios, 2006).

Soil pH, a measure of acidity or alkalinity in the soil influences, the movement of nutrients that are important for plant growth. A soil pH of more than six is considered to be too acidic and a pH of 8.0-8.5 is too alkaline for Jatropha to grow well (Daey Ouwens *et al*., 2007). However, research findings of the National Network on Jatropha in India have indicated that the plant can be cultivated in any type of soil subject to a pH of up to 9.5 (ProBios, 2006). Jatropha also grows in saline conditions with low nutrient content but it cannot survive in waterlogged terrain.

Although Jatropha is adapted to low fertility areas and alkaline soils, better yields are obtained on poor quality soils if fertilizers containing small amounts of calcium, magnesium and sulphur are used (Foidl *et al*., 1996; Tewari, 2007). Phosphorous (P) and Potassium (K), when combined together with nitrogen, facilitates root development system, stem growth, branches and leaves, flowers, fruits and seeds (Jongschaap *et al*., 2007).

When put in planting holes under direct seed propagation, fertilization boosts early establishments and also speeds up plant growth (Daey Ouwens *et al*., 2007).

Organic matter, in the form of well composted fruit walls and seed cake, leaf litter and pruning, improves the soil structure and the water holding capacity of the soil (Heller, 1996, Parsons, 2005). However, experiments on seed cakes with excessive oil content in India have shown that it can be dangerous when applied to soils, as it tends to stop infiltration of water, reduce aeration in the soil, and will eventually slow down microbial activities (Rao *et al*., 2008). Farmyard manure can also be used when seedlings are being transplanted.

3.4 Propagation and Planting of Jatropha

Seed propagation for Jatropha can be generative (direct seeding or precultivated seeds) or it can be vegetative (direct planting of cuttings) (Heller, 1996; Openshaw, 2000; Henning, 2000). For direct propagation, seeds are best sown at the beginning of the rainy season; soon after the first rains when the soil is wet, and at a depth of 2-3 cm (Henning, 2000). Seeds can be first planted in either seed beds or poly-ethylene bags that are filled with a high concentration of organic material about three months before the beginning of the rainy season (Achten *et al*., 2008). Henning (2007) suggests that intervals of presoaking and drying of the seeds can help improve germination. Under good conditions, germination occurs in about 10 days. For the establishment of plantations, direct seeding is preferred because plants are likely to become self sustaining after third rainfall season. The tap roots of directly propagated plants draw water deep underneath the surface during periods of dry weather (Benge, 2006). The germinated plants can be planted out on prepared land when they reach a size of about 30-40 cm (Henning, 2003). The pits for transplant should be kept at 45 x 45 x 45 cm; all stones and other foreign material should be removed while refilling and the seedlings should be planted at the centre of the pit (Kaushik *et al*., undated). Transplanted plants have a higher survival rate than the directly seeded ones and will produce seeds after two rainy seasons (Heller, 1996).

For establishment of a living fence or hedge, and for planting for erosion control, cuttings are favored because their rooting systems strike easily; they are more lateral and stretch to distances despite having only one pseudo tap root (Heller, 1996; Benge, 2006). Research findings on vegetative propagation tend to vary greatly. Henning (2003) recommends readily prepared cuttings for propagation to be older than one year, lignified, and be of about 60-120 cm in length. Kaushik and Kumar (2006), cited in Achten *et al*. (2008), reports that the percentage survival of vegetative propagated plants of Jatropha is a function of the source (whether the cutting was taken from top, middle, or base of the branch), and length and diameter combination of the cutting. A survival rate of 42% was found when the top of the branches were used as cuttings, while cuttings from the middle (72%) and base (88%) showed significantly better results. Their study showed that the product of the length and diameter dimensions of the cuttings they used had a positive correlation on the survival percentage as well.

In plantations that are intended for oil production, distances of 2 x 2 m^2, 2.5 x 2.5 m^2, and 3 x 3 m^2 are adequate to give plant densities of approximately 2 500 plants/ha, 1 600 plants/ha, and 1 111 plants/ha respectively (Heller, 1996). A spacing of three metres between rows of Jatropha gave no management problems for some experiments at sites that were prepared by the Central Research Institute for Dryland Agriculture (CRIDA) in India (Rao *et al*., 2008). In growing hedges for soil conservation, Openshaw (2000) recommends a spacing of 15-25 cm (4 000-6 700 plants/km within and between, *if it is to be grown for a double fence*). The greater the amount of space left between seeds when planting, the lesser the competition for moisture and nutrients, hence, the higher the seed yield (Heller, 1996; Benge, 2006).

3.5 Maintenance and Management Practices

Achten *et al*. (2008) mention weeding, pruning and canopy management as important tending practices of Jatropha. They maintain that regular weeding operations help free the fields from competitive weeds. Pruning and canopy management is believed to help in the production of more branches, and to stimulate abundant and healthy inflorescences, which will eventually enhance good fruit setting and seed yields. Experiments on pruning Jatropha plants that were done in different districts in India showed that the inflorescences, and the capsules bearing branches increase when the trees are pruned at a height of 45 cm or 60 cm. However, pruning has been accepted with mixed feelings on the same experiments as a lot of pests settled on the pruning wounds (Rao *et al*., 2008).

Despite being toxic, Jatropha is susceptible to a range of pests and diseases. The Scutellarid bug (*Scutellera nobilis*), which induces flower fall, fruit abortion and malformation of the seeds, was observed in India and Nicaragua, and it causes economic damage on sites where continuous monoculture is practiced (Shanker and Dhyani, 2006). The inflorescences and capsule borer, which causes economic damage by webbing and feeding on inflorescences as well as the blister miner (which causes noticeable damage to plants), are also common in India. Zimbabwe, with its environmental conditions that resembles almost those of the semi arid regions of Tanzania, is one of the countries in SSA where Jatropha cultivation is currently being emphasized. Openshaw (2000) reports the existence of the Golden flee beetle (*Podagrica*) in some of its parts. It eats young leaves and shoots on young Jatropha plants.

3.6 Production of Oil from Jatropha Fruits

When the Jatropha fruit is ripe, the hard black hull remains on the branches, and is ready for harvesting. Fruits are picked either by the use of pickers or they are collected on the ground after being hit with sticks. Seeds that are going to be replanted are dried in full sunshine. Those that are going to be put into an oil expeller are dried on a black plastic sheet. The removal of capsules (decapsulation) is done either by machine or by hand, and winnowing or sieving is used to separate the seeds from the hulls. Seeds can be stored for either oil pressing or for future planting. Suitable storages must be well ventilated, and be free from direct sun rays (Henning, 2004).

Jatropha processing involves the pressing of seeds to expel oil, leaving the seed cake behind. In order to produce biodiesel, oil seeds have to be first crushed to extract oil. Oil content contained in the seed of the Jatropha fruit ranges between 32-35% (by weight), the percentage tends to differ between varieties and it is also influenced by growing conditions (Von Zon *et al*., 2006). The raw plant oils are then filtered to prepare them for a transesterification (Strong *et al*., 2004). In the transesterification process, the feedstock oil is mixed with alcohol or methanol and chemical catalyst such as sodium or potassium hydroxide (Strong *et al*., 2004; Murphy *et al*., 2005). If methanol is used in the process, "methyl esters" are produced, and if ethanol is used "ethyl esters" are produced. These are used as the basis for biodiesel production. The co-product glycerin from both cases can be used in the manufacture of soap and cosmetics (DESA/DSD, 2007).

3.6.1 Jatropha Production Value Chain

An increase in the need to monitor atmospheric carbon dioxide levels as well as to provide alternative fuels, is paving a way for biofuels production processes to undergo supply chain evaluative principles. The motivation for large scale biofuels production from crops like Jatropha will need the whole production system to be grounded in sustainable economic considerations at each stage, from cultivation to distribution and usage. The costs and benefits of the production system on these scales will need to be assessed to realize the viability of engaging in such projects. The Jatropha supply chain shown on Figure 12 was developed by Caniels *et al*. (2007). Its aim was to assess the impacts of the landscape on the investment prospects of Jatropha.

There are costs and social impacts that are associated with the cultivation of biofuels crops on various scales. For Jatropha production to be perceived as a lucrative opportunity, there must be more benefits than costs. Factors that influence the decisions to develop an on-site refinery to transport the seed to off-site refinery and distribution to users, are also important for large scale commercial farmers. As is shown on Figure 13 and 14, the viability of large scale Jatropha cultivation can also be improved by the decision to set up a subsidiary seed cake refinery as outputs like biogas briquettes and fertilizer produced are useful when produced especially on-site.

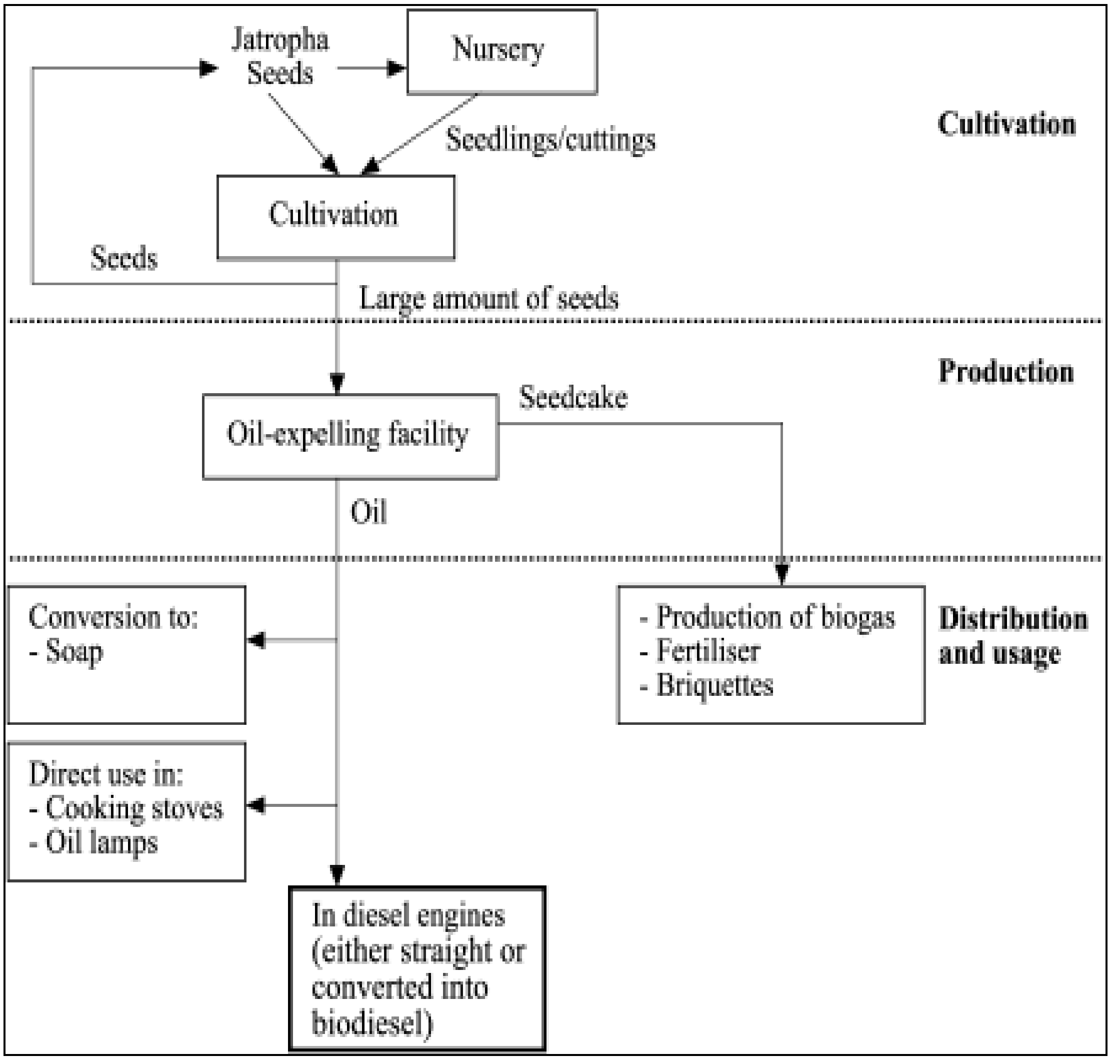

Figure 13: Jatropha Production Supply Chain (Caniels *et al*., 2007)

3.7 Crop Yield

A plant's yield is basically a function of the availability of water, nutrients, heat, its age and cultivation methods. Yield can also be influenced by factors such as number of flowering branches per season, and the genetics of the plant. Average fruit yield from Jatropha plants in literature vary widely, and ranges from around 250 g - 9 kg seeds harvested per shrub. Heller (1996) notes that seed yield is not coherent, mainly because of the incorrect explanations that were made by previous research on annual yield of individual trees to hectare per year yield. Tewari (2007) suggests that, when good sites (good soil and MAP of

900-1 200 mm) are used, a harvest of 5 t/ha/yr of dry seeds can be achieved. Francis *et al*. (2005) concur that yield varies from 0.5-12 t/ha/yr, depending on soil, nutrients and rainfall. Openshaw (2000) reports seed yield of up to 12 t/ha/yr. Jongshaap *et al*. (2007) agree to a yield range of 1.5-7.8 t/ha/yr of dry seeds.

3.8 Potential Uses of Jatropha

The potential uses of the plant are shown in Figure 14. As mentioned in the introduction, a perceived advantage of the hardy Jatropha is its capability to grow in marginal areas with a MAP as low as 250 mm (Achten *et al*. 2007). It is a fact that Jatropha is used for anti-erosion measures, either in the form of plantation together with other species, or in the form of hedges to reduce wind speed. The whole plant is used to demarcate boundaries as a protective hedge for gardens and fields. This is because the plant is not browsed by animals and it has a longer life expectancy.

In the context of this study, the question of whether the semi arid regions lands are non-limiting to the social, economic and ecological viability of Jatropha cultivation on a large scale commercial basis, is necessary to consider if emphasis is to be put to the main objective which is biodiesel production.

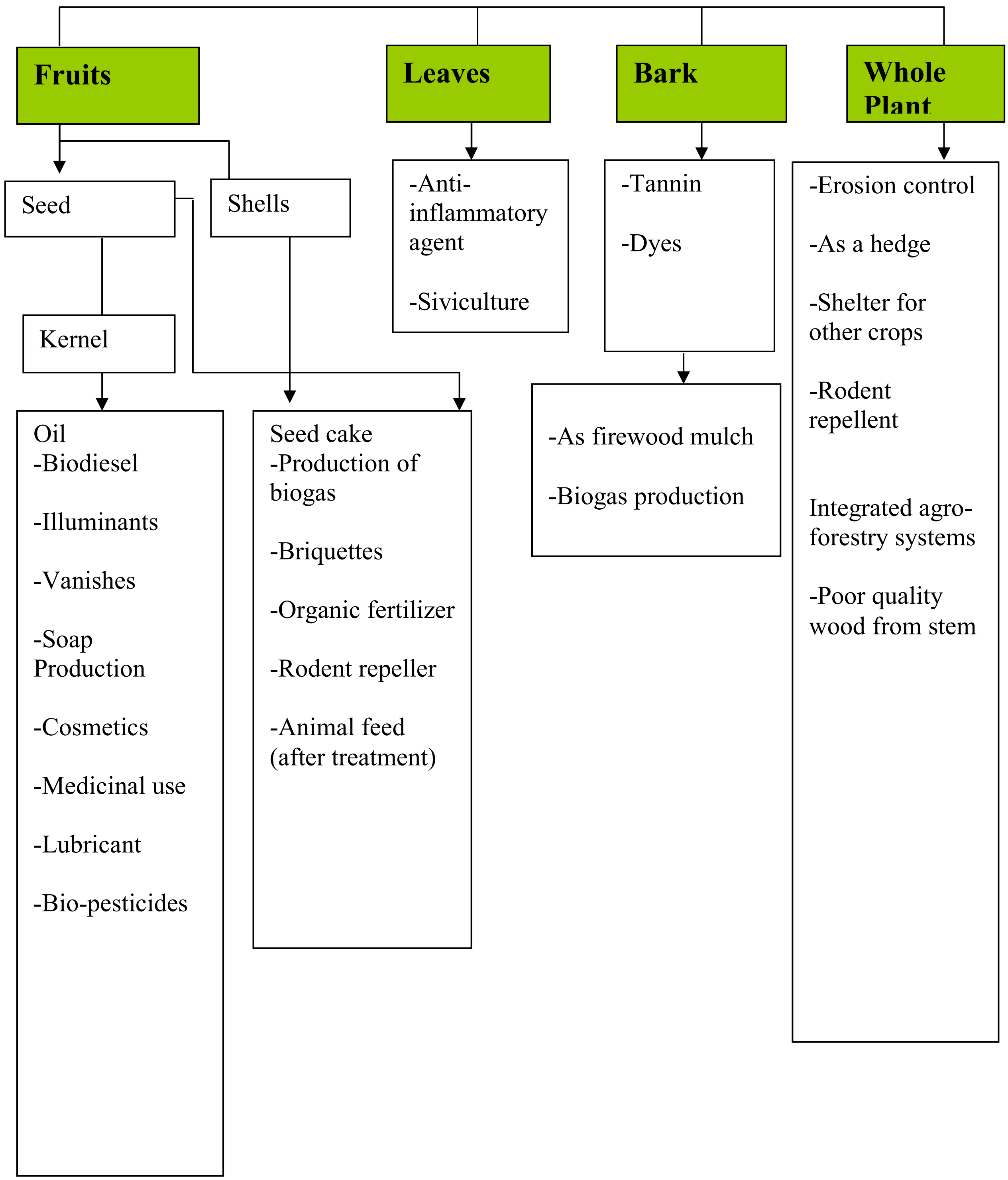

Figure 14: Several Uses of Jatropha Whole Plant (*adapted* from Gubitz *et al*., 1998)

Most parts of the plant are used for traditional medicines and today, the exploitation of Jatropha molluscicidal properties has appeared viable in the medical research fields (Rug and Ruppel, 2000). Some of the verified research on Jatropha medicinal properties have shown that the decoction[6] of leaves can be used to relieve coughs and as an antiseptic after birth. The latex has antimicrobial properties against *Staphylococcus* and *Streptococcus* and arrests bleeding. The oil has a strong purgative action and it can also be used for skin disease and for soothing pain such as rheumatics (Henning, 2003).

As is mentioned is section 3.6, the seeds of the Jatropha plant contain non-edible oil, which is used to manufacture products such as candles for lighting homes, high quality soaps and cosmetics, lubrication, and energy for industrial purposes (Jongschaap *et al*., 2007). One of the most economically viable uses of Jatropha oil has been in commercial soap production in India (Henning, 2003). As is highlighted in section 3.3.4, the products from the fruit namely the flesh, the seed coat and the seed cake are rich in nitrogen, phosphorous and potassium, which can act as soil improvers. Seed cake can also be used as a feedstock for biogas production, and the effluent of the digester will still be valuable as a substitute chemical fertilizer (Achten *et al*., 2007). As is mentioned in section 3.2.2, successful detoxification of the seed cake can also render it useful as a protein rich animal feedstock.

3.9 Bioenergy Systems in Perspective

3.9.1 Biomass and Forms of Biomass Energy

Energy that is derived from biomass is referred to as biomass energy. Fritsche *et al*. (2006:7) define biomass as, "the totality of plants in the terrestrial and marine biosphere that converts carbon dioxide, water and solar energy into an abundance of organic materials, animals feeding on plants and other animals and a variety of decomposers which transforms plants and animals and their organic wastes back into water and carbon dioxide." In this context, biomass plays an important role in the provision of shelter, ecosystems functioning, and nutrient recycling, and as an asset for economic development. A note to consider in this definition is that it does not include the material that is embedded

[6] Decoction is a pharmacology term that describes the extraction of water-soluble drug substances by boiling.

in geological formations, and which is transformed into fossil fuels. Free standing biomass in the form of woody forests (with their cellulose, lignin, hemicellulose derivations from agricultural byproducts) and the developed society's residues from the urban homes and industries are the various sources of biomass energy (Johanssom *et al*., 1993). Biomass can be burnt directly or it can be converted into solid, gaseous and liquid fuels using conversion technologies such as fermentation to produce alcohols, bacterial digestion to produce biogas and gasification to produce a natural gas substitute (Hall and House, 1995).

Fuelwood is the largest traditional biomass resource that has been used. In SSA only, its consumption stands at 61% (Johnson and Rosillo-Calle, 2007). Traditional energy sources produce a non-commercial type of energy that is characterized by low efficiency, uncontrollable heat and smoke and soot that have adverse health and environmental implications (Goldemberg *et al*., 2004; Johnson, 2007). There has been an overwhelming transition from the use of traditional energy sources worldwide, to the use of more efficient and higher quality bioenergy. The energy services for these sources are well controlled and referred to as modern bioenergy (Johnson, 2007). Demirbas (2007) described modern bioenergy as the conversion and use of biomass at higher efficiencies into more versatile energy carriers, for example electricity, liquid, gaseous fuels and process heat.

As mentioned earlier, modern biomass energy that is produced from organic matter (with two main categories being biomass wastes and energy crops) has gained momentum among world energy discussions. Kartha *et al*. (2005) suggests that this energy type can be easily converted to all energy types, i.e. electricity, gases and liquid fuels for several uses, including transport. The biomass wastes or residues define the remaining biomass after harvesting and/or after processing. This includes forest and forest products industry residues, agriculture residues (sugarcane bagasse, straws, leaves, husks, shells, manure dropping, stalks), urban organic wastes, wastes from food and agro industries (Fritsche *et al*., 2006; Johnson and Rosillo-Calle, 2007). Waste vegetable oil (WVO) has to be collected, filtered and dewatered before being used as an alternative fuel. This oil includes restaurant waste frying oils and trap grease, animal fats (beef tallow and pork lard) and float grease (from waste water treatment).

Straight vegetable oils (SVO) are produced from the seeds of the following crops: maize, soybeans, canola, rape, cotton, mustard, oil palm, sunflower, linseed and Jatropha (United Nations Department of Economic Affairs (UNDESA), 2007). According to the SADC region biofuels feasibility studies, Jatropha is ranked fifth with sugarcane, soybeans, sweet sorghum and cassava being first, second, third, forth and sixth respectively (Takavarasha *et al*., 2005). The positioning of Jatropha in this ranking was in view of the two notions (1) food security perspectives and (2) commercial cultivation. It is a fact that Jatropha can be grown on eroded land and drier parts without competing with food crops. The United Kingdom Renewable Fuels Agency review maintains that Jatropha rehabilitates eroded lands. Therefore, it is not expected to displace existing agricultural production (United Kingdom Renewable Fuels Agency (UKRFA), 2008).

3.9.2 Biodiesel

Biodiesel can be produced in three ways: transesterification, microemulsions and pyrolysis (Johnson, 2007). The first involves methanol as a catalyst, and is the most common process used in commercial production. In its neat form, 100% biodiesel is entitled B100. It can be available in a blend with both petroleum and diesel as B2, B5 and B20. B100 reduces carbon monoxide emissions by 50%, particulate matter by 30%, and B20 reduces these emissions by 20% and 22% respectively (ProBios, 2006). In Europe, rapeseed oil is the primary feedstock used to make biodiesel. In the USA, soybean oil is the primary feedstock and the raw diesel is normally blended with it to form diesel fuel (USABAQ, 2006). In India, Jatropha is grown commercially as the main biodiesel feedstock, and on a small scale it is grown for electricity generation. As is mentioned in section 1.2, the Jatropha oil that Africa produces on a small scale is also used to generate electricity.

3.9.3 Bioethanol

Ethanol is produced from any biological feedstock that contains appreciable amounts of sugar, or material that can be converted into sugar such as starch or cellulose (IEA, 2004). Cereals like corn, wheat, maize which contain starch in their kernel alongside sugar beets, sugarcane, and some trees and grasses (which contain cellulose and hemicellulose) are the basic feedstock for bioethanol production. The conversion of sugar by enzymes that are obtained from yeast *(referred to as the alcoholic fermentation)* is the most common way of obtaining bioethanol using the hydrolysis process (Demirbas, 2007). Sugarcane remains the most special and efficient feedstock of the fermentation ethanol (Blume, 1985). Its largest single use has been as a fuel additive for the transport sector. It can be blended with petrol or it can be burnt in its pure form in some recently modified vehicular engines. Biodiesel and bioethanol have been introduced earlier as biofuels but in this study, biodiesel production from Jatropha is focused on in view of the fact that the feedstock does not compete with food and feed crops, and similar to bioethanol, it can be blended with petrol.

3.10 Global Energy Supply

The world`s biomass energy consumption decreased over the past century but has currently resumed to pre-1930`s levels, and represents 11% of the total energy consumed. Its contribution is substantially larger than that of nuclear or other renewables (*Refer to Figure 15*).

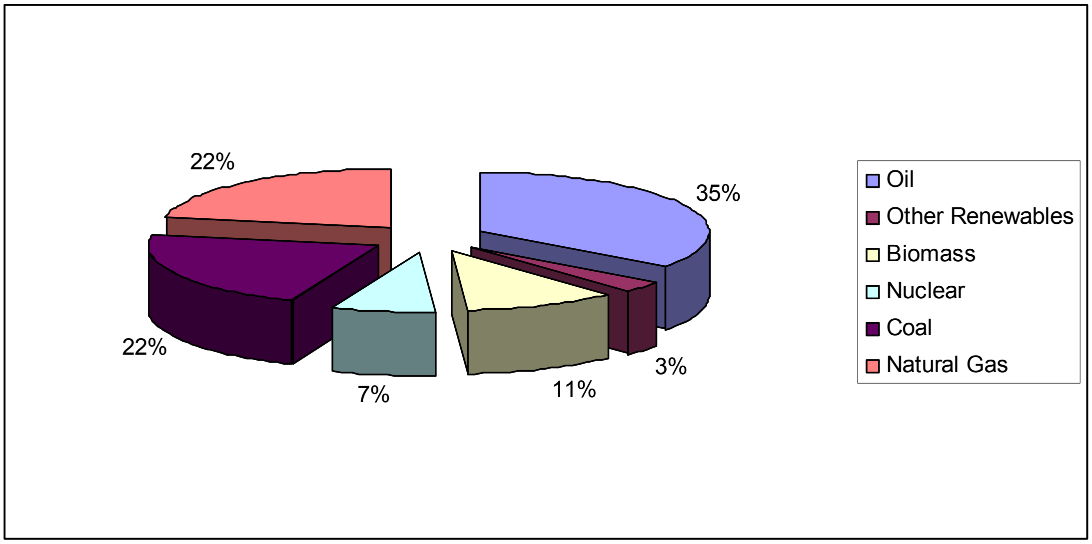

Figure 15: Global Primary Energy Consumption (Johnson and Rosillo-Calle, 2007)

3.11 Sub-Saharan Africa's Energy Perspective

34 of the world`s 50 poorest countries are found in SSA. They are characterized by low incomes, low production, poor marketing strategies, low skills, poor access to information, high child mortality and marginalization of women (United Nations Population Fund (UNFPA), 2005). Most people live in rural areas and rely on agriculture and non-timber forest products (NTFPs) or veld products for their food, fuel and medicinal requirements (International Fund for Agricultural Development (IFAD), 2007). Reliance on traditional use of biomass energy due to lack of access to modern energy has exacerbated a lot of problems (Johnson, 2007). Johnson and Rosillo-Calle (2007) note that dependence on traditional biomass energy in the sub-continent is far greater than in any other world region. Figure 16 shows biomass accounts for over 61% of the primary energy consumed in SSA. If South Africa is excluded, this figure increases to 71% (Ardayfio-Schandorf, undated).

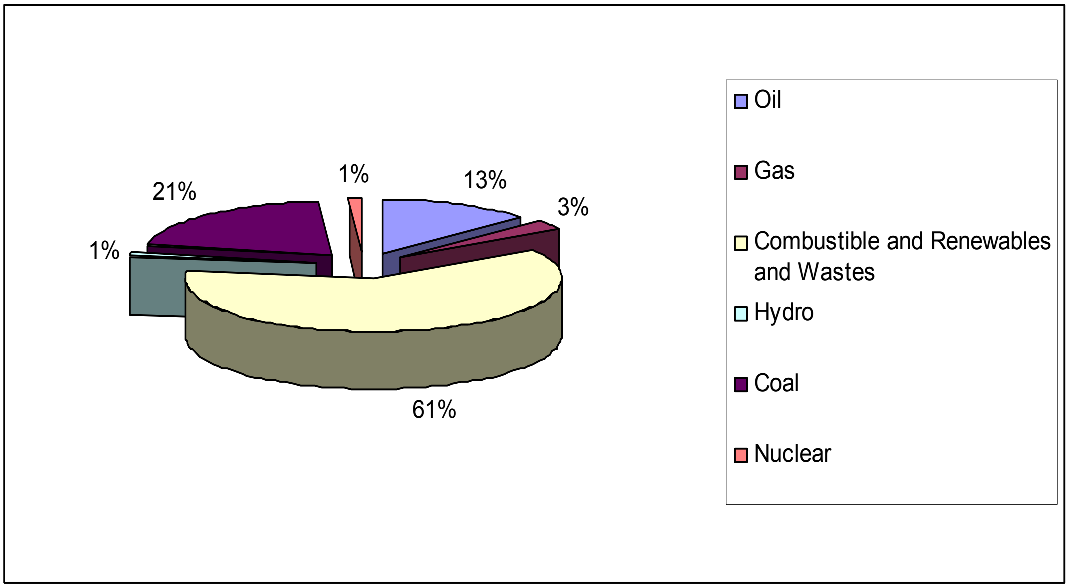

Figure 16: Primary Energy Consumption in Sub-Saharan Africa (Johnson and Rosillo-Calle, 2007)

Fuelwood is traditionally used for cooking, heating and lighting but it is not readily available. Women in rural Tanzania walk four to eight kilometers to collect firewood three times a week, four to five hours each time, to carry home 10-20 kgs of fuelwood (Shuma, 2006). The use of the open fire method in many homes increases the emission of smoke and toxic gases (e.g. carbon monoxide, hydrocarbons, nitrous oxides and sulphur oxides) that are generated by using inferior stoves. The poor indoor air quality due to smoke inhalation continues to subject the rural households to long term health complications (Goldemberg *et al*., 2004). Premature deaths are also on the increase in SSA. Johnson (2007) asserts that the introduction to cleaner modern biomass energy forms, such as biogas, bioethanol, biodiesel and biogel could go a long way to addressing several of the region's health and safety issues. Smeets *et al*. (2004) concluded that, in comparison to any other region in the world, SSA has the greatest potential for bioenergy production.

SSA is between six and seven percent of the world`s proven resources of oil, gas and coal, a 17% share of the world`s untapped hydropower, many promising wind and geothermal sites; abundant sunshine, and a variety of plentiful biomass resources (SEI, 1999). Karekezi

(1995) estimates that 80% of SSA`s oil, and 76% of its natural gas reserves are in Nigeria and Angola, and 88% of its bitumous coal reserves are found in South Africa. The coal reserves that are in South Africa are expected to last for 300 years (Adaryfio-Schandorf, undated).

The existence of available land portions in developing countries, usually dubbed the South to include SSA countries, has attracted researchers from industrialized nations (referred to as the North) who are looking for sustainable ways of fueling their economies. The North desperately needs biofuels as a way of dealing with greenhouse gas emissions and the imminent peaking of oil supplies, while the South have the capacity to build new industries around biofuels and provide "rivers of fuels" to the North. Mathews (2007) maintains that, to meet these concerns, countries of the North are supposed to negotiate a Biopact trade agreement with countries of the South. Based on this notion, a Biopact between the OECD countries representing the North (market regions) and developing countries representing the South (the biofuels source regions) was initiated. It is expected to institute a system that works within the World Trade Organization (WTO) and this will favor sourcing the North's fuel needs from the South suppliers (Mathews, 2007). The Biopact between the North and the South is expected to be one way of redistributing wealth between the rich and the poor nations that are across the globe through bioenergy initiatives while it will be helping to solve the problems of global warming and energy security in the developed nations. Watson (2009) suggests that supplying this market promises many opportunities particularly to the developing countries, such as creating rural employment, earning foreign exchange, addressing deforestation, rehabilitating degraded lands, and improving marginal lands.

3.12 Implication of Biofuels to Sub-Saharan Energy Situation

Despite the various advantages that biomass as a fuel source has, the establishment of any large scale crop production, is not without its own consequences. As is mentioned in section 3.6.1, there is always a need to consider the production of biomass energy crops versus the costs that will be incurred through developing infrastructure (Hall and House, 2005; Jongschaap *et al*., 2008). Hennenburg and Fritsche (2008) note that the magnitude of the impacts of the production of a biofuels feedstock are greatly influenced by the feedstock chosen, the area where it grown, and the cultivation practices. Furthermore, Diaz-Chavez and Woods (2008) note that such production can have detrimental impacts of biomass on biodiversity, hydrology, soils and landscape. Several implications of large scale cultivation of bioenergy crops in SSA are highlighted below using case studies.

3.12.1 Land Availability

The production of food, NTFPs and biofuel feedstock production (BFPs) require the same set of resources, i.e. they both require land. NTFPs play a major role in rural livelihoods and if converted to BFP, they may adversely affect access to NTFPs. Fritsche *et al*. (2006) maintains that the land use effects of bioenergy cropping systems must be considered, with reference to current land use. It should, therefore, be noted that land only becomes available for biofuels cultivation once biodiversity, key examples of ecosystems functioning, food, and rural livelihood have been catered for. On a global scale, the production of biomass fuels can be done on eroded lands and surplus lands. This can make a significant impact on atmospheric carbon levels without impinging on food production (Hall and House, 2005). An example is India, where cultivation of Jatropha on eroded lands has managed to green the formerly waste lands. Matthews (2007) suggests that there are vast tracts of eroded lands in the desert margins of the South that can be put to productive use. As is highlighted in section 3.11, a Biopact with the North is expected to ensure BFPs in the South do not infringe on lands that are currently under agriculture, and will rather help curb deforestation and regreen the deserts (Mathews, 2008).

According to Mathews (2007) responsible cultivation is a way of balancing the production of bioenergy crop with available resources like fertilizers, water for irrigation, herbicides and pesticides, without impacting upon the available ecosystems functioning at a site chosen. In Brazil, the production of nearly 20 billion l/yr of ethanol on just over two million ha of land has been made feasible by the use of the high yielding varieties of sugarcane (Sparovek *et al*., 2007). Sugarcane has been expanded to former extensive pasture lands that that were degraded. Fritsche *et al*. (2006) claims these degraded lands have now been improved by the cultivation of sugarcane. This is contributing to an improvement in the soils` physical and chemical conditions, and these areas have been opened up to Brazilian agriculture.

3.12.2 Influence on Food Security

While food and fuel are both important requirements, they need not to be in competition. The production of biofuels by small holder farmers could improve their household incomes and, at the same time ensure household food security (Takavarasha *et al*., 2005). An example is Jatropha. When grown on eroded lands, and when harvested for bioenergy production, it can add new income sources to farmers. However, a key sustainable development concern is that biofuels, especially when grown on a large scale, may divert agricultural production away from food crops and drive food prices up. This sustainability issue has given rise to the 'food versus fuel debate' among a lot of stakeholders. The assertion is that large scale energy crop cultivation may compete with food crops in that (a) it will require a change in land use, (b) needs more investment, (c) needs infrastructure support (d) increases pressure on the existing water resources and (e) requires fertilizer procurement to boost yield (DESA/DSD, 2007). Johnson and Matsika (2006), Watson (2007) and Watson (2008a) filtered out land that is currently under biodiversity and food cultivation in order identify land in southern Africa that is suitable for sugarcane cultivation. The findings clearly suggest that there is plenty of land for harnessing sugarcane's biofuels potential in the region.

The rise in the demand for food, and the subsequent increase in food prices, has been lobbied by some that it actually is directly linked to the rise in the demand for biofuels. On another note, food shortages are caused more by distribution problems, a lack of purchasing power, bias towards the production of exports crops, the use of food and land for livestock production; underutilized agricultural production potential, political issues, and (in Africa particularly) war and drought (World Resource Institute (WRI), 1990). As is indicated in section 3.12.1, responsible cultivation can help reduce some of the maladies that are associated with bioenergy cropping. In Brazil, for the period 1996-2006, there has been a substantial expansion of 1 330 202 ha in the area of sugarcane from an area of 4 814 084 ha to 6 144 286 ha (Sparovek *et al*., 2007). Crop rotation in sugarcane producing areas has led to an increase in certain foods, while the by-products are being used for animal feed. Jatropha, the focus of this study, represents an even lesser threat to food security than other biofuel feedstocks because it can be grown as hedging or intercropped as feed cake as fertilizer (Openshaw, 2000). It can also be intercropped with food crops (Francis *et al*., 2005; Van Eijck and Romijin, 2006).

3.12.3 Bioenergy Cropping vs. Biodiversity Loss

Integrating BFP with the restoration of degraded land can lead to direct effects, which are negative (UKRFA, 2008). Fritsche *et al*. (2006) maintains that, depending on spatial distribution and cultivation practices, bioenergy cropping results in (1) loss of habitat, (2) extinction of rare species, (3) obstruction of migration patterns and corridors, and (4) degradation of soils and water bodies. According to UKRFA (2008), habitat destruction is significant from a greenhouse gas perspective because the subsequent change in land use result in a significant release of carbon to the atmosphere. In South America, the clearing of forested areas for soybeans cultivation has triggered habitat loss and biodiversity loss (Jongschaap *et al*., 2008). When BFPs are providing environmental benefits, for example a healthy biodiversity and ecosystems are well-functioning, impacts are usually positive.

The UKRFA (2008) also reviewed biofuels' associated indirect effects. The effects include the following examples: (1) the expansion of sugarcane production in Brazil, (in part for biofuels) has led to the displacement of cattle ranching and accelerated deforestation in the Amazonia, (2) the expansion of soybeans production in the South and Latin America has been as a consequence of the USA farmers increasing the production of maize the meet their bioethanol targets, and (3) an increase in the demand for prices of rape seed oil for biodiesel in the EU has been linked to the expansion of oil palm production in South East Asia. Therefore it must be noted, that, like the previously discussed direct effects, indirect effects also have consequences on greenhouse gas emissions that are critical to the atmosphere. In order to reduce greenhouse gas emission from the transport industry, careful planning must ensure both ecological conservation and sustainability of the biofuels feedstock production methods (Hall and House, 1995).

3.12.4 Influence on Water Bodies

BFPs on eroded areas can improve ground water replenishment and surface water health. When grown on marginal lands and on flood plains, BFPs help reduce nutrient runoff that threatens aquatic ecosystems. On another note, Kartha *et al*. (2005) maintains that biomass activities can increase water use. The exacerbation of local water supply concerns and environmental impacts upon water are some of the direct effects that rapid expansion in the demand for biofuels can have (UKRFA, 2008). To enable high and multiple yields of biofuels crops, large scale irrigation is expected to be constructed. Large scale irrigation increases chemical loading which threatens the quality of fresh water. Johnson and Matsika (2006), cited in Watson (2009), note that non-recycling of water in ethanol plants and discharge of vinasse into rivers is also slowing down the efforts to save water that is required to meet biofuels demands. Jongschaap (2008) laments that, the hype in commencement of large scale Jatropha production on fragile zones like degraded lands can have near and long term impacts on groundwater reservoirs.

3.12.5 Impacts on the Atmosphere

A key motivation touted for BFP is that biofuels are environmentally friendly when compared to the conventional fossil fuels. BFP utilize carbon dioxide that the fossil fuels release. In Brazil, the abolishment of preharvesting field burning has had significant environmental benefits in the sugar plantations and the country as a whole. This was because field burning increased the risk of forest fires, and a lot of greenhouse gases were being released to the atmosphere (Pinto *et al*., 2005 cited in Fritsche *et al*., 2006). Sustainable BFP is only possible when positive effects to air quality have been reported (Fritsche *et al*., 2006). It is important to note that negative indirect effects of BFP to air quality depend on the type of land cover that is converted. A lot of the carbon that is stored in soils is usually released when 'virgin' soils are tilled. The UKRFA (2008) maintains that it is important to avoid significant emissions that result from land use change, and use of inappropriate technologies if greenhouse gas savings are to be determined from BFP.

On the contrary, BFP is not necessarily carbon neutral. This is because fossil fuel energy is utilized in the cultivation process, and when seed and produce is transported to the field and to the processing plant and market respectively (Fritsche *et al*., 2006). The excessive use of fertilizers and pesticides that is associated with monoculture encourages the pollution of the air, land and water bodies.

3.12.6 Socio-economic Impacts

To the rural farmers of the developing countries, bioenergy production can help promote rural development. This is because it provides the most needed employment, and open up avenues to income generation (Rossillo-Calle, 2004; Kartha *et al*., 2005). Rural households have limited access to basic energy services for lighting homes, for cooking, and for adequate heat. In SSA, it is expected that, if well properly managed, they have the potential to provide communities with multiple essential energy services such as electricity for lighting, energy for small appliances for battery charging, income generation and education activities, energy for pumping water, energy for cooking, and also for the transport sector (DESA/DSD, 2007). It is important to note that different impacts depend on whether the cultivation of BFP is on a small or large scale. In the case of the latter, whether people have to be moved to make way of BFP, is one of factors that must not be underrated.

An example is the promising and currently exploited uses of *Jatropha curcas* L in Zimbabwe where the oil was expected to promote rural agro-industrial development through the manufacture of soap, candles and lubricants. In 2004, the Government of Zimbabwe further declared the *Jatropha curcas* shrub as a specified plant, which should be promoted to harvest seed from for the processing into oil for biodiesel production (Tigere *et al*., 2006). This has resulted in the massive promotion of the growing of the shrub across the whole country particularly by small holder farmers as live fences around homesteads and gardens, and large scale commercial farmers are now venturing into the cultivation of this crop too. Some small holder farmers have grown Jatropha for at least four decades in

Tanzania (Watson, 2009). It is mainly grown as a barrier plant and candle and soap production that has begun on a small scale basis with the help of NGOs (Van Eijick, 2007).

Bioenergy perspectives, when accessed at grassroots level, could potentially raise the hopes of mainly women and children in developing countries who always have to trek for long distances to obtain the basic fuelwood (Goldemberg and Coelho, 2004). The drive towards clean fuels is also expected to release children from the duties of searching for firewood, thus enabling them to get an education - one of the key drivers of poverty eradication.

Energy security and economic development are threatened by the persistent fuel price increases. Biofuels could stimulate agricultural investments and could lead to the creation of new markets for the SADC region, thereby raising hopes for the farmers in the tropics (Takavarasha *et al*., 2005). Reducing the volume of fossil fuels that are currently imported into the SADC regions has the potential to benefit governments as they will be less dependent on the fluctuating foreign exchange rates. Investing in BFP will also enable these nations to have foreign currency savings (Takavarasha *et al*., 2005).

The decision to develop a large scale BFP for SSA is not without demerits. As this will be accompanied by intensive cash crop cultivation, mechanized harvesting and production chains, small holder farmers are less likely to benefit, as a few agro-energy industries are likely to dominate (DESA/DSD, 2007). Socio-economic disparities are more likely to continue in areas where there will be bioenergy production. It is, therefore, necessary to assess the sustainability of bioenergy production in regions where it is supposed to raise the standards living.

3.13 The Road to Sustainable Development

In the Biopact for the North and South (discussed in section 3.12.1), the developing countries of the South are expected to grow bioenergy crops under the close monitoring of sustainability criteria. The North is expected to be the market for these crops and will only procure land area from those nations that would have met the several criteria (Mathews, 2007). The main aim of this plan is to ensure sustainable development through the utilization of bioenergy crops. A lot of questions can be raised on the contents of these sustainability criteria, which the South producing nations are expected to abide by. Among them are the questions of (a) which biomass energy feedstock is the best candidate?, (b) what scales of production are the most promising?, and (c) what economic and environmental effects does the biofuel feedstock have that merits its choice for cultivation on the chosen scale of preference? Diaz-Chavez and Woods (2008) compiled a list of environmental criteria that are contained in a number of proposals for standards and the systems that are available for bioenergy cropping. These include:

- Biodiversity and natural ecosystems
- Water (efficient use, conservation and pollution)
- Soil conservation and maintenance
- Crop management
- Waste management
- Landscape impacts

However, the international effort into the development of criteria and indicators for sustainable bioenergy production clearly recognizes that bioenergy production must not be at the expense of biodiversity and food security. This has raised debates on whether is it necessary to have sustainability criteria or rather have biofuels policies, which consider a range of issues including production, logistics, linkages, outreach, technical assistance, end user acceptance and pricing (DESA/DSD, 2007). It is also recognized that this policy formulation will have to be done by government alongside the small scale local producers. They will also ensure that the local households, communities and businesses benefit from the energy services through the associated income and job opportunities.

3.14 Conclusion

The extent of expertise on where and how best to cultivate Jatropha have been outlined in this chapter. Potentially, Jatropha has many uses and environmental and socio-economic benefits. Compared to other feedstocks, it has less negative impacts, particularly at small scales. The next chapter outlines the methodological approach and data type the study used.

Chapter 4
Methodology

4.1 Introduction

The chapter prior to this gave in-depth background characteristics of Jatropha, its requirements as well its potential environmental and socio-economic benefits. This chapter describes land use planning and land evaluation as the main methodological approach, and Remote Sensing and Geographic Information Systems as the main tools, that the study used to identify optimal locations for Jatropha cultivation in the semi arid regions of Tanzania. The overview of the methodology, the data sources and how they were used, are described in the sections that follow. Multi-criteria analysis, as a tool that was used to rank the three largest and available areas, is also described and in ending the assumptions and limitations of the study are highlighted. The aim and objectives of the study, the availability of relevant data from several sources, and the available computer software packages influenced the methodological approach that was used for this project.

4.2 Land Use Planning and Land Evaluation

The continued increase in the world`s population and in the degree of consumerism means that the demand for food and fuel continues to increase at an exponential rate. These demands will have to be met from the same land, thus it is necessary to plan and evaluate the suitability of land portions for BFP. In this instance, the main objective of land use planning is to identify and create a prerequisite to achieving a type of land use that is socially desirable, environmentally compatible and economically sound (Betke *et al*., 1999). The FAO Guidelines for Land Use Planning (FAO) (1993:1) defines land use planning as, "the systematic assessment of physical, (land and water potential), social and economic factors so as to assist land users in selecting options that increases productivity, and are sustainable and meet the needs of the society." Land evaluation is a key tool for land use planning, either by individual land use planners (e.g. farmers), by groups of land users (e.g. villages, wards), or by the society as a whole (as represented by governments).

In the context of land use planning, land evaluation exists to provide answers to decision makers who, in some sense, plan the use of the land (Rossiter, 1996). Land evaluation may be defined as the process of assessment of land performance when [the land is] used for specified purposes (FAO, 1985). This approach, based on the matching of different land units in a specific area, with the requirements of actual or potential land use, is referred to as Land Utilization Types (LUT). Each LUT is composed of several attributes and these include crop information such as cultivation practices, input requirements, crop calendars, utilization of main produce, crop residues and by products.

4.2.1 Remote Sensing

Remote Sensing centers much on the gathering of information or data at a distance from a large area of the Earth's surface on large volume of the atmosphere, and in a short space of time (Rees, 1990). Campbell (1996) defined it as the process that derives information about the earth's surface, i.e. can be an object, area or phenomenon, but without coming into physical, intimate conduct with the features under surveillance. The main source of remotely sensed data is the electromagnetic radiation, and the examination of any images that are acquired by it ultimately depends on the differences in brightness of objects and features (Campbell, 2002). A difference in brightness of objects is a factor of reflectance emmition and absorption of energy, usually in the form of electromagnetic radiation. Electromagnetic radiation is the energy that is propagated through space or through material media in the form of an interaction between electric and magnetic fields, and these usually move at the speed of light. The electromagnetic spectrum is a continuum of energy waves of the same speed but with different wavelengths and frequency. The main regions that are used in Remote Sensing ranges from shortwave gamma to long radio waves. For pattern recognition in research that uses remotely sensed data, an object must have a spectral signature. A spectral signature is a radiative transfer pattern of emission and reflection in specific regions of the electromagnetic spectrum (Campbell, 1996). Remote Sensing tools can be used to study things on all scales, ranging from the smallest particles with the atom to the universe as a whole. In this project, digital elevation data and land cover data that were used, are examples of remotely sensed data.

4.2.2 Geographic Information Systems

Skidmore (2002:5) defined Geographic Information Systems (GIS) as, "a computer-based system for the capture or input, storage, retrieval, analysis, output and display of geographic or spatially indexed data." GIS functions through a five-step Input-Output Process, beginning with data input via computer hardware and software into a system of data management, data processing, analysis and modeling, and data output. Data input includes the capture and integration of spatial and non-spatial data from a variety of sources including paper maps, aerial photographs, satellite images and land use. Data is digitized or scanned and often combined with existing digital data to build useable databases of information. GIS consists of two elements, i.e. spatial data (points, polygons and lines), non spatial and attribute data that describes the characteristics of the spatial features. Data processing involve the transformation of projection and coordinates data onto a two-dimensional plane surfaces and the conversion of spatial data into points, lines, areas, networks, and surface (Skidmore, 2002). Once the data is processed, GIS allows for qualitative and quantitative analysis through a variety of tools including overlays, query, measure and proximity analysis to be done at various scales of preference.

4.3 Overview of the Methodology

Following the methodology flow diagram in Figure 17, the methodology followed was follows: There were three layers that the study used. These were (1) the delineations of the semi arid regions of Tanzania, (2) the agro-ecological sub-zones suitable for Jatropha, and (3) delineations of the administration regions within Tanzania. The semi arid regions of Tanzania were extracted by GIS techniques from the SSA`s arid and semi arid regions COMPETE maps of Watson (2008a). Administrative regions of Tanzania that fall within the semi arid areas were delineated. Agro-ecological sub-zones with Jatropha potential within the semi arid regions were digitized and a new database was created. Agro-ecologic sub-zones were verified as suitable against literature on what is suitable for Jatropha and then delineated in the semi arid regions. Unavailable and/or unsuitable areas for BFP, according to Watson (2008a), were overlain on agro-ecological zones suitable for Jatropha. In ending, multi-criteria analysis was used to rank the BFP potential of the three areas.

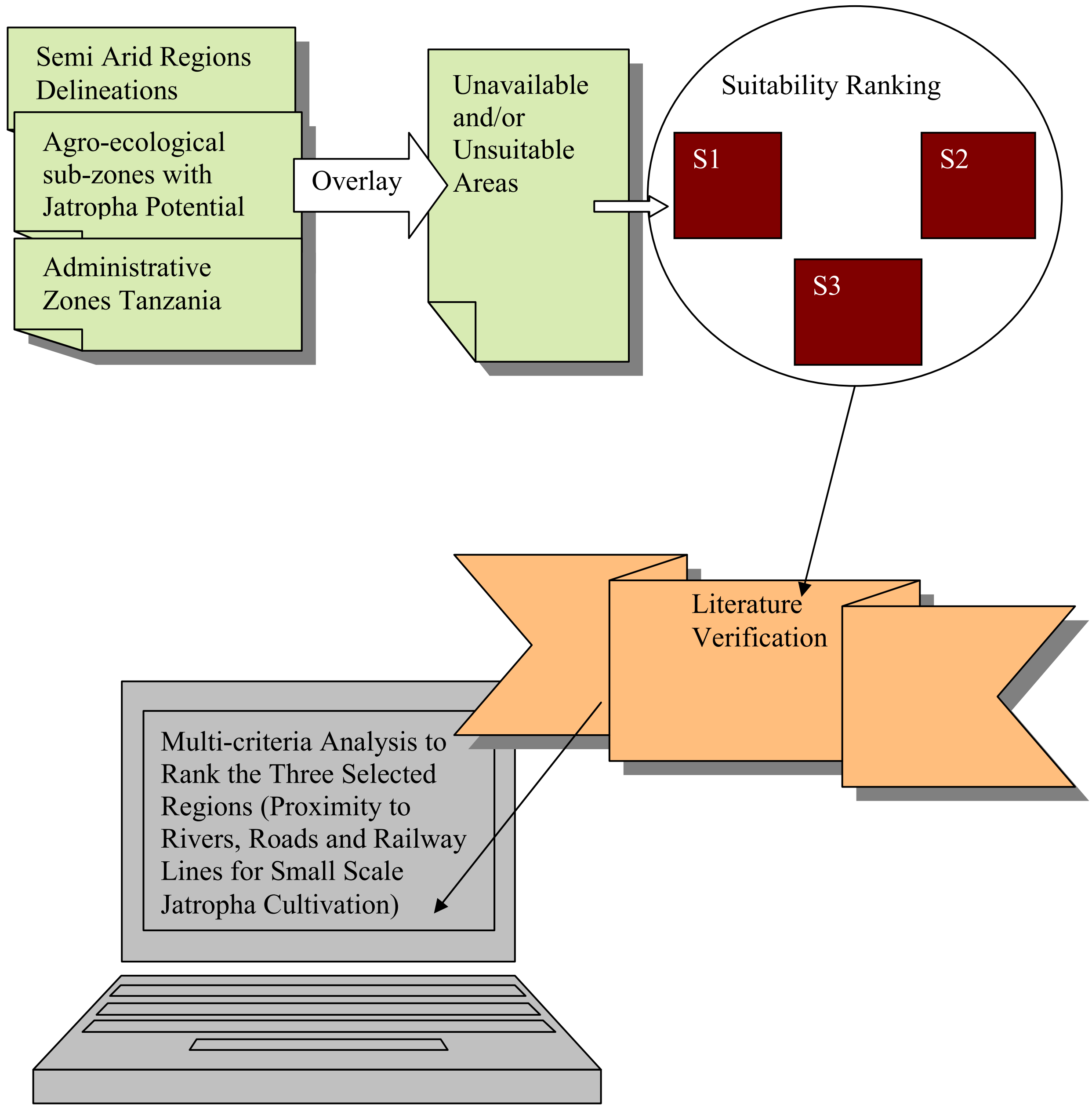

Figure17: Methodology Flow Diagram

4.4 Data Sources and Use

4.4.1 Semi Arid Regions

The major inputs to the study were the delineations of Tanzania semi arid regions. These were obtained from the work of COMPETE by Watson (2008a). She aimed to identify land in the arid and semi arid regions of SSA where intensification of, or conversion to ,bioenergy use on the scales necessary to supply significant shares of national and global energy provision, will not have detrimental environmental and/or socio-economic impacts. The first step in the methodology devised to meet this aim was to decide which of the data sources depicting the spatial extent of arid and semi arid regions in Africa were most accurate. She interrogated different data sources depicting the spatial extent of arid and semi arid regions in Africa. The range of sources that were interrogated gave differences in the area of these regions of up to 16%. The World Meteorological Organization and United Nations Environment Programme (WMO/UNEP) (2001) delineations were finally used, as they appeared to be the most accurate. The ESRI (2006) Africa and African country shape files were used as input layers, and the arid and semi arid regions in all the SSA countries were digitized and produced as a map.

4.4.2 Agro-ecological Zones

De Pauw (1984: 31) defined agro-ecological zones as "natural physical regions which are sufficiently large to be mapped at the scale of 1:2 000 000 and are sufficiently uniform in climate, physiography and soil patterns for generalized descriptions and evaluation of the agricultural potential and constraints to be meaningful." Having explained what agro-ecological zones were, he then produced a map showing these regions in Tanzania. The Agricultural Research Institute-Mlingano Agricultural Research Centre (ARI-Mlingano1) (2006) further used the results of De Pauw (1984) to perform a crop suitability assessment for the whole of Tanzania. They produced an agro-ecologic sub-zones map of Tanzania and a crop suitability table. Crop suitability, an acronym for land evaluation, is used define an approach for rating relative quality of land resources based upon specific measurable features such as pH, rainfall, altitude and temperature, and matching the related land quality with crop requirements (ARI-Mlingano1, 2006). Soil physiography and agro-ecological zones data from the work of De Pauw (1984) as well as literature was the basis for the crop suitability. Special emphasis was placed on crop adaptation and sound growth (ARI-Mlingano1, 2006). The seven major agro-ecological zones that were obtained according to this classification were C, E, H, N, P, R, U and W, and each of these regions was further partitioned into several sub-zones in Tanzania.

The agro-ecological zones representation of Tanzania, in picture format, was obtained from ARI-Mlingano1 (2006). The picture was imported into a GIS, the semi arid regions template was overlain on it, and agro-ecologic sub-zones within the semi arid regions of Tanzania were digitized. Digitizing is a process that encodes geographic features on paper to digital form as x, y coordinates in order to create spatial data from existing hard copy maps and documents. In this study, digitizing was done onscreen in conjunction with editing tools that are found in ArcMap 9.2 software (ESRI, 2007). There were 31 agro-ecological sub-zones in the semi arid regions, and nine of them were mentioned in literature as having potential for Jatropha cultivation. A database for the information of the agro-ecological sub-zones that have Jatropha potential was, therefore, created in a GIS alongside the new output shape file. De Pauw (1984) argues that agro-ecological zones may not answer all the questions that are related to agricultural potential and constraints with reference to a specific crop and cultivars but they can enable the creation of mapping units that are detailed and quantified for the evaluation of potential and constraints of cultivating a particular type of crop in a land unit.

According to FAO (1976) land suitability evaluation is in principal specific to specified land utilization types. All crop requirements are specific and there is no common crop requirement for rainfed agriculture. In this study, the crop Jatropha was selected as a standard for land suitability evaluation for large scale cultivation for bioenergy cropping in semi arid regions of Tanzania. Data on crops that can be grown in Tanzanian agro-ecologic zones was obtained from crop suitability assessment work of De Pauw (1984) and ARI-Mlingano1 (2006). Information on Jatropha for use when comparing land qualities that were mapped for suitability evaluation purposes was gathered from several literature sources that have been reported in sections of the previous chapter such as temperature, rainfall as well as soil requirements.

Although terrain slope can be a governing factor of suitability of an area for sprinkler irrigation, its constraints depend on the finances available. The GTOPO30 Digital Elevation Model dataset was used to evaluate terrain slope on the agro-ecological sub-zones with Jatropha potential. The dataset was developed over a three year period by the US Geological Survey's EROS Data Centre (EDC) with funding and data contributions from the National Aeronautics and Space Administration (NASA) as well as several survey institutions databases. It is one of the packages that are available from the ESRI Data and Maps 2006 media kit, an accessory that is included in the ESRI ArcGIS 9.2 software package. It is a global elevation dataset covering the full extent of latitudes from 90 degrees south to 90 degrees north, and the full extent of longitude from 180 degrees west to 180 degrees east. The horizontal grid spacing is 30-arc seconds (0.0083 degrees) equivalent to one kilometer spatial resolution. The horizontal coordinate system is Geographic, and is referenced to the World Geodetic Survey system of 1984 (WGS84). The vertical units represent elevation in metres above mean sea level (m.a.m.s.l) (ESRI, 2007).

The terrain slope characteristic, i.e. percentage rise, was checked because terrain suitability is one of the important factors that need to be considered for sustainable agriculture. In this perspective, Sys *et al*., (1993) notes that areas with a percent slope of more than 16% are limiting to sustainable agriculture, have implications to manual harvesting and machinery use, and are also prone to soil erosion and runoff. Percent slope analysis was performed using the Spatial Analyst GIS analysis tools, and the raster calculator calculated and filtered out all the pixels that represented slopes with the percent rise exceeding 16%. In this study, percent slope rise calculation was aimed at obtaining slope variability for use of machinery and for further considerations on water transportation.

4.4.3 Administrative Zones-Global Administrative Areas (GADM)

Watson (2008a) designated cities from the GLC2000 database as unsuitable for BFP. In this study, it was considered as primary data and it was, therefore, necessary to have a database with more detail. A detailed database for administrative areas was extracted from the Global Administrative Areas (GADM, version 0.9) database. GADM, designed for the BioGeomencer project, is a database of the location of the world's administrative areas and countries` lower level subdivisions (boundaries). It represents the spatial features of these administrative areas in an ESRI shape file and geodatabase format. The spatial features of these administrative zones are in ESRI shape file format. Tanzania has 21 administrative boundaries, so the GIS overlay function was used to extract the administrative zones that are within the semi arid regions of Tanzania.

4.4.4 Unavailable and/or Unsuitable Areas

The International Union for Conservation of Nature (IUCN) (2004) defines a protected area as "an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means." The United Nations Environmental Programme World Conservation Monitoring Centre (UNEP-WCMC) working in collaboration with governments and non-governmental organizations used this definition to record protected areas information in the World Database on Protected Areas (WDPA). The WDPA consists of numerical and spatial attributes of more than 100 000 sites (marine and terrestrial) that are scattered in about 12% of the Earth's surface (Chape *et al*., 2005). The sites range from tracts of forests, mountains, wetlands, coral reefs, deserts to water bodies like lakes, oceans and rivers. Their management is of value to the surrounding communities for they act as a source of livelihood and their preservation is of much importance to education and research, monitoring for change detection purposes, and compilation of inventories and are also important for generations to come. A lot of international environmental agreements, including the Kyoto Protocol, the Convention on Biodiversity, the Convention to Combat Desertification and the Ramsar Convention on Wetlands, have placed global change at the top of their agendas (scientific and political). They require data such as this found in the database for world protected areas, as it has a unique set of information in the form of insitu data, models and remotely sensed data, and this is useful for implementation, monitoring and compliance (McCallum *et al*., 2006).

Di Gregorio and Jansen (2005) defined land cover as the observed (bio) physical cover on the earth's surface. This definition is confined to the description of vegetation and man-made features, besides the efforts by scientists to include areas, which are covered by water bodies, bare rocks or bare soils in this description. There are four satellite derived global land cover datasets, namely the International Global Biosphere Project (IGBP), the University of Maryland (UMD), the Global Land Cover 2000 (GLC2000), and Moderate Resolution Imaging Spectroradiometer (MODIS). The GLC2000 dataset was produced by the Global Vegetation Monitoring Unit of the Joint Research Centre of the European Union in collaboration with partners around the world (FAO/IIASA, 2007). The objective of the GLC2000 project was to provide a global harmonized land cover database for the year 2000, a reference year for environmental assessment, and in particular the United Nation's Ecosystem-related International Conventions (Fritz and See, 2005). It is based on land surface observations that were made by the *Satellite Probatoire d'Observation de la Terre* (SPOT) 4 between 1 November 1999 and 31 December 2000 (Mayaux *et al*., 2003). The Spot Vegetation sensor provides daily observations of the global land surface and these have a spatial resolution of one kilometer. The sensor was in a sun-synchronous orbit, crossed the equator at 1030 am at an altitude of 822 km and had four bands; the blue, red, near infrared and short wave infrared that were each corresponding to a different camera and optical system (Bartholomè and Belward, 2005). From around the world, partners from 30 research teams, based in 19 production regions, collaborated in harmonizing and categorizing of the 14 months of daily global data to produce this global dataset (FAO/IIASA, 2007).

The product presents a greater level of detail than the MODIS product (22 classes for GLC2000 vs. 17 classes for MODIS product) and has a better accuracy. A number of experts have visually validated it and it has gained an overall positive response. The partners used the Land Cover Classification System (LCCS) nomenclature that is used by FAO and UNEP, and this was meant to ensure consistency between regional classifications (Di Gregorio and Jansen, 2005). The LCCS is a comprehensive, priori classification system that describes land cover according to a hierarchical series of classes and attributes. Giri *et al*. (2004) suggest that the direct involvement of local experts help brought in critical knowledge and experience. Fritz *et al*. (2003) compared overlapping regions between Eurasia, Asia and Europe and found a maximum agreement of 64.26%. However, Hannerz and Lotsch (2006) found significant differences in estimates of areas under cropland in Tanzania viz: - 25.1% of the country or 22 695 000 ha using GLC2000 and 4.2% or 3 972 000 ha using MODIS. Hennenberg and Fritsche (2008) maintain that it is necessary to select a land cover classification scheme that have world wide applicability and can be further specified to capture local requirements. They concluded that the GLC2000 is more accepted because of the hierarchical LCCS that was used. McCallum *et al*. (2006), in their comparison of four satellite derived 1 km global land cover datasets (IGBP, UMD, GLC2000 and MODIS) concluded that, Remote Sensing is a means of producing more consistent, repeatable and unbiased products than were previously possible with traditional ground-based methods. However, from the results obtained they forewarn that users need to exercise caution when deciding on a particular product of global landcover datasets to use.

As Chapter Three specifies, the most criticism for BFP is its potential to detrimentally impact biodiversity food security and rural livelihoods. As a precaution against detrimental impacts on biodiversity, all categories of protected areas from the protected areas database were designated as unavailable for BFP by Watson (2008a). The GLC2000 database was also used by Watson (2008a) to determine the unavailable and/or unsuitable areas for bioenergy crop production. As a precaution against impacts on biodiversity, closed canopy forests and wetlands were categorized as unavailable land for bioenergy considerations. From a food security perspective, all the four categories of areas that are under food crops and/or cash crops on the GLC2000 database are non-negotiable for any bioenergy project, thus they were also designated as unavailable for BFP by Watson (2008a). Unsuitable areas refer to areas, which are physically not suitable for any BFP given the crops` physiology and climatic requirements. The other land covers that were on the GLC2000 database, namely bare rocks, water bodies, built up areas, deserts dunes and salt pans were, therefore categorized as unsuitable for BFP by Watson (2008a).

After designating and merging the unavailable and/or unsuitable areas, GIS was used to filter these from the rest of the semi arid regions land areas. Maps showing the remaining available and suitable areas for BFP, in relation to the distribution of primary rivers, transport infrastructure and populated places for the eight case study countries of COMPETE were, therefore, obtained as results by Watson (2008a). The available and suitable areas are covered by closed or sparse grassland, open grassland with sparse shrubs, open deciduous shrubland, deciduous shrubland with sparse trees, deciduous woodland, mosaic forest/cropland and mosaic forest savannah type of vegetation.

After the designation, the unavailable and/or unsuitable areas were merged by Watson (2008a). However, this resulted in areas within the agro-ecological sub-zones with Jatropha potential filtered out. The protected areas and the GLC2000 land covers were, therefore, overlaid separately so as to ascertain which area was filtered out, for what reasons and also to verify the accuracy of the data that the study was going to use. Before the ArcMap overlay tool was used to delineate the potentially suitable and available areas in the nine agro-ecological sub-zones with Jatropha potential, the nine agro-ecological sub-zones were verified against literature on what the specific habitat requirements of Jatropha are. The matching procedures that were used identified crop-specific limitations arising from prevailing climate, soil and terrain resources under assumed levels of management. The available and suitable areas that remained were, therefore, used to identify the three largest available areas.

Degraded forests are classified as evergreen lowland category in the GLC database. Watson (2008a) delineated these from the GLC2000 database and filtered them but a lot of arguments have been put that these could have not been filtered as their importance for bioenergy production is yet to be fully realized. Locating these areas is of value for

Jatropha cultivation because it rehabilitates degraded forests. The identification of degraded forests has since proved to be working in India where vast land areas that are classified as degraded waste lands are currently being used for cultivation of Jatropha for biodiesel production. The same conditions for defining degraded forests have not been fully appreciated in this study. The study instead focused on the semi arid region as not having degraded forests but as having constraints to crop production due to the amounts of rainfall they receive and due to the condition that their soils are suitable for the production of Jatropha.

It is important to note that degraded forest in the semi arid regions of Tanzania were not clearly recognized as they occurred along with closed forests. The cultivation of Jatropha in such areas will need infield verifications to asses whether this will not encroach on the already existing biodiversity and ecosystems. It is suggested that the GLC2003 with a resolution of 300 m^2 be used to reassess whether this category should be filtered out. A better resolution Google Earth, more recent aerial photographs and ground verification will need to be also used to reassess whether degraded forest should be filtered out.

It should be noted that the Protected Areas are basically all the nationally-designated protected areas and their areas (in hectares) were obtained from tables that were provided by the UNEP-WCMC database. There are various methodologies that are used to collect the data on these protected areas, therefore, a high variability is expected among countries. There also lies many unreported data on protected areas numbers and/or extent within different countries borders, thus it should be noted that the data on Protected Areas varies within countries. The data that was used to designate and filter out Protected Areas in this study is considered as the best available from the UNEP-WCMC. The large scale Jatropha farming activities on the periphery of major Protected Areas will have to be monitored, as it will have constraints on transmigration of herds of animals if the small patches of land are considered within the selected regions.

4.4.5 Multi-criteria Analysis

The three largest and potentially available regions that the study identified were ranked using multi-criteria analysis. Multi-criteria analysis is one of the elements of the agro-ecological zones methodology framework and it involves the use of Land Utilization Types (LUT) (FAO/IIASA, 2007). LUT selects agricultural production areas with reference to input and management relationships, and crop-specific environmental requirements and adaptability characteristics (Fischer *et al*., 2002).

In order to select the largest available locations for Jatropha production, areas that were covered by each agro-ecological sub-zone as well as distance comparability to the other agro-ecological sub-zones were also considered. When the three largest and potentially available areas were selected, GIS was used to buffer categories from rivers, populated places, railways and roads, and to calculate the percentage of the area within each category. Jatropha has to be irrigated in order to obtain commercial viable yields. It was, therefore, assumed that in multi-criteria analysis, proximity to rivers is more important than all the other constraints. Whereas labour can be transported in or accommodated close by, railways and roads can be built. A review of literature on the influences of these constraints was necessary to substantiate the two main assumptions that were made. To substantiate the distance thresholds that were used to analyze proximity to water sources, Boelee and Laamrani`s (2003) results of the studies on irrigation potential in Morocco were used. The studies showed that, practically, farmers are more willing to transport water to distances of between five and ten kilometers within the irrigated area and over 15 km to those areas that are outside of the irrigated area. Moreso, with increasing volume of water (about 4 m^3 or more), water tanks or trucks will have to be used for water transportation.

Primarily, water bodies in the semi arid regions of Tanzania were delineated from the GLC2000 database by Watson (2008a). A more detailed data set on perennial rivers and other water bodies was required in the study and it was, therefore, extracted from the GADM discussed above. The data is in vector format. The database of GADM covers world surface water bodies` areas, types and names, and this data has a spatial resolution of one kilometer.

Built up areas that are on the GLC2000 dataset and were categorized as unsuitable areas for BFP by Watson (2008a) were considered as primary data in this study. Detailed roads and railroads datasets in vector format for the whole country were, therefore, obtained from the Digital Chart of the World database. The clip function was used to extract the roads and railway lines that are only within the semi arid regions of Tanzania.

Population data that the study used was obtained from The ESRI Data & Maps 2007 media kit. Population data is represented by a State-Province layer and is a symbolized and labeled display presentation of the World Administrative Units data set.

In this study, some of the data had to be reprojected to Projected Coordinate Systems Africa Albers Equal Area Conic in order to pave the way for area calculations that were going to be made. This specific projection system was chosen due to its equal area characteristics, i.e. maintaining true area on regions shown despite distorting shape, angles and scale.

4.5 Assumptions and Limitations of the Study

The assumptions and limitations that the study acknowledged shall be highlighted.

- Currently Jatropha is grown on a small scale basis in Tanzania as a barrier plant around plots growing food crops and/or intercropped with them and this is facilitated by NGOs in Arusha province. The GLC2000 data identifies four areas that are under cultivation in the cropland category namely irrigated crops, cultivated crops, tree crops, and croplands with woody vegetation, which are the communal subsistence farmlands. It is, therefore, assumed that GLC2000 included all areas that are under small scale Jatropha cultivation in the cropland category and these areas were filtered.

- Ideally SunBiofuels` intentions for large scale Jatropha cultivation are focusing on the Wami wetlands. It is, therefore, assumed that no large scale Jatropha cultivation has been established in the semi arid regions.

- The land that is currently utilized for Jatropha production in each of the administrative regions with Jatropha potential expressed as the share of all land is not known. The information on seed and oil yield is from the small scale production that is based in the two administrative districts that are in Arusha and Bukoba administrative regions and these are outside the selected regions of concern. It is, therefore, assumed that there is not enough information on Jatropha seed and oil yield.

- Kartha *et al*. (2005) state that bioenergy is a land intensive scheme and to attain sustainable and successful production, large areas are required. Land availability, is therefore, a prerequisite for any large scale development. A minimum threshold of 10 000 ha is presumed as the most feasible for setting up large scale commercial Jatropha farms (Watson, 2008b). A threshold distance of areas greater than 10 000 ha was, therefore, assumed to be substantial for large scale farming to be established in the three selected areas.

- Terrain slope can be one of the governing factors of suitability of an area for gravity or sprinkler irrigation. In this study, suitability for a specific irrigation type was not taken into consideration, as it was assumed that this will depend on the finances available.

- Degraded forests are classified as evergreen lowland category in the GLC2000 database and occur alongside the same with closed forests. This category of forests is protected by International Conventions. In this study degraded forests were not filtered out because literatures classified them as ideal areas to focus on.

- Jatropha has to be irrigated in order to obtain commercially viable yields. It is assumed that, in multi-criteria analysis, proximity to rivers is more important than all the other constraints. Whereas labour can be transported in or accommodated close by, railways and roads can be built.

- When compared to world statistics, Tanzania has 1.4 million people living with HIV/AIDS and is ranked fifth out of the 131 countries that are on the list (United Nations Programme on HIV/AIDS (UNAIDS), 2008). The HIV/AIDS incidence rate stands at 8.8%, thus an increase by 0.7% from the 8.1%, that Ashton and Ramasar (2002) reported by 1995. However, the spread of HIV/AIDS in SSA countries, especially those of the SADC region, have demonstrated a frightening acceleration in the rates of infection and, thus, they now have the highest world HIV/AIDS infection rates. With the prevalence mostly dominant in the economically active population of the 18-45 age range, it is expected that economies of these nations are going to be threatened, as countries will have a reduced life expectancy and an increased dependency alongside more child-headed families. The economic and agricultural sector is not going to be spared in these scenarios as populations are needed to provide labour in the production chain. However, it is beyond the scope of this study to consider.

4.6 Conclusion

The use of GIS and remotely sensed data was the core of this methodology. Several data sources were consulted and reasons why these were employed and the actual steps to perform the data analysis have been articulated. Chapter Five discusses and presents the results that the study found.

Chapter 5
Results and Discussion

5.1 Introduction

The previous chapter detailed the approaches to the methodology as well as the tools that the study used to identify optimal locations for large scale Jatropha cultivation for biodiesel production. This chapter presents the results that the previously discussed methodological steps produced. The results are discussed alongside the presentations both in tabular and in graphic format and a general discussion is also presented in each section.

5.2.1 Unavailable and/or Unsuitable Areas

The two semi arid regions of Tanzania (32 079 657 ha) cover about 33.7 % of the country's total area (*Refer to Figure 2*). These areas occupy the central and south-eastern parts of the country.

The 31 agro-ecological sub-zones in the two semi arid regions are shown in Figure 18. Zones are allocated a letter and sub-zones a number. The landscapes represented by the zone letters are listed below:

- C Coastal plains
- E Eastern plateaux and mountain blocks
- H Highlands and plateaux
- N Volcanoes and rift depression
- P Central plateaux
- R Rukwa-Ruaha rift zone
- S Inland sedimentary sediments
- W Western highlands regions

ARI-Mlingano1 (2006) identified eleven agro-ecological sub-zones with potential for rainfed Jatropha cultivation in the country. Of the eleven, nine of them namely C1, C2, C3, E3, E4 E5, E10, S2 and W4 with a total area of 12 488 434 ha are found in the two semi arid regions. Their topographic and climatic information is shown in Table 3 below. A further analysis that aimed to identify the three most optimal areas for large scale Jatropha cultivation was made with reference to these nine regions.

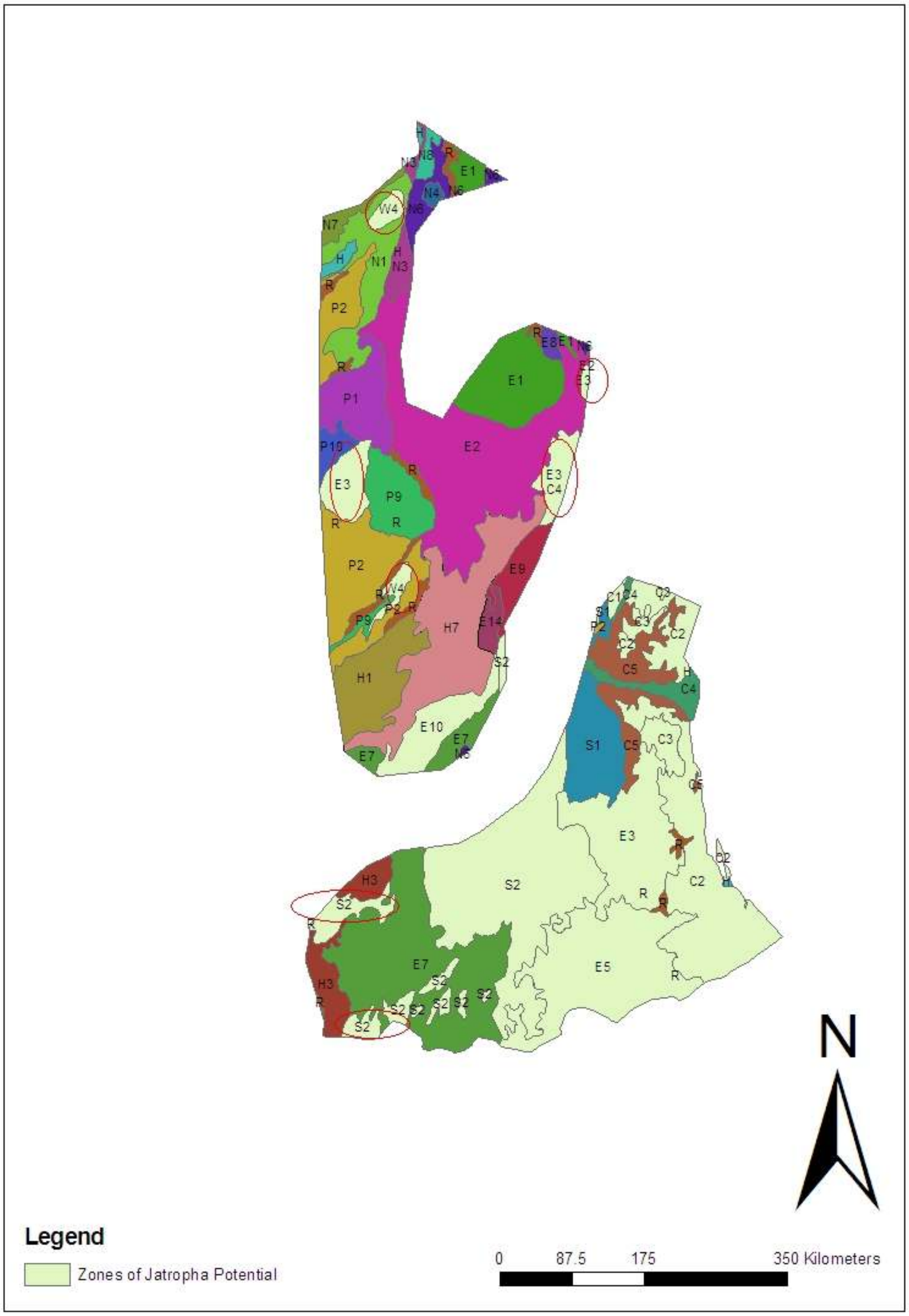

Figure 18: Semi Arid Regions Agro-ecological Sub-zones with Jatropha Potential

Table 3: Topographic and Climatic Data for the Agro-ecological Sub-zones with Jatropha Potential (*adapted from* ARI-Mlingano1, 2006)

AEZ	Rainfall (mm)	Min Temp (°C)	Max Temp (°C)	Altitude (m)	Topography
C1	1000-1200	19-23	29-31	<200	Coastal uplands
C2	800-1000	19-23	29-31	<500	Coastal lowlands
C3	800-1000	19-23	29-31	<500	Rolling to steep coastal plains
E3	800-1000	19-23	29-31	200-750	Flat to rolling plains
E4	800-1000	19-23	29-31	200-1000	Flat to rolling plains
E5	800-1000	19-23	29-31	200-500	Level to rolling plains
E10	400-600	19-23	29-31	400-600	Flat alluvial plains
S2	1000-1200	15-23	27-31	200-1000	Gently undulating to rolling plains
W4	1000-1500	15-18	27-30	1400-1500	Undulation to rolling plains

According to work done by Foidl *et al*., (1996) and Amin (2001) (mentioned in section 3.3.1), Jatropha mainly occurs from sea levels up to 500 m.a.m.s.l but it is viable for cultivation up to 1 800 m.a.m.s.l. The nine selected regions have abnormally high and extremely low rainfall patterns (*Refer to Table 3)*.With reference to altitude, all areas are free of constraints, except for agro-ecological sub-zone C3, where the rolling to steep coastal uplands can be limiting to the use of machinery. As is mentioned in sections 3.3.2 and 3.3.3, the ideal mean annual temperature and MAP for Jatropha are 20-28°C and 250-1000 mm, respectively. Therefore, it is evident from Table 3 that, all areas have ideal rainfall and temperature ranges for Jatropha to thrive well.

All the nine agro-ecologic sub-zones have soil characteristics, which are almost similar. As is represented in Table 4, and with the exception of agro-ecological sub-zones W4 and E10, the dominant soils are the well drained reddish, yellowish red or orange sands and loamy sands with sandy loams in depth. They are moderately deep in depth, their pH ranges from averages of 5.5-6.5, their moisture storing capacity ranges from poor to moderate, and their fertility ranges from very low to moderate. The yellowish or reddish sandy clays in the agro-ecological sub-zone W4 are limiting to Jatropha cultivation because they are infertile and they have a weak structure which promote gleying and waterlogging (*Refer to Table 4*). Agro-ecological sub-zone E10 also has infertile soils which are imperfectly drained. This condition will need to be remedied by the use of organic manure and the manure can be derived from the pruning, leaves, shells from dahulling and from composites of nitrogen, phosphorus, potassium. The introduction of nitrogen and phosphorous fertilization is also important because it will support a high biomass production in marginalized soils (Heller *et al*., 1999).

Table 4: Soil Characteristics for Agro-ecological Sub-zones with Jatropha Potential (*adapted from* ARI-Mlingano1, 2006)

AEZ	Soil Depth	Soil pH (av)	Moisture Storing Capacity	Fertility	Soil Drainage
C1	Moderate	6	Poor	Moderate	Very well
C2	Moderate	6	Favorable	Very low	Moderate
C3	Moderate	6	Poor	Low	Well
E3	Moderate	5.5	Favorable	Low	Very well
E4	Moderate	5.5	Favorable	Very low	Very well
E5	Moderate	6	Poor	Very low	Very well
E10	Moderate	6.5	Moderate	High	Imperfect
S2	Moderate	6	Poor	Very low	Very well
W4	Moderate	5.5	Moderate	Low	Very well

Slope plays an important role where mechanization is concerned. 98% of the semi arid regions are free from constraints posed by slope percent, i.e. they are suitable with respect to topography (*Refer to Figure 19*). However, the remaining 2% represents the areas that are too steep for sustainable agriculture. As was highlighted in section 4.8.3, Sys *et al*. (1993) believes that mechanization becomes impossible on areas which have a percent slope of more than 16% and for slopes that are less than 16% there can still be important variations in productivity. The three largest, available and suitable regions that the study identified for large scale cultivation are free from constraints posed by slope. It must be noted that, a continued use of machinery usually changes the general leverage of an area.

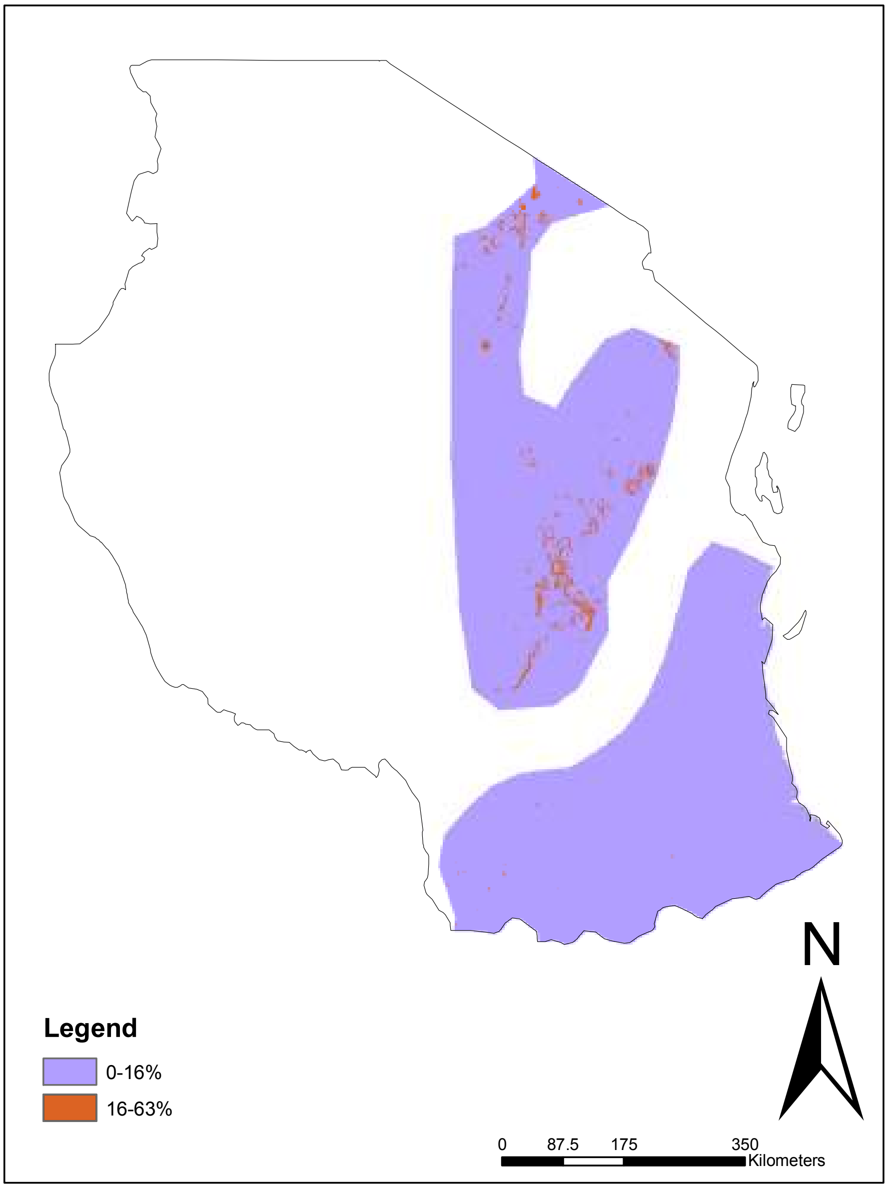

Figure 19: Steep Slopes within the Semi Arid Regions

The administrative zones that the semi arid regions cover include Dodoma, Pwani, Iringa, Ruvuma, Mtwara, Shingida, Lindi, Morogoro as well as parts of Arusha and Tanga (*Refer to Figure 20).* There are also some districts that are arid in Shinyanga and Tabora regions (Shuma, 2008).

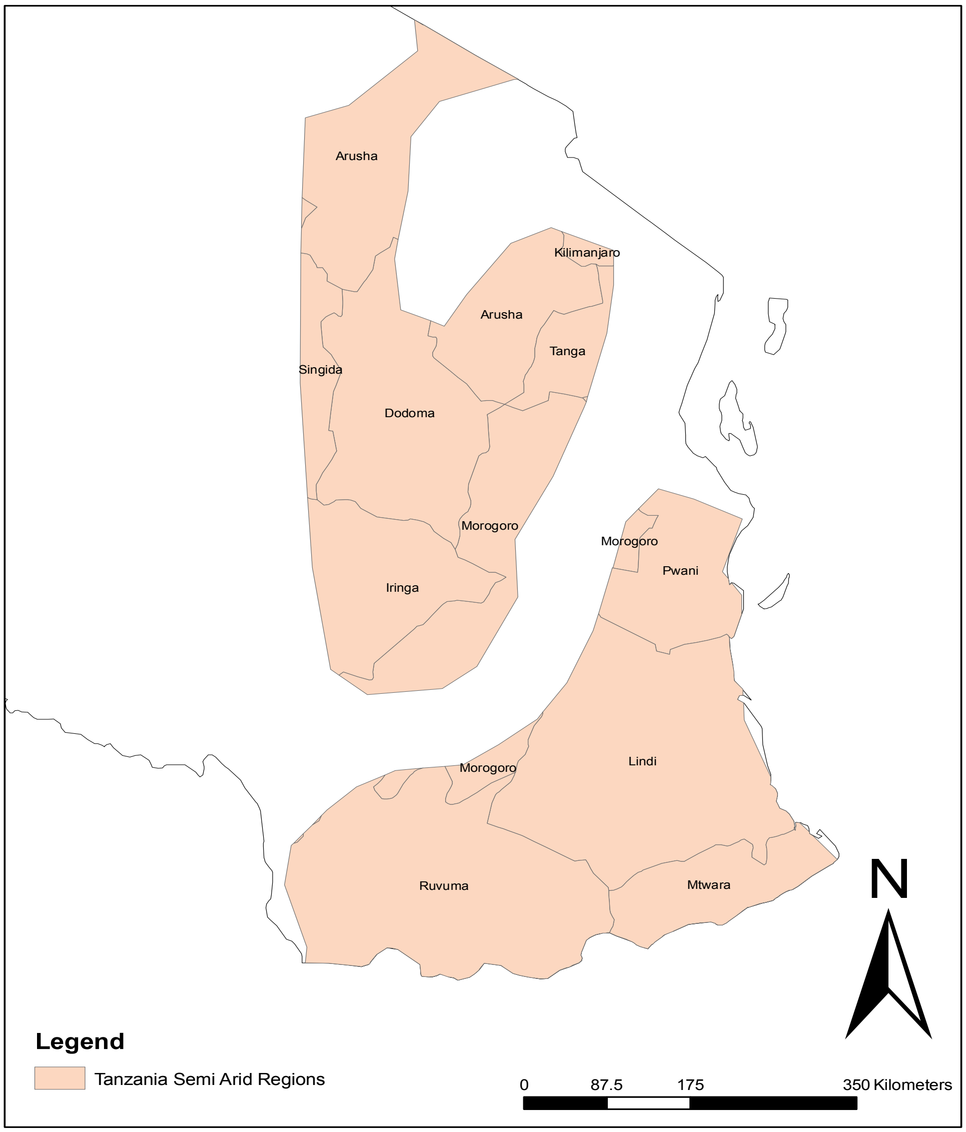

Figure 20: Administrative Zones in Semi Arid Regions of Tanzania

The semi arid regions are characterized by rainfall that is poor and erratic (Mbwambo, 2004). There are a lot of fragile ecosystems and the continuous cropping and extensive vegetation clearing has resulted in land degradation in these regions. The prolonged droughts have worsened the problems of poverty, malnutrition and access to clean water the semi arid regions` communities face. Agriculture, pastoralism, agro-pastoralism and mining remain as the major occupations the populations of the semi arid region depend on (Mbwambo, 2004).

Sustainable agriculture depends mainly on an effective utilization of the available surface and ground water resources. Information on the status of groundwater resources that are in Tanzania was not readily available, therefore, the study did not focus on it. As Figure 5 shows, Tanzania is dissected by several inland water bodies. The major perennial rivers that are of importance to the semi arid regions are the Ruvuma, the Ruvu and the Kilombera river. The Wami/Ruvu river system has a total catchment area of 17 700 km² and a mean annual flow of 65.1 cumecs (ASDP, 2005). The Rufiji Basin with a total coverage of about 25% of Tanzania (177 000 km²) is comprised of the three major river systems, namely the Great Ruaha, the Kilombera and the Luwegu. The Kilombera river has a total catchment area of 39 990 km² and contributes about 65% of its flow to the Rufiji River (ASDP, 2005). The Ruvuma river is shared by Tanzania and Mozambique and has a catchment area of 104 000 km² on the Tanzanian side (ASDP, 2005). Despite the fact these vast water resources exist in the semi arid regions, literature reports that there continues to be shortages of soil water for plants use (Mbwambo, 2004). Households in these areas have begun to improve their cropping systems by making use of harvested rainwater and by cultivating some of the crops on seasonally flooded valley bottoms (Shuma, 2008).

5.2.2 Analysis of Three Selected Regions

There are four agro-ecological sub-zones namely C4, E3, S2 and W4 that exist in seven isolated areas (*encircled in red on Figure 18*). These four sub-zones were left out in the analysis because (1) the study sought to identify areas suitable for large scale production larger than a threshold of 10 000 ha, and (2) they were too isolated from the transport infrastructure that potentially could be consolidated to service the other agro-ecological sub-zones with Jatropha potential. The basis for the 10 000 ha threshold is explained later.

The remaining agro-ecological sub-zones with Jatropha potential were consolidated into three regions shown in Figure 21. After filtering out the unavailable and/or unsuitable areas from the regions, what remained was land covered by closed or sparse grassland, open grassland with sparse shrubs, open deciduous shrubland, deciduous shrubland with sparse trees, deciduous woodland, mosaic forest/cropland and mosaic forest savannah type of vegetation.

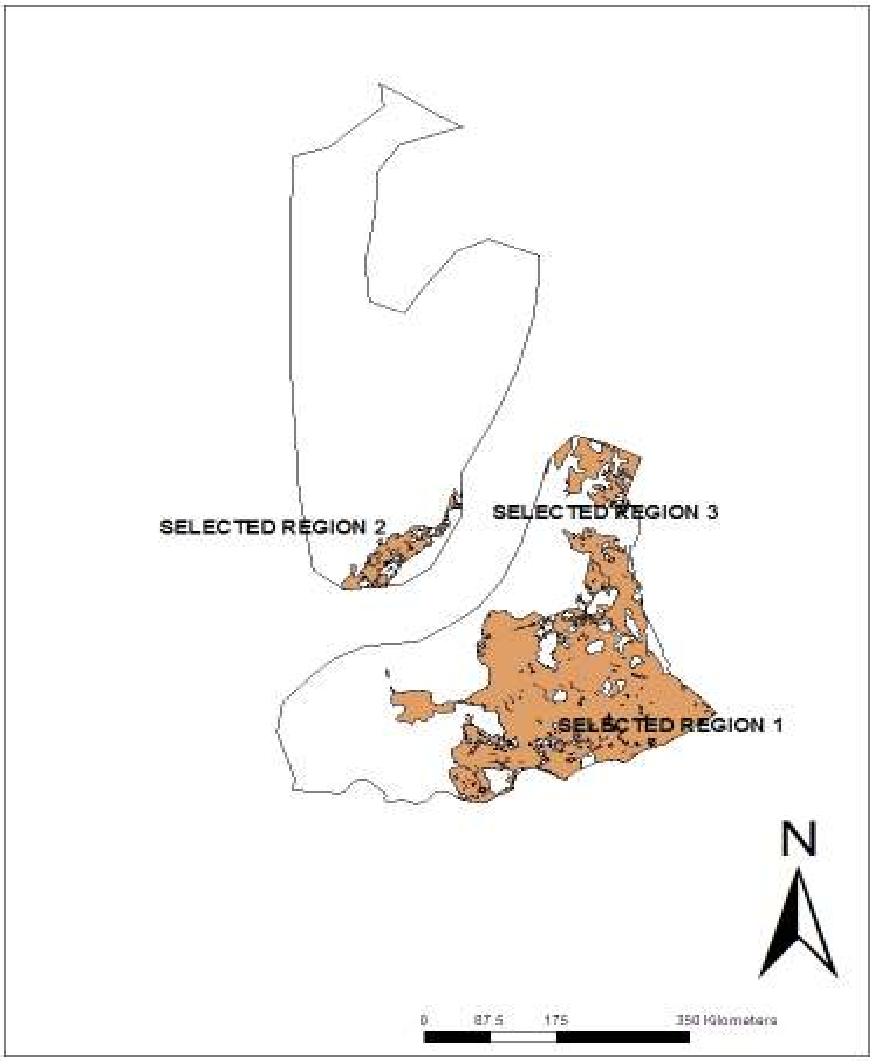

Figure 21: Selected Regions for Potentially Large Scale Jatropha Cropping

Although this study designated grasslands as suitable for Jatropha cultivation, ground verification of their status is essential because they potentially have rich biodiversity. A considerable proportion of Tanzania's landscape is characterized by grassland, dense thickets, woodlands and seasonally flooded grasslands (Shuma, 2008). Although the clearing of grasslands for agriculture expansion, shifting cultivation and for human settlement is currently an issue in its semi arid regions, grasslands have been very useful to the country's livelihoods. Products such as firewood, medicinal plants, honey, wild fruits that are obtained in the woodlands surrounding Morogoro region for example have been traded and have become a source of income (Shuma, 2008). The clearing of land for large scale cultivation of Jatropha could potentially to threaten the survival of flora and fauna, biodiversity and at the same time reduce the household income levels of the small scale producers that are scattered in the semi arid regions.

Regions 1, 2 and 3 (in Figure 21) cover about 7.6 million hectares in the Mtwara, Lindi, Morogoro, Iringa and Pwani administrative zones. A comparative assessment of Jatropha cultivation in arid and semi arid regions of SSA by Moodley (2007) showed that there are six countries in southern Africa, namely Namibia, Mozambique, South Africa, Swaziland, Zambia and Zimbabwe, where large scale Jatropha cultivation has been implemented or are still planning to set aside areas where cultivation can take place. The sizes of these areas, which are either earmarked for large scale cultivation or were already under cultivation, were ranked and they ranged between 20 000 ha and 60 000 ha. On another note, both Takavarasha *et al*. (2005) and Cunhete (2007) agree that Mozambique has suitable land for biofuels cropping. Cunhete (2007) claims that this country has 36 000 000 ha of suitable cropland and only 3 240 000 ha or 9% is currently under cultivation. Sawe (2008) notes that SunBiofuels is looking for more than 9 000 ha of land for Jatropha cultivation in Tanzania. However, they specify that this land area must not be in the semi arid regions. From this literature that was consulted, it is adequate to conclude that the three selected areas in the semi arid regions of Tanzania have enough land that can be converted to large scale Jatropha cultivation. However, it is important to note that there can be no magic threshold for large scale cultivation and it depends on how much the individual investor is willing to use. In the case of these three selected regions, the fact that they are in the semi arid regions means that there may be lower yields because of lower rainfall and also more likely degraded soils.

Tables 5 summarizes the Jatropha seed and oil that can potentially be produced, if all the available land that is in the selected regions is used. Assuming that the large scale farmers will cultivate the areas that the study selected at a plant density of 1 600 plants/ha and at 2.5 m x 2.5 m distances, these areas are able to give a total of 12 226, 3 billion plants *(Refer to Table 5)*. If a seed yield of 5 t/ha/yr is projected for mature Jatropha stands, these 7 590 805 ha will yield about 37 954 000 tonnes of seeds. For an assumed oil content of 35% by weight, and using the density of Jatropha seed of approximately 0.92 kg/l, the ripe seed kernels that the three selected areas will produce are capable of producing 14 439 600 litres of Jatropha oil.

Table 5: Summary of Seed and Oil Yield in the Selected Regions

	Selected Region 1	**Selected Region 2**	**Selected Region 3**
Administrative Regions Covered	Pwani, Lindi, Morogoro, Ruvuma, Mtwara	Morogoro	Pwani, Morogoro
Total Area (ha)	6 580 000	443 507	567 298
Total Plants	10 528 000 000	790 611 200	907 676 800
Seed Yield (t)	32 900 000	2 217 500	2 836 500
Crude Seed Oil at 35% extraction (l)	12 516 800	843 600	1 079 200

The total diesel consumption of Tanzania in its neat form stands at 121 000 Mt per year and this consumption is increasing every year (IEA, 2005). Assuming a diesel density of 0.7 kg/l, the 121 000 Mt of diesel that Tanzania requires equates to 173.03 million litres. As noted by Takavarasha *et al*. (2005), the SADC region is targeting an import substitution of conventional fuels by biofuels of at least 10% by 2020. As also reported by African News Network (2009), Zimbabwe being one of the SADC countries, also plans to plant 120 000 ha and use Jatropha to produce up to 10% of its fuel needs or 100 million litres of biodiesel per year by 2017. The National Oil Company of Zimbabwe (NOCZIM) biofuels programme director, Abisai Mushaka, noted that these biofuels would then substitute the 10% target of the fuel imports. Assuming this target, Tanzania (also in the SADC region) will require 17.30 million litres of Jatropha biodiesel to meet its 10% target substitution of fuel import. When comparing this figure to the 14.44 million litres of Jatropha oil that the three selected regions will produce, 83% of the country's diesel needs will be met by production from the three selected regions.

As noted in section 2.11, less than 10% of the total population of the country has access to electricity and the situation is worse in the rural areas where (1) only one percent of the population who resides there are connected to the national grid, and (2) oil lamps that are used for lighting homes use imported kerosene (Lyimo, 2006; Shuma, 2006). Van Eijick (2006) also notes that cities are constantly affected by power shut downs and, thus, they use diesel generators as a backup source. Large scale Jatropha cultivation for biodiesel production for electricity generation is another option through which these areas may be utilized. About 2 776 GWh of electricity that the county requires is produced from coal, oil and hydropower. No electricity generation has been recorded from biomass energy (IEA, 2005). The 14.41 million litres of Jatropha oil that the three selected regions will produce will enable six percent of the electricity to be produced from bioenergy. The amount of Jatropha biodiesel that is produced in the three areas is significant enough to recommend further investigation into their large scale potential. From this analysis it is clear that the production of Jatropha biodiesel for blending or for electricity generation is going be economically viable for large scale investments.

In addition, one of the advantages of Jatropha biodiesel project is its flexibility, i.e. its capability to have a feedstock supply system (seed) and a consumption pattern that can be either localized or decentralized. The available areas that remained in the agro-ecological sub-zones that were too isolated and could not meet the criterion for large scale cultivation were further analyzed for small scale Jatropha cultivation from the perspective of NGO investment. The biodiesel that will be produced from them can be fed into backup generators and lighting lamps for both the rural and urban areas of Tanzania. As noted in section 2.7, the two natural sites namely The Ngorogoro

Conservation Area (828 800 ha) and especially The Selous Game Reserve (4 480 000 ha), extend into the three selected regions. The proposal to establish several small scale Jatropha farms adjacent to these areas of high conservation value will maintain corridors of migration of herds of wild animals during breeding and feeding seasons unlike the amalgamating the land.

When small scale farmers have equipment to till, collect and transport produce and are assured of a guaranteed market for their produce, they are more willing to contribute to the betterment of Tanzania's energy situation. In this scenario, the small scale farmers are also free to cultivate the Jatropha along with other crops. They are more likely to cooperate when they know there are higher economies of scale ranging from the benefits of paid labour, knowledge to be gained from agricultural extension services and also the income obtained from the sale of their produce. Other advantages that the small scale farmers have will arise from the direct purchase of the useful lamp oil which is obtained soon after the seeds have been crushed and when the oil is about to be sent to the transesterification plant. In the rural areas of Mali, small scale lister type of engines that are used to drive grain mills and water pumps have been running on the Jatropha oil that the women in these areas extract (MFC Nyetaa, 2007). The government of Mali and the NGOs that are facilitating the development of biofuels in the country have successfully electrified villages where 3 000 inhabitants dwell. A 60 kVA power plant and a mini grid have been constructed and commercial production has not yet been realized. A useful co-product, potassium sulphate fertilizer is produced when glycerol, a by-product of the transesterification process, is neutralized with sulphuric acid (DMEWR, 2007). This co-product can be sold to both subsistence farmers besides being used on farms in each of the selected regions.

Large scale bioenergy crop cultivation will undoubtedly results in an expansion of energy crop monoculture. Monoculture aggravates the problems of soil erosion, pollution from nutrient leaching and overdraft of underground water. A sudden infestation of some new serious pests or disease can wipe out other plantations. Other problems like weed shift may also occur and these need not to be oversimplified (Ghosh *et al*., 2007). These negative impacts of large scale cultivation can therefore be avoided if land parcels in the isolated agro-ecological sub-zones are used for small scale cultivation.

5.2.3 Proximity of Selected Regions to Infrastructure and Access to Resources

It was already clear that obtaining optimal yields from the three areas was viable. Multi-criteria analysis was used to interrogate and rank their irrigation, infrastructure and job creation potential from various perspectives, i.e. government subsidy to create jobs, NGOs to create jobs and generate electricity. Multi-criteria analysis involves the use of Land Utilization Types (LUT) and it is one of the elements of the agro-ecological zones methodology framework (FAO/IIASA, 2007). LUT selects agricultural production areas with reference to input and management relationships, crop-specific environmental requirements as well as adaptability characteristics (Fischer *et al*., 2002). Jatropha has to be irrigated in order to obtain commercial viable yields. In multi-criteria analysis it was assumed that proximity to rivers is more important than all the other constraints. Whereas, labour can be transported in or accommodated close by, railways and roads can be built. GIS was used to buffer categories from rivers, populated places, railways and roads and to calculate the percentage of the area within each category.

5.2.3.1 Proximity of Selected Regions to Water Sources

As is highlighted in section 2.8, Jatropha requires water for optimal growth levels to be attained especially during the initialization phase. As also noted in section 3.3.3, it experiences optimal growth levels where MAP ranges between 250 mm-1 000 mm. Areas that have MAP ranges of 500/600-1 000/1 200 mm provide optimal growing conditions and hence economic yield. As the study focused on crop cultivation in the semi arid areas that have MAP shown in Table 6 below, Jatropha will have to be irrigated to improve productivity. Irrigation opens up opportunities for semi arid regions lands to be used but it must be noted that little investment upon establishment of the infrastructure and low maintenance costs are two important preconditions that are necessary for better economic yields.

Table 6: MAP and Average Water Capacity of Potentially Available Areas

AEZ	AWC (mm/m)	MAP
C1	30-80	1 000-1 200
C2	80-150	800-1 000
C3	80-100	800-1 000
E4	70-120	800-1 000
E5	70-120	800-1 000
E10	80-150	400-600

There are potential sources of water for irrigation in all the three selected regions (*Refer to Table 7*). River systems are mostly concentrated in Selected Region 1, as it has six river systems and 10 perennial rivers. Selected Region 2 and Selected Region 3 each have one major river system and two perennial rivers that pass through them. As noted in section 2.8, some of the surface water resources of Tanzania are shared with neighboring countries (AQUASTAT, 2008). These sources are ideal for functional irrigation but it must be noted that there are water institutions that control the day to day activities within these perennial rivers. They maintain that every water use must not compromise the needs of other stakeholders to meet their own water needs (Kauzeni *et al*., 1993).

Table 7: Major River Systems within the Selected Regions

	Selected Region 1	Selected Region 2	Selected Region 3
Major River Basins	Ruvuma River and Southern Coast	Rufiji	Wami/Ruvu
Major River Systems	Mbwemkuru, Matandu, Mavuji, Lukuledi, Mambi, Ruvuma	Kilombera	Ruvu
Number of Perennial Rivers	10	2	2

Table 8 and Figure 22 show the proximity to water resources analysis. Within a distance of 5 km the greatest areas that can be watered without any difficulty are 864 833 ha, 51 635 ha, and 35 593 ha for Selected Region 1, 2 and 3 respectively. The rest of the remaining areas are beyond the 10 km threshold, i.e. 73%, 75% and 87% of the land area in Selected 1, 2 and 3 respectively, thus, they are far away from water sources. They will have to be irrigated with water that trucks and tanks will transport. Irrigation canals that transport volumes of water per unit time to the selected sites will have to be developed but it is important to note that it requires a capital outlay to set up such infrastructure.

Table 8: Proximity of Water Resources to Selected Regions

	Selected Region 1		**Selected Region 2**		**Selected Region 3**	
	ha	**%**	**ha**	**%**	**ha**	**%**
Areas within 5 Km	864 833	13	51 635	12	35 595	6
Areas within 10 Km	932 644	14	56 991	13	40 044	7

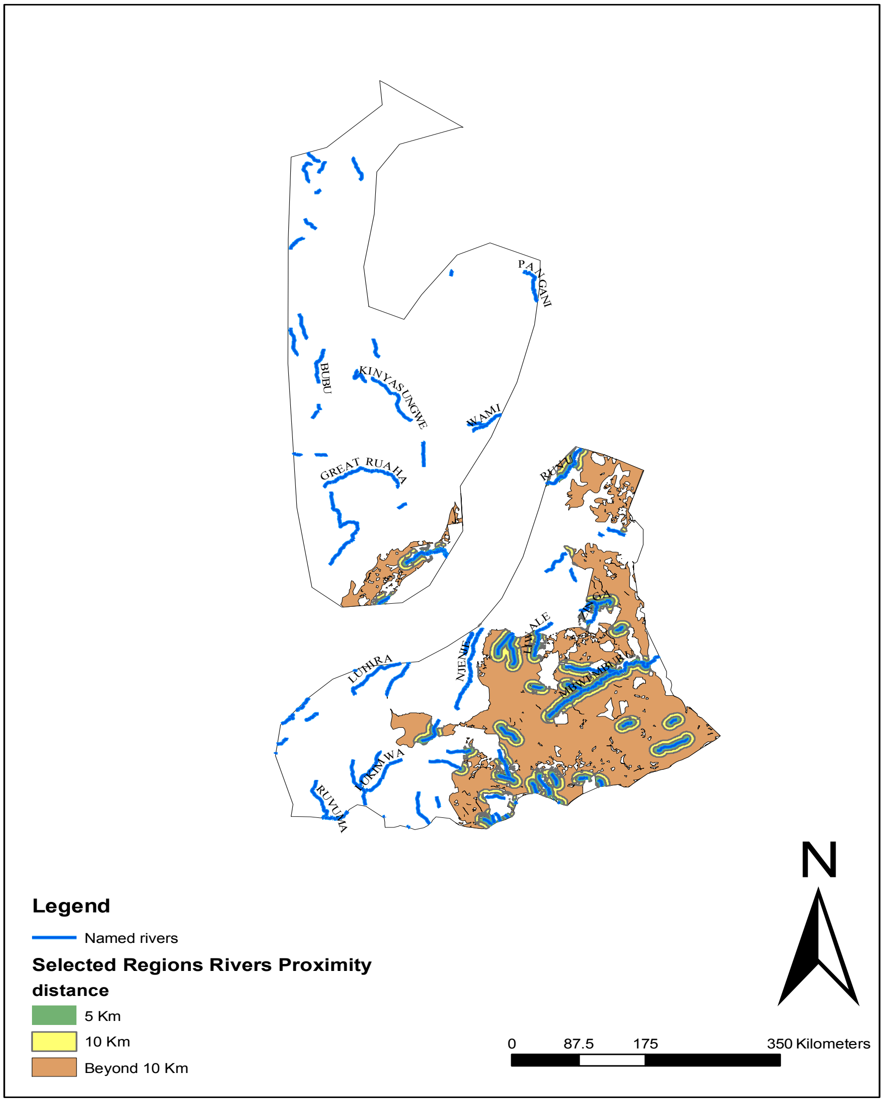

Figure 22: Proximity of Selected Regions to Water Resources

It is important to note that irrigation increases the rate of returns in agriculture but it can contribute to negative impacts to the environment. The development of large scale irrigation systems increases the salinity of cultivated lands, hence an introduction of salt pans which hardens the soil and cause soil compaction (Stockle, 2001). Withdrawing surface water implies changes to the natural hydrology of rivers and water streams, changes to water temperature, alterations to the natural conditions in waters and these consequences affect the aquatic ecosystems. Water logging can also result from overuse and/or poor management of irrigation water (Stockle, 2001). All these factors will need to be considered when planning for irrigation infrastructure in the identified regions because there are fears that irrigating Jatropha during the first years of initialization will devastate the once productive land. Downstream degradation of water quality by salts, agrochemicals and toxic leachates as well as groundwater pollution are also serious environmental problems that will need not to be oversimplified when recommending for land for irrigation. On the areas that will be used for small scale Jatropha cultivation, the damage is expected to be less.

5.2.3.2 Proximity of Selected Regions to Roads

The distribution of transport networks and its associated costs were evaluated to assess whether percent coverage in each selected region is feasible for the transportation of labour, seed, the crushed Jatropha oil and biodiesel. A distance within the range of 0-10 km is practically feasible for local workers to travel to and from work in these three selected regions. Outside of the 10 km range to about 20 km, workers are willing to travel to and from their work places on bicycles on simple graded dust roads. For a distance of more than 20 km, transport to carry workers will have to be provided. It is important to note the need to construct either houses or staff quarters for farmers to stay during working days, after which they will go to their family homes during non-working days. As Figure 23 and Table 9 indicate, Selected Region 1 is the most constrained because more than 90% of its area cannot be accessed via the available primary road networks. This is followed by Selected Region 3 where only 25% of the area is within the 10 km coverage and about 44% lie outside of the 30 km reach. Selected Region 2 is the most accessible within the 10 km threshold. Farming inputs, produce and labour resources will easily get to the farm without transport problems in Selected Region 2 than in any of the other two selected regions. Dust roads will have to be constructed outside of the 30 km reach so that workers, seed and oil may be moved without problems. When Jatropha seed is collected by diesel tankers from several collection centres, and when transesterification processes are done, biodiesel will be produced locally. It is important consider the development of power generation plants at or near production sites as well as infrastructure that will link the power generation sites to the national grid.

Table 9: Proximity of Roads to Selected Regions

	Selected Region 1		Selected Region 2		Selected Region 3	
	ha	**%**	**ha**	**%**	**ha**	**%**
10 km Coverage	48 702	0.7	443 507	100	140 617	25
20 km Coverage	71 706	1	0	0	98 581	17
30 km Coverage	103 782	2	0	0	77 287	14

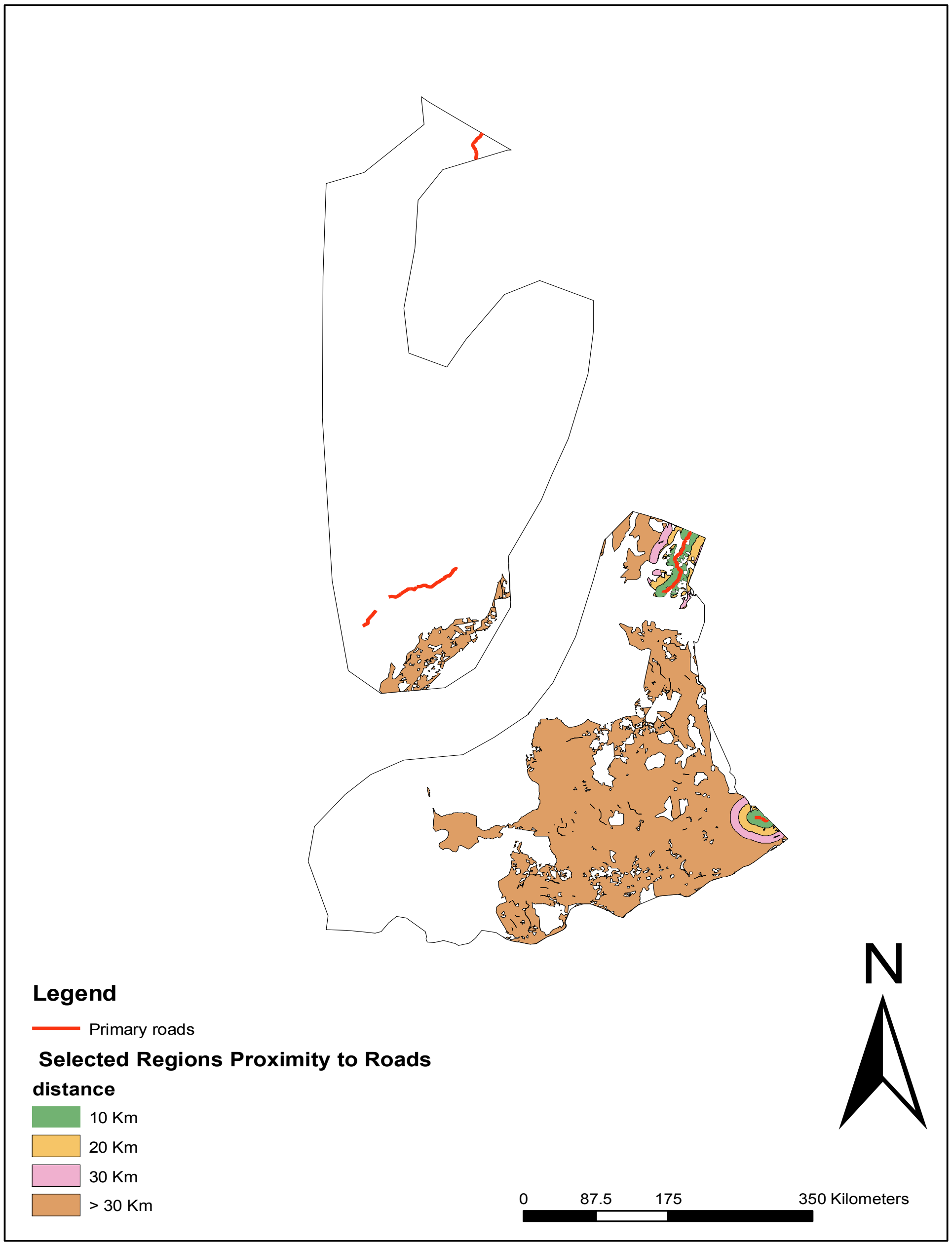

Figure 23: Proximity of Selected Regions to Roads

5.2.3.3 Proximity of Selected Regions to Railroads

When comparing the cost of transporting bulk cargo, rail transport is generally cheaper than road transport. The proposed large and small scale farmers will benefit from this generally cheap mode of transport therefore proximity to railroads was an important variable to consider. Within a practical distance of 50 km, Selected Region 2 is well accessible to the Tazara Railway line *(Refer to Figure 24)*. More than 70% of Selected Region 3 is also accessible within the 50 km practical distance thus cargo (seed and/or crushed oil) and workers within this threshold can be carried out without difficulty *(Refer to Table 10)*. More than 80% of Selected Region 1 land area is 200 km away from the available railway lines, thus, it is the most constrained of when the three areas are ranked according to accessibility to the railroads infrastructure.

Table 10: Proximity of Railroads to Selected Regions

	Selected Region 1		**Selected Region 2**		**Selected Region 3**	
	ha	**%**	**ha**	**%**	**ha**	**%**
50 km Coverage	0	0	443 507	100	405 200	71
100 km Coverage	11 874	0.18	0	0	153 203	27
150 km Coverage	187 879	3	0	0	8 896	2
200 km Coverage	670 999	10	0	0	0	0

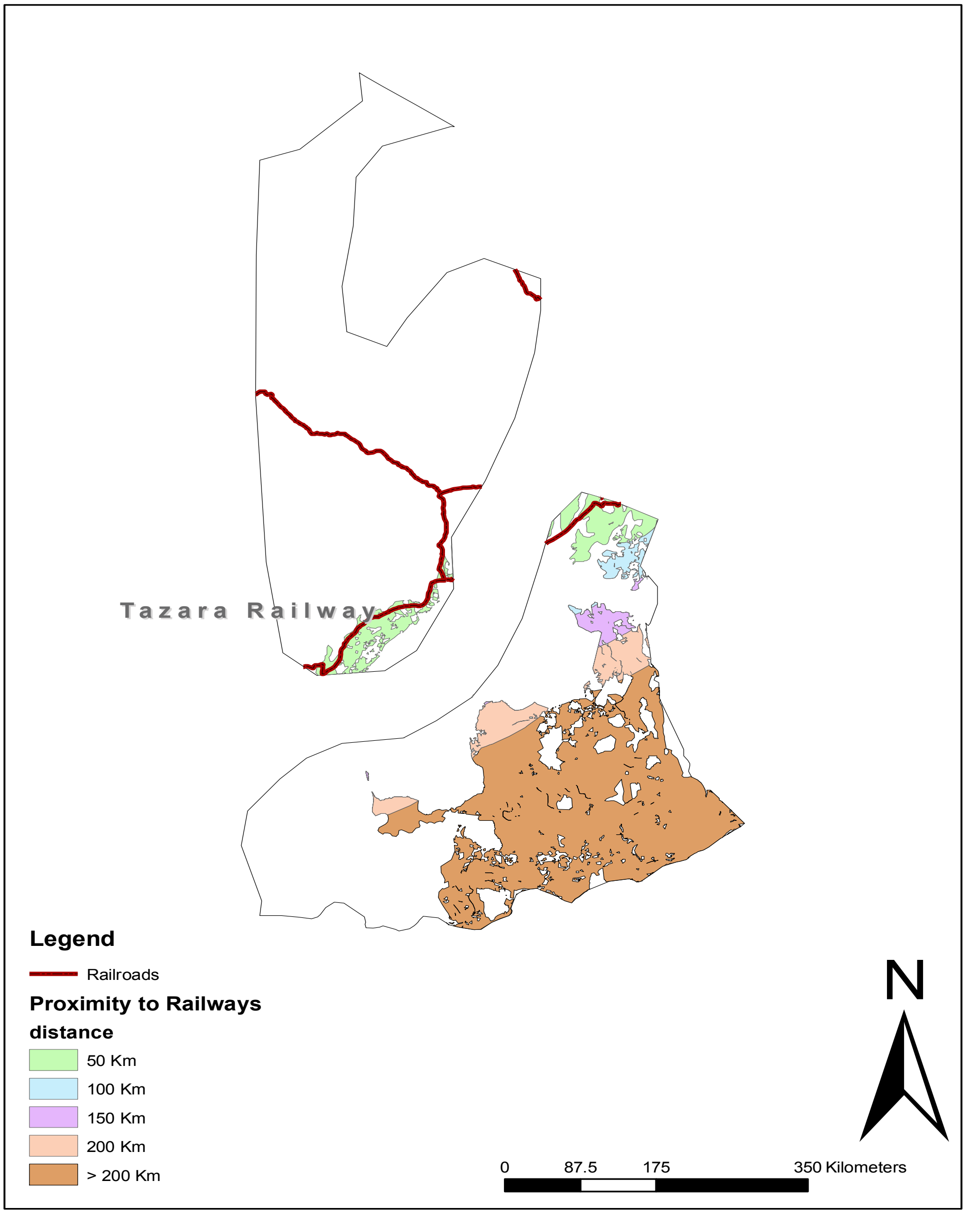

Figure 24: Proximity of Selected Regions to Railroads

For large scale biodiesel production, railway line construction is a long term project, which requires a high capital investment, even if it may be a convenient mode to carry the crushed oil for further transesterification, to the blending sites and to electricity production centres. It must be noted that the construction of such infrastructures can have detrimental effects on the ecosystems that exist within the semi arid regions, as there will be clearing of lands and relocation of livelihoods. This may not be welcomed by the already existing small scale farmers, pastoralists, miners who dwell in them. The available railway lines will be made more useful to the large and even small scale farmers when link graded dust roads are also constructed. These link roads will have to be used to transport either seed or oil to the nearby railway stations for carriage to the nearby depots (*can be an expeller, crude biodiesel production plants, or electricity production site)*.

5.2.3.4 Proximity of Selected Regions to Populated Places

The land that is viable for large scale cultivation is in the semi arid regions but it is important to note that there are villages that are populated in them. The village dwellers may not have to be displaced and this will be an added advantage, as the economically active people in them will have to be employed on the farms because biodiesel production will in no doubt generate employment. Manpower that is required for Jatropha production ranges from cultivation, tending, harvesting to oil production, blending and finally the marketing and sale of the oil. However, after establishment, the plant itself requires minimum maintenance for the rest of its life (Openshaw, 2000). The three selected regions for large scale cultivation are located in five administration zones but most jobs are expected to be created in the regions` rural districts where cultivable land is. Selected Region 1 dissects parts of Pwani, Lindi, Morogoro, Ruvuma and also takes the whole of Mtwara administrative zone (*Refer to Figure 20*). When density of the five administrative zones in Selected Region 1 is compared, Mtwara (68 p.km^2) is the most densely populated. Morogoro and Pwani administrative zones cover Selected Region 3 and their population densities are 25 p.km^2 and 27 p.km^2 respectively (Tanzania SENSA, 2003). Each of the three selected regions has populated places that are dotted across the space and Selected Region 1 has the greatest number of populated (74 places), followed by Selected Region 3 (14 places) and lastly Selected Region 3 where there are eight populated places (*Refer to Table 11*). The populated places data used in this study gave no indications of the number of people at each place. It must be noted that people in these populated places could potentially stay as a labour source for large scale investors.

Table 11: Proximity of Populated Places to Selected Regions

	Selected Region 1	Selected Region 2	Selected Region 3
Number of Populated Places	74	8	14
Number of Administrative Regions	5	1	2
Administrative Regions Involved	Pwani, Lindi, Morogoro, Ruvuma, Mtwara	Morogoro	Pwani, Morogoro
Area Served by Population within 10 km Walking Distance	1 698 823 ha (26%)	89 689 ha (20%)	298 618 ha (53%)

Within a practical walking distance of 10 km, workers are more willing to travel to and from work on foot but outside of this threshold, workers are less motivated to travel to the farms unless if a mode of transport is provided for them. As Table 11 and Figure 25 indicate, Selected Region 3 has the greatest share of populated places from which people can travel to the large scale farms on foot without difficulties. Selected Region 1 also has a 26% percent share and, therefore, will have more workers enrolled from this threshold to do on and off farm activities.

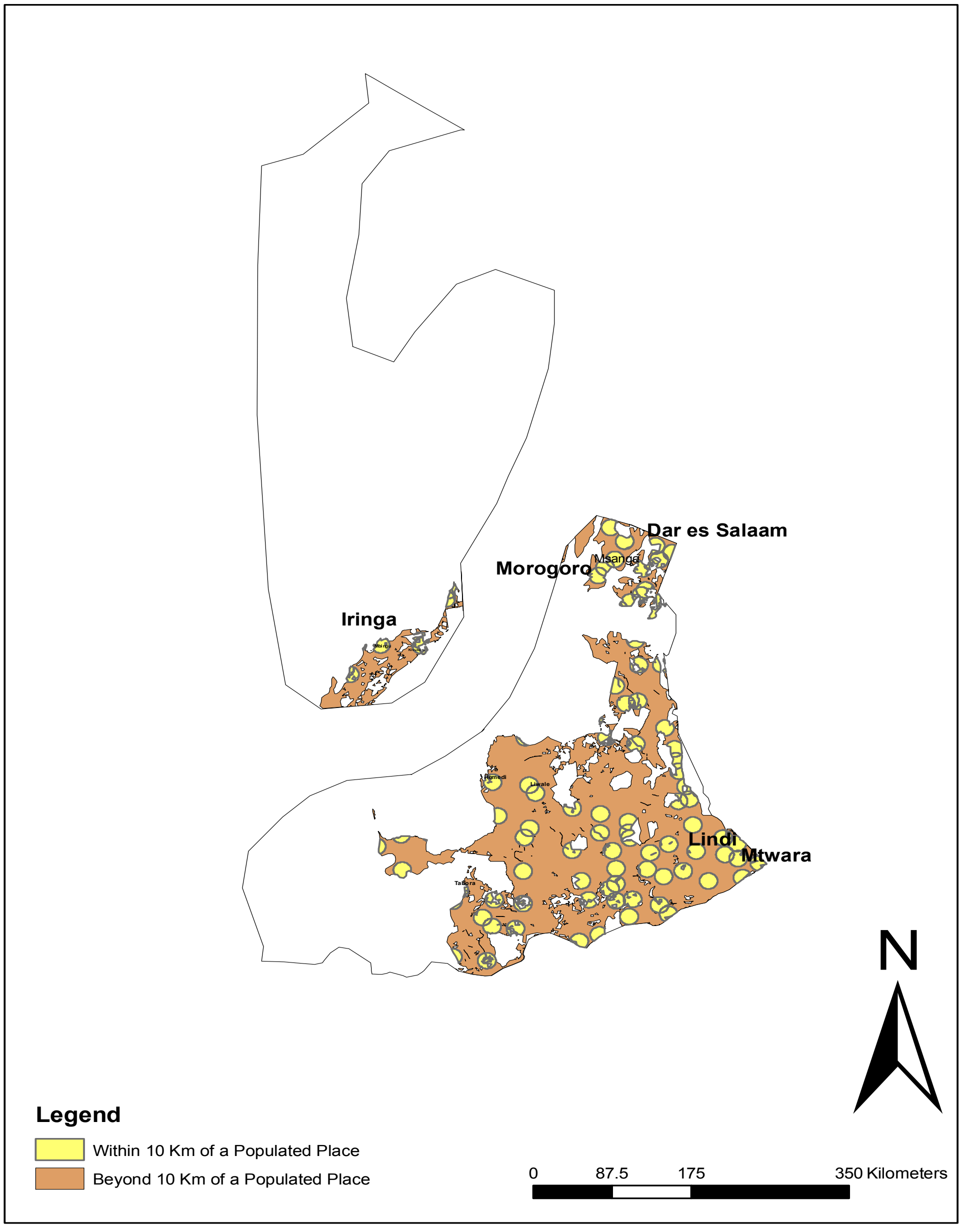

Figure 25: Proximity of Selected Regions to Populated Places

Formal wage employment in Tanzania constitutes only a small proportion of the total employment. Official unemployment stands at 12.9% and it is relatively higher in the urban areas (Wiskerke, 2008). As noted in section 2.10.2 by HDR (2008), agriculture is the highest employer of the country providing for 82% of employment. Women are the backbone of the Tanzanian rural economy, they do not have any control over the productive assets like land or cash and they have equal shares of workload in the agricultural activities with men (WFP, 2006b). The resources that are generated from the farms are managed predominantly by the male head of the household despite the fact that they all participate. To the areas where Jatropha has been known in Tanzania, gathering from Jatropha hedges is the most common activity and harvesting is considered to be a side activity that is mostly done by women and children. Manual harvesting is considered as the most labour intensive activity so far (Shuma, 2008). To the marginalized women and children of the rural districts where large scale Jatropha cultivation will be practiced, it will become an important source of employment and income generation. To the small scale farming areas, the women will also work on their own fields and at the same time work on their farms. However, job creation on small scale farms will have to be subsidized by the government or NGOs.

Takavarasha *et al*. (2005) notes that the rural SADC is being emptied of its labour force as people hope to make more money in the cities. It is also noted by NPPT (2006), in section 10.2.1, that rural urban migration has put a burden on public services and social infrastructures that are in the major cities of Tanzania. As suggested by Takavarasha *et al*. (2005), biofuels can completely change the setting as at macro-scale, their production could employ million rural laborers, thereby boosting economic growth. Table 12 shows the jobs that can potentially be created only in the agriculture sector of the semi arid regions` economy. A total of about 759 080 jobs are expected to be created. The growing of Jatropha is usually once and after the tree has established itself these jobs are more likely to be translated onto being seasonal thus during pruning and harvesting phases. DMEWR (2007) acknowledges that Jatropha oil seed plantations have the greatest job creation potential because they are profitably maintained and harvested under a labour intensive production system. It should be noted that the other jobs are created during phases of oil extraction, biodiesel production, blending, marketing and distribution of the final product.

Table 12: Jatropha Production Socio-economics

	Selected Region 1	Selected Region 2	Selected Region 3
Total Land Area	**6 580 000**	**443 507**	**567 298**
No of potential Jobs	**658 000**	**44 350**	**56 730**

Estimated at 0.1 job/ha (South Africa Study, 2006)

A suitability matrix with three levels and making use of the proximity analysis discussed above, was finally used to rank the three optimal locations for sustainable Jatropha cultivation. The ranking is presented in Table 12 below. When extend of area is used as the suitability defining factor, Selected Region 1 is the highly suitable location. This is followed by Selected Region 2, which is moderately suitable and lastly by Selected Region 3, which is marginally suitable. Selected Region 1 has several river networks where water to irrigate the crop can be drawn from, thus, it is highly suitable when considering its proximity to water sources. Proximity to transport infrastructure, places Selected Region 2 as highly suitable through both the use of road and rail transport. Several specific infrastructure design considerations will have to be considered if the accessibility of Selected Region 1 is to be improved. A suitability ranking for large scale cultivation according to population for labour requirements in the Jatropha production system, places Selected Region 1 as the most suitable, Selected Region 3 second best and Selected Region 2 as the least suitable for it has fewer populated places (*Refer to Table 13*).

Table 13: Suitability Ranking of the Selected Regions

	Rivers	Roads	Railway lines	Populated Places
Selected Region 1	HS	MG	MG	HS
Selected Region 2	MS	HS	HS	MG
Selected Region 3	MS	MS	MS	MS

NB: Highly Suitable (HS); Moderately Suitable (MS); Marginally Suitable (MG).

5.3 Conclusion

The three largest, most suitable, available areas in the semi arid regions are capable of producing enough Jatropha oil that can attract large scale investor interests. Multi-criteria analysis has interrogated and ranked their irrigation, infrastructure and job creation potential from various perspectives, i.e. government subsidy to create jobs, NGOs to create jobs and generate electricity. Jatropha will have to be irrigated to increase economic yield and construction of infrastructure to those areas that are not served by roads and railway lines will also help improve Tanzania's economy. While these three largest, most suitable and available areas are capable of producing enough Jatropha oil that can attract large scale investor interests, the government of Tanzania must avoid displacement and exploitation of people by these investors. People who stay in the populated places could be kept on the land as they will work on the farms. The small scale areas would grow to supply the large scale farmers with more seeds for the plants to continue running or they would generate electricity of their own use.

Chapter Six
Conclusion and Recommendations

6.1 Conclusion

The aim of the study was to identify three optimal locations for large scale Jatropha cultivation for biodiesel production in the semi arid regions of Tanzania without detrimentally affecting biodiversity and rural livelihoods. The objectives that accompanied this aim were outlined in Chapter One. The previous chapter presented and discussed the key findings that this project obtained. A conclusion to the key findings of the whole project, the objectives met as well as recommendations emanating from this study will be presented in this chapter.

The study identified the three largest, most suitable, available areas in the semi arid regions where Jatropha cultivation is most probable. These areas have a total area of 7.6 million hectares and they are enclosed in Morogoro, Pwani, Lindi, Ruvuma and Mtwara administrative zones. An optimal yield analysis to rate the potentiality of these areas showed that, about 14.44 million litres oil can be produced from them. Tanzania requires 17.30 million litres of biodiesel to meet its 10% fuel import substitution. The production from these three areas can, therefore, meet 83% of the country's needs. This showed that the three areas are able to produce substantial amounts of biodiesel that can be fed into the country's transport fuel requirements. Tanzania is not well electrified and therefore depends on the use of backup generators and lighting fuels for the homes when electricity goes out. An analysis to rate the potential for electricity generation showed that these three areas are able to produce six percent of the 2 776 GWh of electricity that country requires. It was concluded that these three areas, even though they are in the semi arid regions, could provide a win-win offer, i.e. they are significant to blending or could make a contribution to electricity if large scale cultivation is considered.

The available and suitable areas that were in the agro-ecological sub-zones, which were too isolated, were further analyzed because the results were viable in terms of ranking the areas for small scale perspective for NGO investment. Based on the assumptions that Jatropha has to be irrigated in order to obtain a viable commercial yield, whereas labour to work on the farms can be transported in or accommodated, railway lines and roads can be built, GIS was used to buffer categories for rivers, populated places, railways and roads to calculate the percentage of the areas within each category. A suitability ranking identified Selected Region 1 as the highly suitable location, Selected Region 2 as moderately suitable and Selected Region 3 as marginally suitable when area extend is used as a criterion for ranking. Selected Region 1 is highly suitable when considering proximity to water sources because it has several river networks to which potential irrigation water can be drawn. Selected Region 2 was selected as highly suitable when proximity to transport infrastructure (both roads and railway lines) was used as the ranking criterion. The development of infrastructure on the areas that are not served by roads and railway lines will depend on investor's capital outlay but if realized, this will help improve the economy of Tanzania. Several specific infrastructure design considerations will have to be considered if the accessibility of Selected Region 1 is to be improved. There is viable land in the semi arid regions of Tanzania that can attract investors and it is in no doubt that the Jatropha production system will generate employment. However, it must be noted that the government of Tanzania must avoid displacement and exploitation of people by these investors. A suitability ranking for labour requirements placed Selected Region 1 as the most suitable, Selected Region 3 second best and Selected Region 2 as the least suitable for it has fewer populated places.

Tanzania semi arid regions are dissected by several inland water bodies and the rivers that can have their water resources harnessed to the semi arid regions are the perennial Ruvuma, Ruvu and the Kilombera River. Most of the semi arid regions are free from constraints posed by slope percent, i.e. they are suitable with respect to topography. After integrating the number perennial river networks in each selected region to percent slope calculation findings, one will conclude that it is possible to irrigate Jatropha in its initialization phase. Small scale farmers would have to grow Jatropha and supply the seeds to the large scale farmers` biodiesel plants or they could generate electricity for home consumption after using the small scale oil expellers. The cultivation of Jatropha on a small scale is more likely to reduce the desire to go to towns and to look for employment.

6.2 Recommendations

- The government must encourage large scale investors to utilize land that the study identified as largest, available and most suitable in the semi arid regions of Tanzania. People must not be displaced and instead they will have to work on the large scale farms.

- Jatropha will have to be irrigated to enhance economic yield.

- Roads and railway infrastructure will have to be constructed to areas that are not well served. Dust roads will have to be constructed in areas that are within 10 km or less for transporting seeds, crushed oil or biodiesel from the farms to the nearest roads/railway lines or electricity generation plants. A depot will have to be constructed next to the railway lines so that workers can drop the produce, i.e. seed to go to oil expellers or crushed oil to go to the transesterification and finally blending plant.

- The amount of labour that is required to ensure sustainable biodiesel production is still a grey area, which will need to be studied before final recommendations are made to set up large scale Jatropha biodiesel production. In other words, the ratio of labour to oil production from planting still needs to be looked at to ensure the production will attract higher economies of scale.

- The study was basically desktop-based and the several datasets that were sourced and used were the best available. Infield verifications of the identified areas will have to be done, for it will shed more light on the characteristics of Jatropha that can be used to come up with overall suitability. The infield verifications will also provide adequate evidence on whether the suitable areas, if cultivated, will not have any effects on natural resources and livelihoods of people that dwell in the nearby rural areas.

- A Cost Benefit Analysis (CBA) must be first performed before Jatropha cultivation is considered. For example, the study did not account for the energy inputs that are involved in the full production of the energy from Jatropha. From cultivation stage to the final selling of biodiesel, energy is required and the associated expenditure needs a costs benefit analysis to be done first so as to assess the economic viability of biodiesel production using Jatropha obtained from these three largest, available and potentially suitable areas.

- The agro-ecological regions, which have potential for Jatropha cultivation, were not considered for analysis due to some limitation posed by slope steepness. These can have Jatropha cultivated on a small scale basis and intercropped with some other food crops. Terracing of the land will have to be done by small scale farmers if the full potential of their land is to be realized.

- In field verification of closed forest areas are also necessary to assess whether the degraded forest areas really exist and to verify whether the cultivation of Jatropha is the best option, i.e. will not pose threats to evasiveness when these forests are rehabilitated by it.

References

Achten, W.M.J., Mathijs, E., Verchot, L., Singh, V.P., Aerts, R. and Muys, B., 2007: Perspective-Jatropha biodiesel fueling sustainability? *Bioproducts and Biorefining*, 1(4), 283-291.

Achten, W.M.J., Verchot, L., Franken, Y.J., Mathjis, E., Singh, V.P., Aerts, R. and Muys, B., 2008: Jatropha biodiesel production and use, *Biomass and Bioenergy,* 32(12), 1063-1084.

Africa News Network, 2008: *Tanzania government skips international biofuels meeting held in its capital*, 22 September 2008 [online], http://africanagriculture.blogspot.com/search/label/Tanzania Accessed, 04 November 2008.

Africa News Network, 2009: *Zimbabwe sets ambitious to Jatropha fuel targets*, 30 March 2009 [online], http://africanagriculture.blogspot.com/2009/Zimambwe-sets-ambitious-fuel.html Accessed, 15 April 2009.

Amin, D.K.H., 2001: *Global project on development of Jatropha plant*, Global Warming/Biodiversity/Antidesertification. Rep., United Nations Industrial Development Organisation and Global Environment Facility, Khartoum, XP/GLO 00/024, 1-68.

AQUASTAT, 2005: *FAO`s information system on water and agriculture-United Republic of Tanzania*, Food and Agriculture Organization, Rome [online], http://www.fao.org/ag/agl/aglw/aquastat/countries/tanzania/index.html Accessed, 15 September 2008.

AQUASTAT, 2008: *Country profile-Tanzania* [online], http://www.fao.org/ag/agl/agl/aglw/aquastat/countries/index.stm Accessed, 17 August 2008.

Ardayfio-Schandorf, E., undated: *The Fuel/energy crisis in Sub-Sahara Africa* [online], http://www.unu.edu/unupres/unupbooks/809Eod-htm Accessed, 10 March 2008.

ARI-Mlingano1, 2006: *Rainfed agriculture: Crop suitability for Tanzania*, Ministry of Agriculture, Food Security and Cooperatives, Dar es Salaam.

ARI-Mlingano2, 2006: *Soils of Tanzania and their potential for agriculture development*, Ministry of Agriculture, Food Security and Cooperatives, Dar es Salaam.

ASDP, 2005: *Environmental and social management framework,* Agricultural Sector Development Program, Government of Tanzania. Rep., Dar es Salaam.

ASDS, 2005: *The United Republic of Tanzania, Agricultural Sector Development Strategy*, Government of Tanzania, Dar es Salaam.

Ashton, P. and Ramasar, V., 2002: Water and HIV/Aids: Some strategic considerations in Southern Africa, In Turton, A. and Henwood, R., (eds.) *Hydropolitics in the developing world: a southern African perspective*, African Waters Issues Research Institute, University of Pretoria, Pretoria, 217-235.

Bahgat, G., 2003: The new geopolitics of oil: The United States of America, Saudi Arabia, and Russia, *Orbis*, 47(3), 447-461.

Barbier, E.B., Sanchez, P., Thomas, R. and Wagner, A., 1997: The Economic determinants of land degradation in developing countries, *Philosophical Transactions: Biological Sciences*, 352(1356), 891-899.

Bartholomè, E. and Belward, A.S., 2005: GLC2000: A new approach to global land cover mapping from Earth Observation Data, *International Journal of Remote Sensing*, 26(9), 1959-1977.

Basalirwa, C.P.K., Odiyo, J.O., Mngono, R.J. and Mpeta, E.J., 1999: The climatological regions of Tanzania based on the rainfall characteristics, *International Journal of Climatology*, 19, 69-80.

Benge, M., 2006: *Assessment of the potential of Jatropha curcas (biodiesel tree for energy production and other uses in developing countries)* [online], http://www.echotech.org/mambo/index.php?option=com_docman&task=doc_view&gid=179 Accessed, 02 March 2008.

Berry, L. and Berry, E., 1969: Land use in Tanzania, In Kauzeni, A.S., Kikula, I.S., Mahomed, S.A., Lymino, J.G. and Dalal-Clayton, D.B., 1993: *Land use planning and resource use assessment in Tanzania: a case study*, Institute of Research Assessment, University of Dar es Salaam and Institute of Environment and Development. Rep., Dar es Salaam, 71(35), 1-132.

Betke, D., Klopfer, D., Kutler, A. and Wehrmann, B., (eds.) 1999: *Land use planning: Methods, strategies and tools,* Deusche Gesellschaft fur Technische Zusammenarbeit (GUT) Gmbt, Eschborn, Germany.

Blume, H., 1985: *Geography of sugarcane*, Verlag Dr. Albert Bartens, Berlin, 185.

Boelee, E. and Laamrani, H., 2003: *Multiple uses of irrigation water in northern Morocco*, International symposium on water, poverty and productive uses of water at the household level, 21-23 January 2003, Muldersdrift, South Africa.

Bryant, L., 1976: The development of the diesel engine, *Technology and Culture*, 17(3), 432-446.

Butler, R.A., 2006: *Diversity of image-rainforest diversity* [online], http://rainforest.mongabay.com/0305/htm Accessed, 21 August 2008.

Campbell J.B., 1996: *Introduction to remote sensing*, 2nd Edition, Taylor and Francis, London, United Kingdom, 1-622.

Campbell, J.B., 2002: *Introduction to remote sensing,* 3rd edition, Taylor and Francis, London, United Kingdom.

Caniels, M.C.J., Van Eijck, J. and Romijin, H., 2007: *Development of new supply chains: Insights from Strategic Niche Management*, Eindhoven Centre for Innovation Studies, Working Paper, The Netherlands, GE 07-01, 1-17.

Chagache, B., 2003: *Jatropha oil as a renewable fuel for road transport: Policy implications for technology transfer in Tanzania*, Published MSc thesis in Environmental Management and Policy, The International Institute for Industrial Environmental Economics, Lund University, Lund, 1-70.

Chape, S., Harrison, J., Spalding, M. and Lysenko, I., 2005: Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets, *Philosophical Transactions of the Royal Society Biological Sciences*, 360(1454), 443-455.

Constanza, R., d'Arge, R., De Groot, R., Farberk, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and Van den Belt, M., 1997: The value of world`s ecosystems services, *Nature*, 87, 253-260.

Cummins, T., 2008: *Biodiesel-The good, the bold and the beautiful (1)*, Ezine Articles, February [online], http://ezinearticles.com/?Bio-Diesel---The-Good,-the-Bold-and-the-Beautiful-(1)&id=982761 Accessed, 01 May 2008.

Cunhete, F., 2007: *Mozambique and biofuels*, Powerpoint presentation at Eastern and Southern Africa Regional Workshop on Biofuels, UNEP, Nairobi, Kenya, 28-29 June 2007.

Daey Ouwens, K., Francis, G., Franken, Y.J., Rijssenbeek, W., Riedacker, A., Foidl, N., Jongschaap, R. and Bindraban, P., 2007: *Position paper on Jatropha curcas, state of the art: Small and large scale project development*, Expert seminar on *Jatropha curcas L*. agronomy and genetics hosted by FACT Foundation, Wageningen, 26-28 March 2007.

Dehgan, B., 1984: Phylogenetic significance of interspecific hybridization in Jatropha (Euphorbiaceae), *Systematic Botany*, 9(4), 467-478.

Demirbas A., 2007: Progress and recent trends in biofuels, *Progress in Energy and Combustion Science*, 33(1), 1-18.

De Pauw, E.F., 1984: *Soils, physiography and agro-ecological zones of Tanzania*, Crop Monitoring and Early Warning Systems Project. Final Report., Ministry of Agriculture, Food and Agricultural Organization/Government of Tanzania, Rome/Dar es Salaam.

DESA/DSD., 2007: *Small scale production and use of liquid biofuels in Sub-Saharan Africa-perspectives for sustainable development*, Commission on Sustainable Development, Fifteenth Session, 3 April-11 May 2007, New York.

Diaz-Chavez, R.O. and Woods, J., 2008: *Sustainability assessment of biofuels in practice*, 5th International conference on biofuels hosted by Winrock International India, 7-8 February 2008, New Delhi.

Di Gregorio, A. and Jansen, L.J.M., 2005: *Land cover classification systems-Classification concepts and user manual software version (2),* Food and Agricultural Organization. Rep, Rome, Italy.

DMEWR, 2007: *The feasibility study for the production and use of biofuels in Botswana*, Department of Minerals, Water and Resources, Government Printer, Gaborone, October, 1-74.

Duncan, R.C. and Youngquist, W., 1999: *Encircling the peak of world oil production* [online], http://www.mforsustain.org/oil_duncan_and_youngquist_encircling_oil.htm

Accessed, 10 April 2008.

EIA, 2007: *International energy annual 2005 glossary*, International Energy Agency [online], http://www.eia.doe.gov/emeu/iea/glossary.html Accessed, 27 August 2008.

ESRI, 2007: The *guide to geographic information systems* [online], http://www.gis.com/whatisgis/index.html Accessed, 12 August 2007.

Euler, H. and Gorriz, D., 2004: *Case study "Jatropha Curcas,"* Global Facilitation Unit for Underutilized Species, Frankfurt.

FAO, 1976: *A framework for land evaluation*, Soils Bulletin 32, Food and Agricultural Organization, Rome

FAO, 1985: *Guidelines: Land evaluation for irrigated agriculture*. Soil Bulletin 55, Food and Agricultural Organization, Rome [online], http://www.fao.org/docrep/X5648E/x5648e00.HTM Accessed, 12 March 2008.

FAO, 1993: *Guidelines for land-use planning*, Food and Agricultural Organization Development Series 1, Rome.

FAO, 2007: *Sustainable bioenergy-A framework for decision makers*, Food and Agricultural Organization, Rome.

FAO, Forestry, 2007: *FAO Forestry Tanzania country profile*, Food and Agricultural Organization, Rome [online], http://www.fao.org/forestry/site/countryinfo/en/tza Accessed, 21 July 2008.

FAO/IIASA., 2007: *Mapping biophysical factors that influence agricultural production and rural vulnerability, Environment and Natural Resources Series*, 11, Food and Agriculture Organization/International Institute for Applied Systems, Rome, 1-93.

Fischer, G., Van Velthueizen, H., Shah, M. and Naachtergaele, F., 2002: *Global agro-ecological assessment in the 21st century: Methodology and results*, Food and Agriculture Organization/International Institute for Applied Systems, Rome.

Foester, E., Assamann, D., Clashausen, C., Kerckow, B. and Fritsche, U.R., (revs.) 2005: *Liquid biofuels for transportation in Tanzania: Potential and implications for sustainable agriculture and energy in the 21st century*, Germany Technical Cooperation. Rep., Eschborn, August, 1-149.

Foidl, N., Foildl, G., Sanchez, M., Mittelbach, M. and Hackel, S., 1996: *Jatropha curcas L*. as a source for the production of biofuels in Nicaragua, *Bioresources Technology*, 58, 77-82.

Francis, G., Edinger, R. and Becker, K., 2005: A concept of simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded areas in India: Need, potential and perspectives of Jatropha plantations, *Natural Resources Forum*, 29, 12-24.

Fritsche, U.R., Katja, H., Hermann, A., Schulze, F. and Wiegmann, K., 2006: *Sustainability standards for bioenergy*, WWF Germany, Frankfurt am Main, 1-80.

Fritz, S., Batholome, E., Belward, A., Hartley, A., Stibig, H.J., Eva, H., Mayaux, P., Bartalev, S., Latifovic, R., Kolmert, S., Roy, P.S., Agrawal, S., Bingfang, W., Wenting, X., Ledwith, M., Pekel, J.F., Giri, G., Mucher, S., De Badths, E., Tateishi, R., Champeaux, J.L. and Defourny, P., 2003: *Harmonization, mosaicking and production of the Global Land Cover 2000 database (Beta version)*, European Commision Joint Research Centre, Ispra, Italy, 41 [online], http://www.gvm.jrc.it/glc2000 Accessed, 28 September 2008.

Fritz, S. and See, L., 2005: Comparison of landcover maps using fuzzy agreement, *International Journal of Geographical Information Sciences*, 19(7), 787-807.

Geology.com, 2007: *Tanzania map-Tanzania satellite image* [online], http://geology.com/world/tanzania-satellite-image.shtml, Accessed, 31 October 2007.

Ghosh, A., Chaudhary, D.R., Reddy, M.P., Rao, S.N., Chikara, J., Pandya, J.B., Patolia, J.S., Gandhi, M.R., Adimurthy, S., Vaghela, N., Mishra, S., Rathod, M.R., Prakash, A.R., Shethia, B.D., Upadhyay, S.C., Balakrishna, V., Prakash, R. and Ghosh, P.K., 2007: Prospects for Jatropha methyl ester biodiesel in India, *International Journal of Environmental Studies*, 64(6), 659-674.

Giri, G., Zhiliang, Z. and Reed, B., 2004: A comparative analysis of the Global Land Cover 2000 and MODIS land cover data sets, *Remote Sensing of Environment*, 94, 123-132.

Gnansounou, E., Panichelli, L. and Villegas, J.D., 2007*: Sustainable liquid biofuels for transport: The context of Southern African Development Community*, Working

Paper Ref. 430.100 for the Ecole Polytechnique Federal De Lausanne, Lausanne, Switzerland, 1-21.

Goldemberg, J., Monaco, L.C. and Macedo, I.C., 1993: The Brazilian fuel alcohol program, In Johansson, H., Kelly, H., Reddy, A.K.N. and Williams, R.H., *Renewables for fuels and electricity*, Island Press, Washington D.C, 841-864.

Goldemberg, J. and Coelho S.T., 2004: Renewable energy-traditional biomass vs. modern biomass, *Energy Policy,* 32 (2), 711-714.

Gubitz, G.M., Mittelbach, M. and Trabi, M., 1998: Exploitation of the tropical oil seed plant *Jatropha curcas* L, *Bioresource Technology*, 67(1999), 73-82.

Hall, D.O. and House, J.I., 1995: Biomass energy development and carbon dioxide mitigation options, *International Conference on National Action to Mitigate Global Climate Change*, United Nations Environment Programme Collaboration Centre on Energy and Environment, Rise National Laboratory, Copenhagen, Denmark, 7-9 June 1994.

Hannerz, F. and Lotsch, A., 2006: *Assessment of land use and cropland inventories for Africa,* Discussion Paper No. 2 for the Centre for Environmental Economics and Policy in Africa, University of Pretoria [online], http://www.ceepa.co.za/docs/CDPNo22.pdf Accessed, 7 October 2008.

HDR, 2008: *Fighting climate change: Human solidarity in a divided world*, United Nations Development Programme: Human Development Report (2007/2008). Rep, New York [online], http://hdrr.undp.org/en/media/hdr_2007/2880_en_complete.pdf Accessed, 28 June 2008.

HEDON, 2007: *Tanzania country report synthesis*, Household Energy Network [online], http://www.hedon.info/goto.php/TanzaniaCountrySynthesis Accessed, 30 June 2008.

Heller, J., 1996: *Physic nut, Jatropha curcas L*, International Plant Genetic Resources Institute, Rome, Italy [online], http://www.ipgri.cgiar.org/publications/pubfile.asp?ID_PUB=161 Accessed, 20 March 2008.

Heller, J., Foidl, N., Foidl, G., Sanchez, M., Mittelbach, M and Hackel, S., 1999: *Jatropha curcas* L. as a source for the production of biofuels in Nicaragua, *Bioresources Technology*, 58, 77-82.

Hennenberg, K.J. and Fritsche, U.R., 2008: *Expert meeting on biodiversity standards and strategies for sustainable cultivation of biomass for non food purposes*., Final report on the Vilm Expert Meeting on Biomass and Biodiversity for German Federal Agency for Nature Conservation (BfN) , Oko-Institute Darmstadt, 12-15 March 2008 [online], www.oeko.de Accessed, 17 September 2008.

Henning, R.K., 2000: *The Jatropha booklet-A guide to Jatropha production in Zambia*, Bangani, GbR, Rothkreuz, Weissensberg.

Henning, R.K., 2003: *The Jatropha booklet: A guide to Jatropha system and its dissemination in Africa,* bangani, GbR, Rothkreuz, Weissensberg.

Henning, R.K., 2004: "The Jatropha system"- Integrated rural development by utilization of *Jatropha curcas* (JCL) as a raw material and as a renewable energy-economy and dissemination, *International Conference on Renewables*, Born, 2004 [online], www.jatropha.de Accessed, 6 May 2008.

Henning, R.K., 2007: Jatropha curcas L, In: Van der Vossen, H.A.M. and Mkamilo, G.S., (eds.) 2007: *PROTA 14-Vegetable oils/Oléagineux* [CD-Rom], PROTA, Wageningen, Netherlands.

IEA, 2005: *World Energy Outlook-Energy balances of non-OECD countries*, Organization for Economic Cooperation and Development/International Energy Agency, Paris, France.

IEA, 2008: *Key world energy statistics 2007*, International Energy Agency, France, 1-82

IFAD, 2007: *Rural poverty portal* [online], http://www.ruralpovertyportal.org Accessed, 24 September 2008.

IMF, 2008: *United Republic of Tanzania: Poverty Reduction Strategy Paper- Annual Implementation Report 2006/07*, International Monetary Fund. Rep., Washington, DC, 08/22.

INCRAF, 2003: *Jatropha curcas,* International Centre for Research in Agroforestry database [online], http://www.worldagroforestrycentre.org/Sites/TreeDBS/AFT/SpeciesInfor.cfm?SPID=1013 Accessed, 25 August 2008.

IUCN, 2004: *Guidelines for protected areas management categories*, International Union for Conservation Nature, Publications Services Unit, Cambridge, Switzerland, 1-261.

Jackson, I.J.., 1970: Some physical aspects of water resources development in Tanzania, *Geografiska Annaler, Series A, Physical Geography*, 52(3/4), 174-185.

Johanssom, T.B., Kelly, H., Reddy, A.K.N. and Williams, R.H., (eds.) 1993: *Renewable energy: sources for fuel and electricity*, Island Press, Washington D.C, 1-691.

Jongschaap, R.E.E., Corre, W.J., Bindraban, P.S. and Brandenburg, W.A., 2007: *Claims and facts on Jatropha curcas L- global Jatropha curcas evaluation, breeding and propagation programme*, Plant Research International. Rep., Wageningenur, 158, 1-42.

Johnson, F.X., 2007: *Bioenergy and the sustainability transition: From local resource to global commodity*, Stockholm Environmental Institute, Stockholm, Sweden, 1-22.

Johnson, F.X. and Matsika, E., 2006: Bioenergy trade and regional development- the case bioethanol in southern Africa, *Energy for Sustainable Development*, X, 1, 42-53.

Johnson, F.X. and Rosillo-Calle, F., 2007: *Biomass, livelihoods and international trade-challenges and opportunities for the European Union and Southern Africa*. SEI, Climate Energy Report 2007-01, Stockholm Environmental Institute, Stockholm, Sweden, 1-80.

Karekezi, D.M., 1995: *Renewable energy technologies as an option for a low carbon energy future for developing countries: case example from eastern and southern Africa*, Africa Energy Policy Research Network, Nairobi.

Karekezi, S., Kimani, J. and Wambile, A., 2007: *Renewables in Africa, Energy experts` concept paper*, Africa Energy Policy Research Network, Nairobi.

Kartha, S., Leach, A. and Rajan, S.C., 2005: *Advancing bioenergy for sustainable development: Guideline for policymakers and investors (Volumes l-lll),* Report prepared by the Stockholm Environmental Institute for the Energy Sector Management Assistance Program, World Bank, Washington DC, 1-234.

Kaushik, N. and Kumar, 2006: *Jatropha curcas L-siviculture and uses,* 2nd edition, Agrobios, Jodhpur, 1-90.

Kaushik, N., Kumar, S. and Kumar, K., (undated): *Agro-technology of Jatropha curcas cultivation, CCS HAU Regional Research Station, Rewari, India*, Unpublished Rep, [online], www.bioruta.com/Jatropha/Agrotechnology%20of%20Jatropha.pdf Accessed, 26 September 2008.

Kauzeni, A.S., Kikula, I.S., Mahomed, S.A., Lymino, J.G. and Dalal-Clayton, D.B., 1993: *Land use planning and resource use assessment in Tanzania: A case study*, International Institute of Research Assessment, University of Dar es Salaam and Institute of Environment and Development, Dar es Salaam

Kingsbury, J.M., 1964: Poisonous plants of the United States and Canada, In Makkar, H.P.S., Becker, K., Sporer, F. and Wink, M., 1997: Studies on nutritive potential and toxic constituents of different provenances of *Jatropha curcas, Journal of Food Chemistry*, 45, 3152-3157.

LEAT, 2008: *Review of the decentralization process and its impacts on environmental and natural resource management in Tanzania*, Lawyers Environmental Action Team [online], http://www.leat.or.tz/publictions/decentralisations/1.3/envproblems.php Accessed, 25 September 2008.

Limbu, F., 1995: *Agricultural and rural development in Tanzania: A survey of the 1980-1985 literature*, Economic and Social Research Foundation (ESRF), Dar es Salaam.

Lovett, J.C., 2007: Biofuels and ecology, *African Journal of Ecology*, 45(20), 117-119.

Lyimo, B.M., 2006: *Energy and sustainable development in Tanzania*. Rep., Helio International Sustainable Development Watch (2005/2006).

Ma, F. and Hanna, M.A., 1999: Biodiesel production: a review, *Bioresource Technology,* 70, 1-15.

Maguje, A.E., 2004: *Gateway to land and water information report*, Tanzania National Report Institute of Resource Assessment. Rep, University of Dar es Salaam. Dar es Salaam.

Makkar, H.P.S. and Becker, K., 1997: Potential of Jatropha seed cake as a protein supplement in livestock feed and constraints to its utilization, In Makkar, H.P.S., Becker, K., Sporer, F. and Wink, M., 1997: Studies on nutritive potential and toxic constituents of different provenances of *Jatropha curcas, Journal of Food Chemistry*, 45, 3152-3157.

Mathews, J.A., 2007: Biofuels: What a biopact between North and South could achieve, *Energy Policy*, 35, 3550-3570.

Mathews, J., 2008: Biofuels, climate change and industrial development- can the tropical South build 2000 biorefineries in the next decade? *Biofuels, Bioproduction and Biorefinery*, 2, 103-125.

Martínez-Herrena, J., Siddhuraju, P., Francis, G., Dávila-Ortíz, G. and Becker, K., 2005: Chemical composition, toxic/ antimetabolic constituents, and effects of different treatments on their levels in four provenances of *Jatropha curcas* L. from Mexico, *Journal of Food Chemistry,* 96(2006), 80-89.

Maselli, F., Gregorio, D. A., Capecchi, V. and Breda, F., 2008: Enrichment of land cover polygons with eco-climatic information derived from MODIS NDVI imagery, *Journal of Biogeography*, 1-12.

Matlock, M., (ed.) 2008: "Water profile of Tanzania," *Encyclopedia of Earth* [online], http://www.eoearth.org/article/Water_profile_of_Tanzania Accessed, 29 August 2008.

Mayaux, P., Bartholome, E., Massart, M., Van Custem, C., Cabral, A., Nonguierma, A., Diallo, O., Pretorius, C., Thompson, M., Cherlet, M., Pekel, J.F., Defourny, P., Vasconcelos, M., Di Gregorio, A., Fritz, S., De Grandi, G., Elvidge, C., Vogt, P. and Belward, A., 2003: *Land cover map of Africa*. Rep., European Commission/Joint Research Commission, Italy.

Mbilinyi, B.P., Tumbo, S.D., Mahoo, H.F., Senkondo, E.M. and Hatibu, N., 2005: Indigenous knowledge as decision support tool in rainwater harvesting, *Physics and Chemistry of the Earth*, Parts A/B/C, 30 (11-16), 792-798.

Mbwambo, L., 2004: *Status of arid and semi arid lands of Tanzania*, Tanzania Forestry Research Institute, Paper presented at the Dryland Agroforestry Workshop, 1st-3rd September 2004, International Centre for Research in Agroforestry Headquarters Nairobi-Kenya.

McCallum, I., Obersteiner, M., Nilsson, S. and Shvidenko, A., 2006: A spatial comparison of four satellite derived 1 km global land cover datasets, *International Journal of Applied Earth Observation and Geoinformation*, 8, 246-245.

Mendoza, T.C., Castillo, E. and Aquino, A.I., 2007: *Towards making Jatropha "Tubang Bakod" a viable source of biodiesel in Philippines*, Uni P Los Banos College, Laguma.

MFC Nyetaa, 2007: *Biofuels in Mali*, United Nations Industrial Development (UNIDO), Paper presented at the Biofuels Workshop, December 2007, Accra, Ghana [online], http://www.tcs.triesterit/Portal/Activity/Document.aspx Accessed, 1 April 2009.

Moodley, P., 2007: *Exploring biofuel possibilities in Sub-Saharan Africa-Assessment of experiences and status quo of Jatropha curcas cultivation is arid and semi arid region of Sub-Saharan Africa*, Unpublished BSc Honours thesis, University of KwaZulu-Natal, Durban.

Morgan, W.T.W., (ed.), 1969: *East Africa: Its people and resources*, Oxford University Press.

Murphy, M.J., Ketola, N.H. and Raj, P.K., 2005: *Summary and assessment of safety, health, environmental and system risk of alternative fuels*, United States of America Department of Transportation, Federal Transit Administration. Rep., No FTA-MA-90-7007-95-1 [online], http://transit-safety.volpe.dot.gov/publications/cleanair/alt_fuel/alt_fuel.htm Accessed, 6 August 2008.

NBST, 2009: *What's new*, National Bureau Statistics of Tanzania [online], http://www.nbs.go.tz/ Accessed, 15 February 2009.

NAPA, 2006: *United Republic of Tanzania*, National Adaptation Programme of Action, Vice President`s Office, Division of Environment, January 2007 [online], http://unfccc.int/resource/docs/napa/tza01.pdf Accessed, 12 July 2008.

NMEC, 2006: *Integrated ecosystems assessment in Tanzania: Experiences in ecosystems management*, National Environmental Management Council, Dar es Salaam.

NPPT, 2006: *United Republic of Tanzania*, Ministry of Planning and Economic Empowerment, Dar es Salaam.

Olderman, L.R., Hakkeling, R.T.A. and Sombroek, W.G., 1991: *World map of the status of human-induced soil degradation-explanatory note*, International Soil Reference and Information Centre/ United Nations Environment Programme, Wageningen/Nairobi [online], http://www.isric.org/webdocs/Docs/ISRIC Accessed, 13 March 2009.

Openshaw, K., 2000: A review of Jatropha curcas: an oil plant of unfulfilled promise, *Biomass and Bioenergy*, 19, 1-15.

Parsons, E., 2005: *Jatropha in Africa-fighting the desert and creating wealth* [online], http://ecoworld.com/features/2005/08/21/jatropha-in-africa/ Accessed, 27 August 2008.

Pinto, A.C., Guarieiro, L.L.N., Rezende, M.J.C., Ribeiro, N.M., Torres, E.A., Lopes, W.A., Pedro, A., Pereira, De P. and De Andrade, J.B., 2003: Biodiesel: an overview, *Journal of Brazil Chemistry Society*, 16(6B), 1313-1330.

PRB, 2007: *World population data sheet-Tanzania,* Population Reference Bureau [online], http://www.prb.org/Datafinder/Geography/MultiCompare.aspx?variables=24,1,2,1 Accessed, 30 March 2008.

ProBios, 2006: *Promotion of biodiesel for sustainable development in south and south east Asia*, Working Conference Proceedings, Newcastle, 12 September 2006.

Rao, G.R., Rao, J.V., Rao, K.V., Korwar, G.R. and Ramakrishna, Y.S., 2008: *On-farm research experiences of CRIDA on bio-fuel plantations*, 5th International conference on biofuels hosted by Winrock International India, 7-8 February 2008, New Delhi.

Rajagopal, R., 2008: Best practices for long-term Jatropha development: Position paper by KnowGenix [online], www.knowgenix.com Accessed, 15 September 2008.

Raju, A.J.S. and Ezradanam, V., 2002: Pollination ecology and fruiting behavior in monoecious species, *Jatropha curcas L. (Euphorbiaceae)*, *Current Science*, 83(11), 1395-1398.

Ramadhas, A.S., Jayaraj, S. and Muraleedharan, C., 2003: Use of vegetable oils, I.C engine fuels- a review, *Renewable Energy*, 29(5), 727-742.

REA, 2005: *The United Republic of Tanzania*, *No.8 of 2005*, Rural Energy Act [online], http://www.meme.go.tz/documents_storage/2007-7-13-18-46-10_rural%20energy%2oact%202005.pdf Accessed, 15 September 2008.

Rees, W.G., 1990: *Physical principles of Remote Sensing, 3rd edition,* Cambridge University Press, Cambridge, 1-5.

Rossiter D.G., 1996: A theoretical framework for land evaluation, *Geoderma*, 72 (3-4) 165-190.

Roy, R.N. and Nabhan, H., (eds.) 1999: *Soil and nutrient management in Sub-Saharan Africa in support of the soil fertility initiative*, Proceedings of the Expert Consultation hosted by Food and Agricultural Organization, Lusaka, Zambia, 6-9 December 1999.

Rug, M. and Ruppel, A., 2000: Toxic activities of the plant Jatropha curcas against intermediate snail hosts and larvae of schistosomes, *Tropical Medicine and International Health*, 5(60), 423-430.

Rupert, E.A., Dehgan, B. and Webster, G.L., 1970: Experimental studies of relationships in the genus Jatropha. *J.curcas* x *intergerrima, Bul Torrey Bot Club,* 97, 321-325.

SADC TIIR, 2007: *United Republic of Tanzania*. Southern African Development Community Trade, Industry and Investment Review 2007/2008 [online], http://www.sadcreview.com/country_profiles/tanzania/tanzania.htm accessed on 16April 2008 Accessed, 20 January 2008.

Sawe, E.N., 2008: *Bioenergy policies in Tanzania*, Powerpoint presentation at Competence Platform on Energy Crop Agroforestry Systems for Arid and Semi arid Ecosystems international workshop on bioenergy policies for sustainable development in Africa, Bamako, Mali, 25-28 November 2008 [online], www.compete-bioafrica.net Accessed, 20 January 2009.

Schafer, G.N., 2008: *Personal communications*, Soil scientist, Sun Biofuels Ltd, United Kingdom.

Schroers, J.O., 2006: *Zur Entwicklung der land nutzung and grenzstandoeten in abhangeikeit agrarmarktpolitischer*, in, Hennenberg, K.J. and Fritsche, U.R., 2008: *Expert meeting on biodiversity standards and strategies for sustainable cultivation of biomass for non food purposes*, Final report on the Vilm Expert meeting on Biomass and Biodiversity for German Federal Agency for Nature

Conservation (BfN), Oko-Institute Darmstadt [online], www.oeko.de Accessed, 17 September 2008.

SEI, 1999: *Renewable energy for development* , Stockholm Environmental Institute, Newsletter of the energy programmes, 12(2/3) [online], http:// www.sei.se/red/red9909.pdf Accessed, 2 July 2008.

Shahid, E.M. and Jamal, Y., 2007: A review of biodiesel as vehicular fuel. *Renewable and Sustainable Energy Review*, 12(9), 2484-2494.

Shanker, C. and Dhyani, S.K., 2006: Insects pests of *Jatropha curcas L*. and the potential for their management, In, Achten, W.M.J., Verchot, L., Franken, Y.J., Mathjis, E., Singh, V.P., Aerts, R. and Muys, B., 2008: Jatropha biodiesel production and use, *Biomass and Bioenergy,* 32(12), 1063-1084.

Shuma, J., 2006: *Rural Energy Agency: Opportunities and challenges in Tanzania*, Tanzania Traditional Energy Development Organization. Rep., Dar es Salaam, 3, 1-3.

Shuma, J., 2008: *Energy crops and agroforestry in arid and semi arid areas (Case of Tanzania)*, WP2, 1-30 [online], www.compete-bioafrica.net Accessed, 25 January 2009.

Silayo, E.H., 2003: *Tanzania 2003 country report*, University College of Lands and Architectural Studies, Dar es Salaam [online], http://www.cadastraltemplate.org/countryreport/Tanzania.pdf Accessed, 22 September 2008.

Singh, V. and Nimbkar, N., 2007: *Biofuels-promise/prospects*, National Agricultural Research Institute [online], http://www.nariphaltan.org/biofuels.pdf Accessed, 14 March 2008.

Skidmore, A., 2002: *Environmental modelling with GIS and remote sensing*. Taylor & Francis, London and New York, 1-268.

Smeets, E., Faaij, A. and Lewandowski, I., 2004: *A quickscan of global bioenergy potentials to 2050*, Copernicus Institute, Department of Science, Technology and Society, Utrecht, Netherlands, 1-122.

South Africa, 2006: *An investigation into the feasibility of establishing a biofuels industry in the Republic of South Africa*. Final report, in, DMEWR, 2007: *The* *feasibility study for the production and use of biofuels in Botswana*, Department of Minerals, Water and Resource, Government Printers, Gaborone, October, 1-74.

Sparovek, G., Barretto, A., Berndes, G., Martins, S.P. and Maule, R.F., 2007: *Environmental, land use and economic implications of Brazilian sugarcane expansion 1996-2006*, accepted manuscript for publication in Mitigation and Adaptation Strategies for Global Change.

Stockle, C., 2001: *Environmental impacts of irrigation- A review*, Water research Centre, Washington State University, Washington.

Strong, C., Erickson, C. and Shukla, D., 2004: *Evaluation of biodiesel fuel-literature review*, Western Transport Institute, Report., Bozeman, January 2004, FHWA/MT-04-001/8117-20.

Sweet Maria's, 2009: *Coffee cupping reviews* [online], www.sweetmarias.com/coffee.africa.tanzania.php, Accessed, 16 March 2009.

Sys, I.C., Van Ranst, E., Debaveye, I.J. and Beernaert, F., 1993: *Land evaluation*, Part I-III, Agricultural Publications/General Publications for Development Cooperation, Brussels, 1-718.

Takavarasha, T., Uppal, J. and Hongo, H., 2005: *Feasibility study for the production and use of biofuel in the SADC region*, Southern African Development Cooperation, Gaborone.

Tanzania SENSA, 2003: *2002 Population and housing census, General report* [online], http://www.tanzania.go.tz/census/census/figures.htm Accessed, 18 June 2008.

Tewari, D.N., 2007: *Jatropha and biodiesel*, 1st Edition, Ocean Books Ltd, New Delhi.

The Ramsar Bureau, 2008: *The Ramsar Bureau- List of wetlands of importance* [online], http://www.ramsar.org/sitelist.pdf Accessed, 12 September 2009.

Tigere, T.A., Gatsi, T.C., Mudita, I.I., Chikuvire, T.J., Thanangani, S. and Mavunganidze, Z., 2006: *Potential of Jatropha curcas in improving small holder farmers` livelihoods in Zimbabwe: An Exploratory study of Makosa ward, Mutoko district* [online], http://www.jsd-africa.com/Jsda/Fall2006/PDF/Arc_Potential%20of%20JC%20in%20Improving%20Smallholder%20Farmers's%20livlihoods%20in%20Zimbabwe.pdf Accessed, 14 September 2008.

Turton, A. and Henwood, R., (eds.) 2002: *Hydropolitics in the developing world: A southern African perspective*, African Waters Issues Research Institute, University of Pretoria, Pretoria.

UKRFA, 2008: *The Gallagher review of the indirect effects of biofuels production*, United Kingdom Renewable Fuels Agency, UK.

UNAIDS, 2008: *Report on the global AIDS pandemic 2008*, United Nations Programme on HIV/AIDS, Geneva, Switzerland [online], http://data.unaids.org/pub/GlobalReport/2008/jc1510_2008_global_report_pp1_10_en.pdf Accessed, 12 March 2009.

UNDESA, 2007: *Small-Scale production and use of liquid biofuels in Sub-Saharan Africa: Perspectives for sustainable development*, Division of Sustainable Development and United Nations Department of Economic Affairs, Commission on Sustainable Development, Fifteenth Session, New York, USA, 1-51.

UNESCO, 2002*: Man and biosphere reserves*, United Nations Educational, Scientific and Cultural Organization, Paris [online], http://www.unesco.org/mab/wnbil.htm Accessed, 26 September 2008.

UNESCO, 2008: *World heritage list*, World Heritage Centre, United Nations Education, Scientific and Cultural Organization, Paris [online], http://whc.unesco.org/en/list Accessed, 12 September 2008.

URT, 2008: *United Republic of Tanzania* [online] http://www.imcg.net/gpd/africa/tanzania.pdf Accessed, 08 April 2008.

USABAQ, 2006: *Biodiesel fuel study-emission benefits and costs in Virginia*, Biodiesel Group, Virginia.

Van Eijick, J. and Romijn, H., 2006: *Prospects for Jatropha biofuels in developing countries: An analysis for Tanzania with Strategic Niche Management*, Eindhoven University of Technology, Eindhoven.

Van Eijick, J., 2006: *Transition towards Jatropha biofuels in Tanzania? An analysis with Strategic Niche Management*, Eindhoven University, Eindhoven.

Van Eijick, J., 2007: *Transition towards Jatropha biofuels in Tanzania? An analysis with Strategic Niche Management*, African Studies Centre, Leiden, 1-182.

Vedeld, P. and Kengera, Z., 2006: *The fast track initiative: an assessment of a public-private partnership process on developing the fertilizer value chain of Tanzania*.

Rep., Department of International Environmental and Development Studies, Noragric, 37, 1-74.

Von Braun, J., 2007: *When food makes fuel: promises and challenges of biofuels for developing countries and food security for the poor*, International Food Policy Research Institute, Washington DC.

Von Zon, L., Asselbergs, B., Winjnen, L., ten Velden, C., Van der Noort, L., Harms, R., Vervuut, R., Van Hemert, J. and Jochem, B., 2006: *Size does matter: The possibilities of cultivating Jatropha curcas for biofuels production in Cambodia*. Rep., Expertise Centrum voor Duurzame Ontiwilleling, University of Amsterdam.

Watson, H.K., 2007: *Potential to expand sugarcane cultivation in Southern Africa: an assessment of available and/or suitable land*, Proceedings of COMPETE Workshop, 22 June 2007, Mauritius Sugar Industry Research Institute [online], www.compete-bioafrica.net Accessed, 22 February 2009.

Watson, H.K., 2008a: *ANNEX 1-3: Task Report on WP1 Activities-Current land use patterns and impacts*, Appendices 1-10, 1-123 [online], http://www.compete-bioafrica.net/current_land/Annex1-3-COMPETE-032448-1stReport2007-WP1-TaskReport.pdf Accessed, 20 March 2009.

Watson, H.K., 2008b: *Personal communications*, Senior Lecturer, School of Environmental Sciences, University of KwaZulu-Natal, Durban, South Africa.

Watson, H.K., 2009: *Potential impacts of European Union biofuels policies on sustainable development in the Southern African Development Community*, Proceedings of IEEP and EGMONT conference on "External dimensions of EU sustainable development strategy", 29 January 2009, Brussels.

WBCSD, 2007: *Mobility for development*, World Business Council for Sustainable Development, University of Dar es Salaam, Dar es Salaam.

WFB, 2008: *The World Fact Book* [online], http://www.cia.gov/library/publications/the-world-factbook/index.html Accessed, 03 March 2008

WFP, 2006a: *Comprehensive food security and vulnerability analysis*, *United Republic of Tanzania*, World Food Programme of the United Nations, Rome.

WFP, 2006b: *Draft country programme-United Republic of Tanzania 10437.0 (2007-2010), Agenda item 8. Rep.,* World Food Programme*,* WFP/EB.A/2006/8/6/Rev.1*,* Rome.

Wijgerse, I., 2008: *The electricity system for a rural village in Mali*, Published MSc thesis in Sustainable Energy Technology, Eindoven University of Technology, Eindoven.

Wiskerke, W., 2008: *Towards a sustainable biomass energy supply for rural households in semi-arid Shinyanga, Tanzania: A cost/benefit analysis*, Published MSc Thesis, Master of Science program, Sustainable Development, Track Energy and Resources , Utrecht University, Utrecht, The Netherlands.

WEC, 2007: Energy and climate change, World Energy Council, London.

WMO/UNEP, 2001: *Climate change 2001*: *Impacts, adaptation and vulnerability,* World Meteorological Organization/United Nations Environmental Programme, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, New York.

WRI, 1990: *World Resources 1990-1991*, World Resource Institute, Washington D.C.

Zuzarte, F., 2007: *Ethanol for cooking: Feasibility of small scale ethanol supply and its demand as a cooking fuel- Tanzania case study*, Published., MSc thesis, KHT School of Energy and Environmental Technology, Stockholm, Sweden.

APPENDIX 1: Relief of Tanzania