e Cycle Assessment of Biofuels in Mozambique

by

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Curriculum Vitae

João Fernando Chidamoio was born in Sofala Province, Mozambique in 1975. He studied at Eduardo Mondlane University where he completed a Bachelor of Science degree in Chemical Engineering with honors in 2001. After graduation Mr. Chidamoio was employed as a Chemical Engineering Lecturer at Eduardo Mondlane University (full-time) and at the High Institute of Science and Technology (part-time).

Since graduation, Mr. Chidamoio has completed a SADC (Food Agriculture and Natural Resource Project) course in processing and food security (2001); a UEM course on education methods (2002); a UEM course of student evaluation (2003.

He has conducted field research and surveys to garner basic data on energy consumption in Mozambique and on agricultural production systems.

He was a participant in the "Energy Supply Extensions in Rural Mozambique" pre-feasibility study completed in early 2006. He spent four weeks in Rochester, working closely with AHEAD Energy Corporation on this study and returned in 2007 to do biofuel research.

Mr. Chidamoio came to the University of Rochester in fall 2007 and began graduate studies in sustainable energy under the direction of Professor Ben W. Ebenhack. The focus on his research is life cycle assessment of biofuels.

Upon returning to Mozambique, Mr. Chidamoio will resume his academic teaching and also serve as AHEAD Energy field staff.

Dedication

This dessertation is gratefully dedicated to:

My late father Fernando Chidamoio and my mather Lina Muloi Jequessene for their prayers, endless support, and love extended throughout my life;

My wonderful wife; Márcia Chidamoi,o and close friends; for sacrificing so much and providing every help possible so that I might complete my Master's. program;

and

my handsome son Jacob Chidamoio and beautiful daughterLina Chidamoio for filling my life with love and joy.

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Many people provided assistance, inspiration, and support that contributed to the completion of this dissertation. I would like to thank Pofessor Ben Ebenhack, my Advisor, for his tremendous help in guiding me through the entire research. Frequent discussion of the research issues with him added a new twist and improved it substantialy. I extend my deepest thanks to Dr. M J Ebenhack for her constant guidance through innumerable ups and downs of my Ms. program and for valuable editing of the entire thesis. Her moral and financial support was very critical in completing this journey.

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I am very thankful to fellow Master's student Steven Kraft for explaining to me all the steps of cassava fermentation.

My thanks is extensively to the Chemical Engineering office staff, namely Sandra, Tiffany and Andrea for their helps in all I needed.

I must extend my deepest thanks to my wife Márcia Chidamoio for believing in me and always being there for me when I needed her. Her moral support has been so invaluable

Abstract

Non-renewable natural resources are only available in limited quantities; they will be depleted one day. The recent high price of oil is one of the consequences of the depletion of resources.

Mozambique, a country with a tropical climate, may have a comparative advantage in growing biomass feedstock, a sustainable alternative to fossil fuels. This dissertation evaluates the potential of producing biofuels from various crops (sugarcane, cassava, sunflower, Jatropha), agriculture by products (cotton seeds), sugar cane molasses and waste streams (brewery waste) in the country through a life cycle assessment.

The main issues addressed are net energy value, water balance, land use and greenhouse gas emissions.

Calculations of greenhouse gases emissions due to land use changes were determined assuming that tropical forest, temperate grassland and tropical savannas as the native ecosystem.

The analysis indicates that there is not enough water to supply water consumptive crops like sugarcane. Reliance on the Massingir dam as source of water for biofuels production would create a disaster, the consequence of which would be hunger for more than 1,200 million people.

Biodiesel production from sunflowers and jatropha is land intensive compared to ethanol production from sugarcane. This is due to low agricultural yield (ton/ha),

and if the biofuel crops are irrigated, the water requirements are the same as for sugarcane.

Sugar cane molasses, brewery waste and cotton seed all provide high net energy ratios and low impact in land and water use, making them the best candidates for biofuels production in Mozambique.

Mozambique has the potential to produce 22,500,000 liters of ethanol from sugar cane molasses and 13,500,000 liters of biodiesel per year from cottonseed without displacing even 1 ha of land dedicated to food crops.

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List of acronyms

BP	British Petrol
CMH	Companhia Mocambicana de Hidrocarbonetos
CVRD	Companhia do Vale do Rio Verde
DNA	Direcao Nacional De Aguas
EdM	Electricidade de Mocambique
EU	European Union
FAO	Food and Agriculture Organization
HCB	Hidroeletrica de Cabora Bassa
IFC	International Finance Corporation
IMOPETRO	Importadora Moçambicana de Petroleos
INA	Instituto Nacional de Açucar
INE	Instituto Nacional de Estatistica
LSSE	Life Style Support Energy
MOTRACO	Mozambican Transmission Company
PetroMoc	Petroleos de Moçambique
SASOL	Swid-Afrikanse Steenkool en Olie

List of symbols

EJ	ExaJoule = 10^{18} Joule
kg	Kilogram
kWh	Kilowatt-hour
MJ	MegaJoule = 10^{6} Joule
Mt	Million tones
MW	Megawatt
t	Tones
tcf	Trillions of cubic feet
TCF	Total Food Consumed
TJ	TeraJoule = 10^{12} Joule

1. Introduction

Negative effects such as a depletion of fossil fuels, increase in greenhouse gas emissions and climate changes are associated with the present system of energy supply.

The energy sector in Mozambique plays an increasingly important role in the country's economic development. The main reason for this is that Mozambique has abundant and yet largely unexplored energy resources, which are attracting substantial foreign investments in large energy-intensive industries.

Providing energy to rural communities in the developing world has proved to be a great challenge. [IEA, 2006] , Today, still more than half the world's population lives in rural areas, with most sub-Saharan African countries having even larger rural populations. The vast majority of these people is dependent on the traditional fuels (wood, crop residue, dung), often using primitive and inefficient technologies.

Mozambique is not exception to this reality, the main source of energy in Mozambique is biomass, which is one of the most carbon intensive fuels (it has high carbon emissions) carbon emissions are responsible for the global environmental threat of climate change.

The consumption of biomass in Mozambique is increasing. In 2006 firewood consumption in Mozambique was about 275000 TJ and charcoal less than 25000 TJ [Ministry of Energy, 2006]. Burning biomass also releases toxic pollutants, which contributes to poor air quality and health problems.

The availability of natural gas condensate in Mozambique offers an unusual and exciting opportunity. It may well be possible to effectively combine it with locally-grown copra oil and Jatropha oil to create large quantities of fuel for household and commercial use.

Since a full life cycle assessment analysis of biofuels in Mozambique has not yet been conducted, this study may serve as framework, enabling energy and natural resources policy makers to ascertain whether biofuels, are a feasible and practical energy alternative.

1.1. Purpose

The purpose of this study is to evaluate the potential of producing biofuels from various crops, agriculture by-products and waste streams in Mozambique. The main issue is: Does Mozambique has the potential for biofuels production? The study also will focus on:

- Mass and energy balance of biofuels from crops; as well as net natural resource balance. The main focus will be on land, water and food security.
- Competing uses of land. The need for land to produce food and feed is a potential key barrier to bio-energy production.
- Further, analyses of biofuels demand versus natural resource availability and a comparative forecast with fossil fuels will be presented.
- Water availability and land degradation will be discussed and appropriate advice will be addressed. I will calculate and analyze in detail the energy inputs of producing biofuels from different sources of crops and the net environmental impact.

Water availability and land degradation will be discussed and appropriate adviser will be addressed. We will calculate and analyze in detail energy input of producing biofuels from different sources of crops as well as the net environmental impact issues associated.

In terms of biofuels production four alternatives will be investigated:

- Ethanol production from sugar cane ;
- Ethanol production from cassava roots;
- Ethanol production from molasses (a sugar by-product) ;
- Methane production from brewery waste;
- Biodiesel production from Jatropha;
- Biodiesel production from sunflower oil;
- Biodiesel production from cotton seed oil (agriculture by-product).

1.2. Assumptions

In conducting this study, two broad sets of assumptions are used. The first set is comprised of general assumptions related to environmental benefits stemming from growing feedstock; transporting of feedstock; and reduction of GHG emissions. The second set is comprised of assumptions that I use in estimating, evaluating, or quantifying certain variables. These assumptions can be found in further chapters as I address the assessment of unknown variables.

1.3. Justification

Energy is one of the factors that contribute to economic development and poverty reduction. Mozambique has considerable energy resources that could satisfy not only internal demand but energy demand throughout Southern African. The availability of energy resources (hydro, natural gas and coal) at relatively low prices, comparing to the other options of the regional, put the country in a privilege position.

Mozambique has many natural energy resource options. Action is being taken to expand access to electricity, liquid fuel and renewable energies. Nevertheless, the population's economic inability to access modern energy means that biomass will continue for long time to be the main source energy for the majority of families.

1.4. Thesis overview

Chapter one present any introduction, porpuse, justifaction and assumptions

The folowing chapter adresses food secuty in Mozambque , namely food consumption, agricultura sutation in Mozambique and water avaialbilty. Water availabilty is described in three regions of the country.

Chapter three focus on energy resource. In this chapter different energy resources are discussed. Availability demand and use are evaluated.

Energy transition in Mozambique is pointed out in chapter four. Factor as poverty, low demand and long coastline are pointed as the main barrier.

Chapter five in this study pointed out the impact of cleaner flues for development

where is discussed the impact of modern source of energy in economy, health and poverty alleviation.

Ethanol production thought alcoholic fermentation of cassava waste is described in chapter nine as well as the life cycle assessment of biofuels. This analysis is done for various food crops, agricultural by products and waste stream. Special attention was addressed for energy input, land, water and greenhouse gas emissions due to land use change.

2. Food security in Mozambique

2.1. About the Country

Mozambique is located on the east cost of southern Africa, on the India Ocean. Its coastline 2,470 km long. It has a land border of 4,330 km - Tanzania to the north, Malawi and Zambia to the northwest, Zimbabwe to the west, and Swaziland and South Africa to the southwest. A tropical to subtropical climate is characteristic of the country, which has 799,380 km^2 of total area including 13,000 km^2 of inland water bodies.

According to a survey conducted in 2007, Mozambique has a population of 21,284,701 and the population is expanding a rate of about 1.792% per annum. The per capita GDP in Mozambique is $380. Cultivable land is estimated at 36 million ha amounting to 45% of the total land of the country. O only 3.3 million ha are suitable for irrigation [INE [b], 2007; African Economic Outlook 2008; Kundell, J. 2007; FAO [c], 2007].

Table 2.1 shows GDP per capita by sector. The agriculture sector is the main contributor to Mozambican GDP.

Table 2.1: Mozambique's GDP by Sector in 2006 (%)[1]

Agriculture and Fisheries	27.4
Manufacturing	15
Finance and Business services	12.3
Trade	12.1
Transport and communications	9.9
Government Services	9.7
Electricity and Water	5.7
Constructions	3.3
Other services	1.8
Hotels and Restaurants	1.7
Mining and quarrying	1.1

[1] Source: African Economic Outlook, 2006

2.2. Food security

Forty-five percent of the population in Mozambique is undernourished; the average calories intake is about 2070 kcal/person/day [FAO [b], 2006]. In rural areas of country, 70% of the population produces their own food from subsistence agriculture production [INE [a], 2007]. Since food crop production is principally subsistence, much agricultural production never reaches the market consequently; access to markets is also limited, increasing reliance on one's own production. Availability of basic food is characterized by surpluses in the agriculturally productive north and deficits in the south, and at times, the central regions [INE [a], 2007; Bias; Donovan, 2003].

The ideal scenario would be for the north and centre region of the country to supply the food needs of the south, but transport due to long coastal and other infrastructural constraints like paved roads makes this uneconomical to implement. So the immediate solution is the southern regions import food from South Africa and Swaziland while the north exports to Malawi.

2.3. Agriculture sector in Mozambique

Mozambique's agriculture sector comprises two categories of producers: the small landholder sub-sector and the commercial sub-sector. Small farmers account for 95% of the area under production [INE [a], 2007] and produce almost all food crops, – maize, cassava, rice, sorghum and millet. This sub-sector is characterized by low productivity per hectare due to low mechanization and fertilizer application.

The Commercial sub-sector uses technology to improve yields. They use agrochemicals, have access to credit and use irrigation. They have been an important source of employment and notably contribute to technological development.

Historically Mozambique has had potential for cash crops such as sugar cane, cotton, tea, tobacco, cashew nuts and fruits. It is the eighth largest producer of tea in Africa and has the largest coconut plantations in the world (7000 ha in Zambezia province). In the 1960s and 1970s, Mozambique was the largest cashew nut producer in the world supplying 50.8% of world production in 1972 (Freitas; Fatissone, 2000).

The population of Mozambique is growing exponentially and from figure 2.1 we see the same trend with basic food consumption. This scenario can continue in the near future and will saturate in long term and predict the saturation phenomena when will occur, is difficult.

The total cultivable land is estimated to be 36 million ha. The potential for irrigation is only about 8.5% of the cultivable land. Currently 120,000 ha are equipped for irrigation but only 40,000 ha are operating. Surface water from rivers is most often used to irrigate crops.

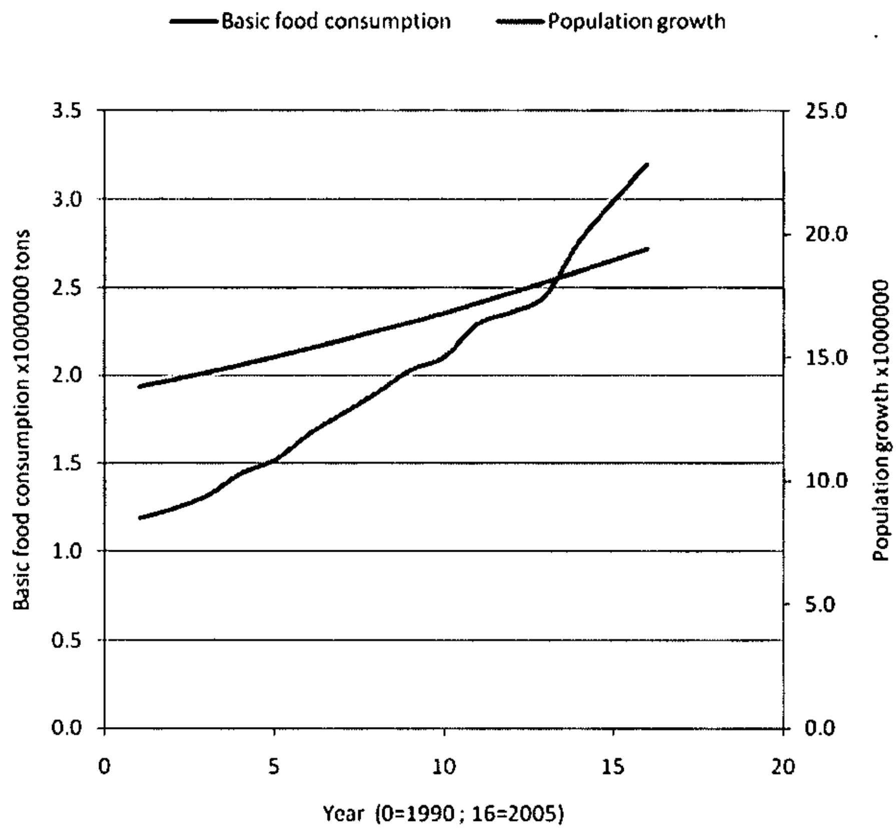

Figure 2.1: Basic Food consumption [2] versus population growth in Mozambique[3].

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[2] Basic food consumption includes imported cereals and national production, neglecting the cereals exported from the country.

[3] Graphic created by the author based on data from FAO * .2006; INE * .2007.

2.4. Sugar cane Industry as example of success in Mozambique

Sugar cane is the oldest economic activity in Mozambique; it was introduced commercially in Mozambique at the end of 19th century in the Zambezi and Buzi valleys where the soil conditions, climate and water were suitable. The sugar industry expanded in the following decades, stimulated by British investment, and after 1950s, with increased Portuguese investment [INA, 2006; Samo, 2005].

In 1992, after the civil war, the Government promoted the sugar industry by privatization, investment and construction of sugar factories. Consequently, the sugar industry is gradually getting back to normal although the four functioning factories are now mostly foreign owned: South Africa and Mauritius.

Figure 2.2 shows the productivity increases in sugarcane in Mozambique from 50 tons/ha in 1998 to 75 tons/ha in 2007. Rehabilitation of manufacturing plants, privatization, and promotion by the Government are contributors to that success. This success confirms the high potential of the country in sugar cane sector.

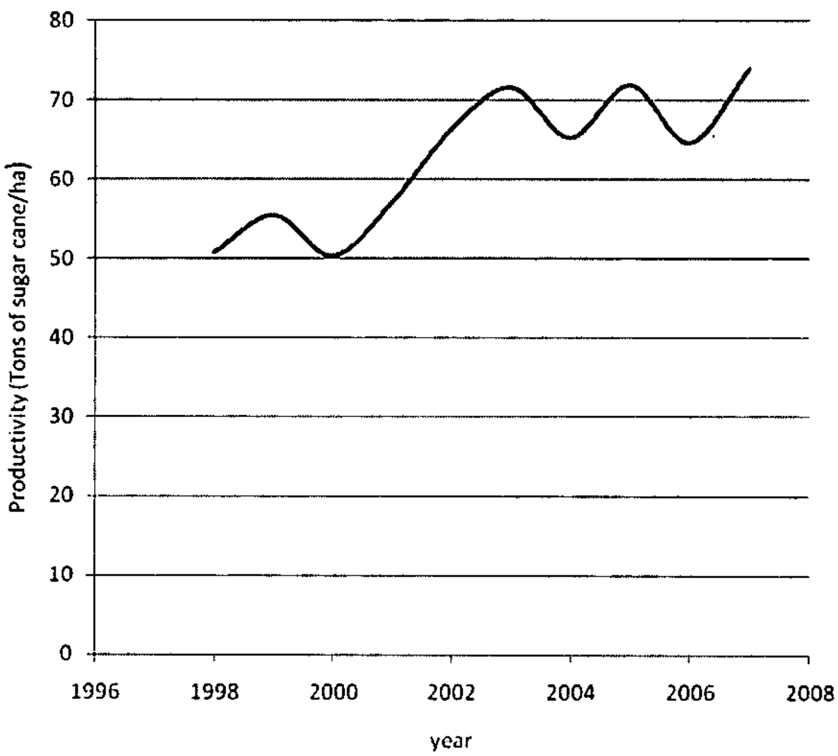

Figure 2.2: Sugar cane productivity in Mozambique[4].

[4] Graphic created by the author based on data from INA, 2006

2.5. Water availability

Mozambique is considered highly water insecure because of the increasing uncertainty in the national water resources base [Aquastast, 2005; DNA, 1999]. This is due to:

- dependence on international river basins (over half of the national water resources are shared with neighboring countries),
- climactic variability (large variations in annual and inter-annual rainfall, frequent floods and droughts),
- the uneven geographic distribution of water resources across the country and
- competing demands by water-dependent businesses located in river basins [Aquastat, 2005; Tauacale, F. 2002].

These factors are aggravated by an underdeveloped and largely degraded stock of water infrastructure, thus increasing water vulnerability and posing a serious risk to the national economy.

The high dependence of Mozambique on shared water resources is an important factor in the national water vulnerability. The naturally high flow rates, necessitating high storage capacity, along with significant subtraction from these

rivers in the upstream countries, reduces water availability and increases water vulnerability in Mozambique.

In 2000, water use was about 0.635 km^3; 87% was used in agriculture, 11% was used for domestic purposes, and the remaining 3% was used by the industry [FAO [c], 2007; Kundell, 2007].

For example the combined average natural flow in the four basins located in the south of Mozambique is about 11 km^3/year. It is predicted to decrease to about 5 to 6 km^3/year over the next 20 years [Aquastast survey, 2005]. This will pose a serious challenge to biofuels production both in terms of irrigation requirements and the use of water in processing.

For example, the total rainfall required for a sugar cane plantation is estimated to be 1500 to 2500 mm/year. The maximum annual rainfall of the country is 1600 mm. The annual rainfall in the southern part of Mozambique is about 500 to 600 mm/year. Thus, water is a limiting factor for sugar cane crop production in southern Mozambique. Sugarcane production in Mozambique cannot rely on rain. For that reason all five (four operating and one non-operating) sugarcane factories are located close to rivers. This will pose a serious challenge to agricultural biofuels both in terms of irrigation requirements and water use in processing.

Table 2.2: Water resource [5]

Source of Water	**Quantity km^3/year**
Internal surface water	97.3
Ground water	17
Total internal renewable Water	100.3
Total capacity of 27 dams	64.5
Total renewable water resource	217.1

[5] Source: FAO [c], Aquastat. Information system on water and agriculture. 2007.

Kundell, J. Water profile of Mozambique. Encyclopedia of Earth. 2007

For example the total rainfall required for sugar cane plantation is estimated at 1500 to 2500 mm/year. For comparison the annual rainfall in the southern part of Mozambique is about 500 to 600 mm/year.

From figure 2.3 indicate that water can be a limiting factor for sugar cane crop production in southern part of Mozambique if rainfall has to be source of water. The maximum annual rainfall of the country is 1600 mm meaning that to produce sugarcane in Mozambique we cannot only account with rainfall. That is the reason why all five (four operating and one non- operating) sugarcane industries are located close to the rivers in the country.

Table 2.3: Water demand by region in Mozambique[6]

	Mean annual runoff		
Region	At the border (km^3)	Generated in Mozambique (km^3)	Total (km^3)
South	17	3.8	20.8
Centre	89.2	71.6	160.8
North	10	24.9	34.9

[6] FAO [c], Aquastat. Information system on water and agriculture. 2007.

Kundell, J. Water profile of Mozambique. Encyclopedia of Earth. 2007

3. Energy resources in Mozambique

3.1. Renewable non-combustible energy resources

3.1.1. Hydropower potential

Hydropower is the energy derived from moving (falling) water and comes in many forms from conventional to new emerging technologies including ocean waves, tides and hydrokinetic energy. Hydropower is a local source of clean, renewable, reliable and affordable electricity. Large hydroelectric power stations provide much of the power used in several countries by allowing water to fall at a controlled flow rate from a reservoir or river.

There are many advantages to hydropower projects. Beside electricity, they also can provide recreational enhancements, flood control, and irrigation. It is an extremely important energy resource in Mozambique and has significant growth potential. It can help the nation meet new energy demand with a reliable and non-polluting, local energy source.

Hydropower critics maintain that some dams contribute more to climate change than a fossil fuel plant. Hydro-electric dams can cause significant damage to the environment by releasing methane into the atmosphere. Bacteria break down organic matter on the bottom of lakes and reservoirs, producing methane [Pacca,

2007]. When intake pipes at hydro-electric plants suck this methane rich water or matter up, methane it is released into the air. It's the reason for much controversy surrounding what is often thought of as a green source of power.

With the construction of the Cahora-Bassa hydro dam (HCB) in 1974, Mozambique became a potentially large producer of hydroelectricity (for export to South Africa), but destruction of the transmission lines during the post-independence civil war prevented this from happening for a long time. Post-war reconstruction allowed for production to pick-up in 1997, and since then the amount of electricity produced has been gradually increasing. Hydroelectric power production will continue to grow because of new projects.

The Cahora Bassa Hydro-electric dam in the Tete province of Mozambique is currently producing only 2352 MW, most of it exported to South Africa. The dam has the capacity to produce 14,000MW but this is not happening because transmissions lines were sabotaged during the civil war. Long running, stalemated discussions ended in December of last year when the governments of Mozambique and Portugal signed a new agreement. Mozambique now controls 85% of shares and Portugal 15%. There are also plans to build another hydroelectric dam in the northern-most region of the country; currently a feasibility study is underway.

3.1.2. Wind and Solar energy

Since climate change has no regard for national borders, strategies that seek to address the issue should be borderless as well. Renewable energy– wind and solar power in particular – have a significant role to play in gradually reducing the fossil fuel intensity of the global energy supply mix. Wind and solar energy projects are environmental projects in that they are designed to find sustainable sources of energy that might otherwise come from fossil fuels with their harmful impact on the environment, humanity, and climate.

The exponential growth of wind and solar energy developments over the past years [Rodgers, A.] reflects a dramatic shift in thinking about how human impacts on the planet and how we can tackle the many environmental and social challenges facing us.

Wind energy plays an important role in the transition from an energy system strongly based on fossil fuels to a more environmentally-friendly system based on renewable. For the efficient development of wind power, a systematic planning activity is needed to identify suitable sites and conditions.

The average wind velocity for Mozambique was reported to be 2.6 m/s [Karekezi, 2003]. For renewable energy in general, and for wind and solar energy in particular, accurate spatial mapping is very difficult because they are intermittent and geographically and temporally variable [Cellura, M. et *al.*2007] This variability persists over a very wide range of scales, both in space and time.

Solar technologies take advantage of energy from the sun. The most common solar device is the photo-voltaic (PV) solar panel. The PV cell converts light energy into electrical energy. Another popular device is the solar water heater, which has panels of exposed pipe that contains a highly conductive fluid which is pumped throughout a closed system containing heat exchangers. In this way water for showers or sinks can be heated. Other solar techniques include building designs that make use of the sun's heat through intelligently placed and well insulated window systems.

Mozambique is very suitable country to use solar energy. Direct beam radiation ranges from 16.6 MJ/m^2 to 20.4 MJ/m^2 in November and August respectively, and the annual mean daily global radiation is 16.8 MJ/m^2 [Nijegorodov, 2003]. These values mean that solar energy can be used effectively for heating domestic water and electricity generation, especially in off-grid locations. In Provinces like Sofala, Niassa, and Maputo with high potential in solar energy (figure 2.1), small scale projects can have significant impact in energy transitions.

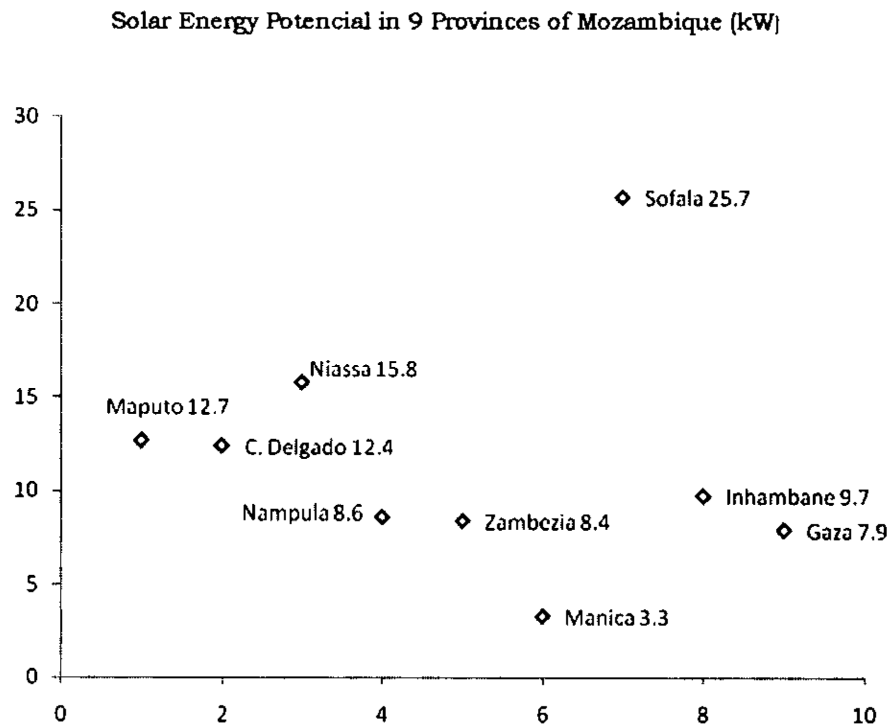

Figure 3.1: Solar energy potential in Mozambique[7].

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[7] Graphic created and updated by the author based on data from Ministry of energy, 2006

3.2. Renewable combustible energy resource

3.2.1. Biomass

Mozambique is considered a promising region for biomass production within Southern Africa due to the relative abundance of land resources, favorable environmental conditions, and low population density. Biomass resources assessments indicate considerable potential within the sub-region. The total biomass production potential from eucalyptus plantations in Mozambique was estimated to be 6.7 EJ per annum [WRI, 2004]. The total primary energy demand in Mozambique is about 0.3 EJ of which wood-fuel accounts for 87%, hydroelectricity represents 8% and 5% is fossil fuel [Ministry of Energy, 2007].

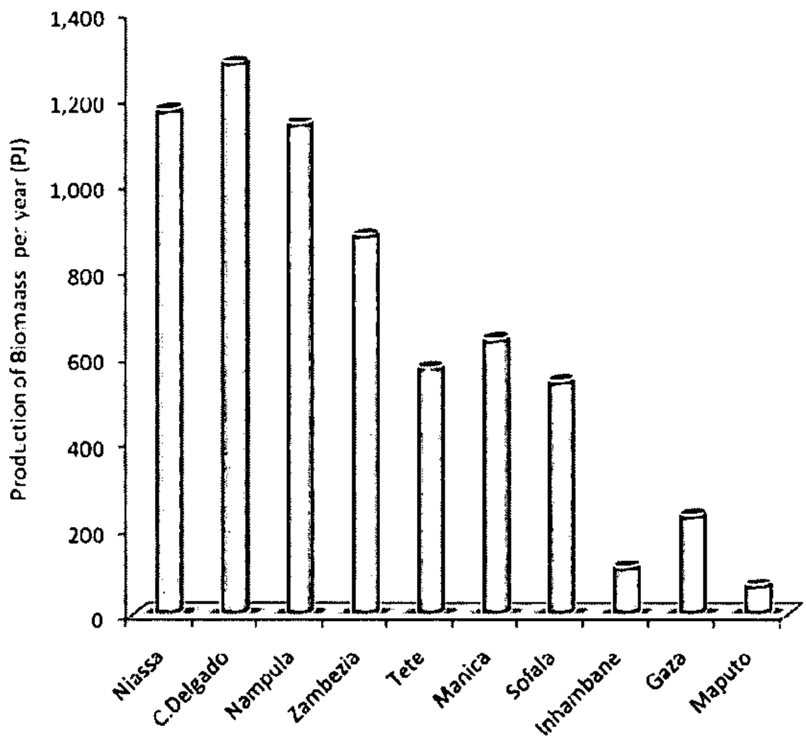

Figure 3.2: Biomass potential in Mozambique.[8] .

[8] Graphic adapted by the author based on data from Ministry of energy, 2006

3.3. Non-renewable combustible energy resources

3.3.1. Natural Gas

There are some 5 tcf of natural gas in two Mozambican fields (Pande and Temane) [ENH, 2008]. In 2003, a partnership between Mozambique and South Africa and a $1.2 billion investment by SASOL, a South African synthetic fuel manufacturing company, resulted in construction of an 865-kilometers pipeline. Since then, it has ferried gas from the Temane and Pande fields in Mozambique to a distribution network in Secunda, South Africa.

Exploiting the gas fields is in the hands of a consortium led by the South African petro-chemical giant SASOL (with 70 per cent of the shares). Its partners are the Mozambican Hydrocarbon Company (CMH), with 25 per cent, and the private sector funding arm of the World Bank, the International Finance Corporation (IFC), with the remaining five per cent.

The consortium was granted rights to exploit the Pande and Temane fields for 30 years. Because of high demand for gas, the entire known potential of the two fields is now pledged to customers on long term contracts. Most of the gas goes directly to SASOL's factories in the South African town of Secunda.

Inside Mozambique, the gas is used to generate 1 MW of electricity to supply the districts in the northern part of Inhambane Province and to supply industrial consumers in the southern city of Matola, who use up to 1.5 million gigajoules a year.

Currently, the SASOL pipeline is carrying 120 million GJ/annual [Itai, 2007] from the Temane gas field (Mozambican side) to Secunda (South African side). Mozambique has rights to 5% of the gas. Thus, the gas currently available to Mozambique is about 6 million GJ/year. Up to 20 million GJ/year may be available to Mozambique in the future as pipeline capacity is expanded and additional gas field are developed.

Mozambique's production of natural gas rose to 2.31 billion cubic meters in 2005 from nearly 1.3 billion cubic meters in 2004 and 1 million cubic meters in 2003 [INE, 2007] and 98.7% of this gas is exported to South Africa, the remaining 1.7 % in used in the country for electricity generation and consumption.

3.3.2. Mineral coal

The Moatize coal mine, which suffered extensive damage during Mozambique's civil war in the 1970s and 1980s, is believed to hold about 2.4 billion tons of coal reserves, making it one of the largest untapped deposits of coking and thermal coal in the southern hemisphere.

The Moatize coal mine is being developed by the Brazilian company CVRD and is expected to produce 14 million tons of coal per year. Much of the coal is for export but CVRD is seeking a partner to build a thermal power station at the mine with a capacity of 1500 MW [Thomas, 2007] and develop adequate port facilities and a rail link to the port.

4. Energy transition in Mozambique

4.1. Electricity

In terms of electricity generation, Mozambique has the largest hydropower plant in Africa, Cahora-Bassa. It ranks first throughout the continent, with a total hydropower output of 2352 MW. Electricity is known as a clean source of energy. To date, only 9% of Mozambicans have access to electricity. Electrification in Mozambique is expensive due to many factors such as low population density (26.6 Inhabitants /Km^2); an extensive coastline (2470 km) and low demand due to high poverty (54.1%) [Nhete, 2007; African Economic Outlook, 2008].

Another factor influencing the electrification in Mozambique is the low rate of urbanization (29%). Most of the houses are made of precarious materials that do not lend themselves to electricity installation.

Figure 4.1 shows that Maputo Province has highest rate of electrification in the country (34%) followed by Gaza and Sofala. It is interesting to note that most electricity comes from Tete Province where HCB is located but Tete Province has one of the lowest rates of electrification– probably because there is no demand there. Another important observation is that rural areas have only 2.5% of total electricity (figure 4.2).

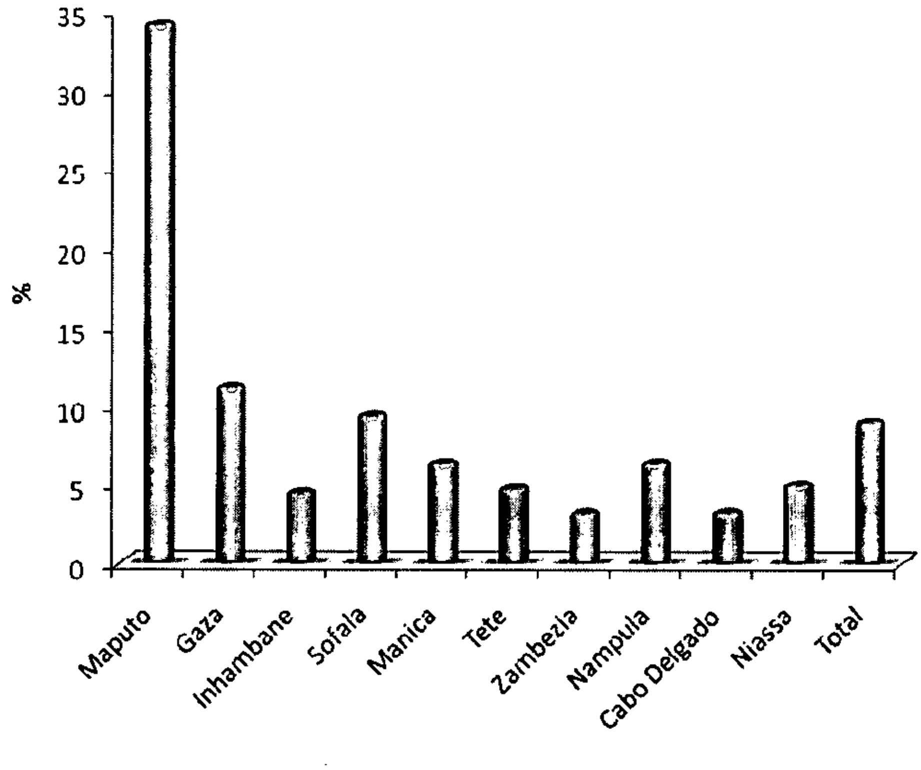

Figure 4.1: % of population with access of electricity by province.[9].

[9] Source: Ministry of energy, 2006

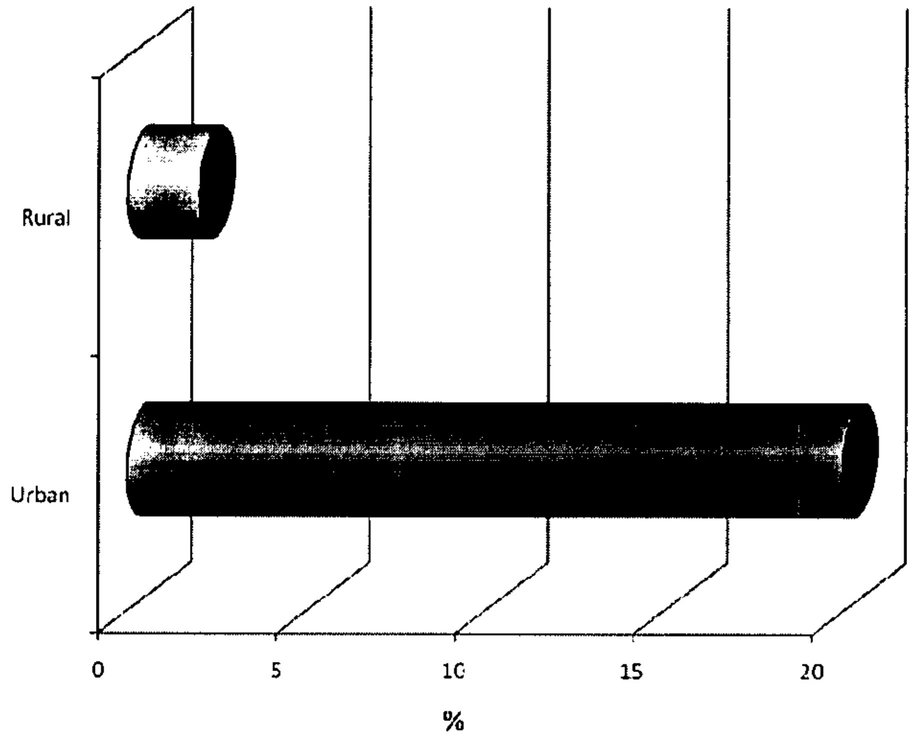

Figure 4.2: Electrification rate in Mozambique.[10].

[10] Source: Nhete, T.D. 2007.

The electricity sector in Mozambique is dominated by three service providers. Electricidade de Mozambique (EdM) is the national power utility, wholly owned by the government. It is involved in all stages of the electricity supply chain from generation through transmission and from distribution to the final billing of consumers.

Hidroelectrica de Cahorra-Bassa, is a private company that manages and operates Cahorra-Bassa hydro electric power station and its associated transmission network to the Southern Africa Power Pool.

The third organization is the Mozambique Transmission Company (MoTraCo) which is a joint venture between the power utilities of Mozambique, South Africa and Swaziland, formulated to transport power from South Africa to the Mozal Plant in Maputo.

Figures 4.1 and 4.2, shows how challenging electrification is in Mozambique. The situation is more dramatic in rural areas with only a 2.5% rate of electrification. Even in urban areas, this rate is still very low compared with other developing countries.

4.2. Fuel Oil

Mozambique is an oil import-dependent country with 12 oil companies operating in the country, including the State owned national oil company (PetroMoc) an oil procurement company owned by the other eleven oil companies (ImoPetro). The oil imports follow international competitive tender rules.

Annual domestic consumption of oil products in Mozambique averages 700,000 m^3; at a cost of US$ 270 million.

The three ports of Mozambique - Maputo in the south, Beira in the center, and Nacala in the north - offer an economic supply corridor to neighboring landlocked countries. Presently, Zimbabwe transports most of its petroleum products through Mozambique. Swaziland, receives approximately 5% of its product through the Maputo port and Malawi receives 18% through the Nacala port.

The current downstream oil market in Mozambique is relatively small. However, Mozambique's consumption of liquid fuel products has increased 90% from 1996 to 2007. The increase has mainly been in the area of gasoline, jet fuel, and gasoil, while the consumption of fuel oil has declined and kerosene has remained stable.

The main consuming areas of petroleum products are the southern and central parts of the country with a smaller percentage in the North. Consumption is heavily skewed towards gasoil, which represents the majority of the region's demand.

Mozambique has adequate storage facilities for refined petroleum products situated all over the country. There are 28 depot facilities with nominal capacities of between 30 to 600 cubic meters. Twenty are owned by Petromoc, while the

balance is owned by BP (7) and Mobil (1). There are also two marine depots at Quelimane and Pemba, each with a capacity of 6000 to 7000 m^3.

Mozambique is importing more diesel compared to gasoline as is showed in figure 4.3. Since agriculture is largest economic sector in the country, this trend is expected to continue in the near future due to increased mechanization in agriculture.

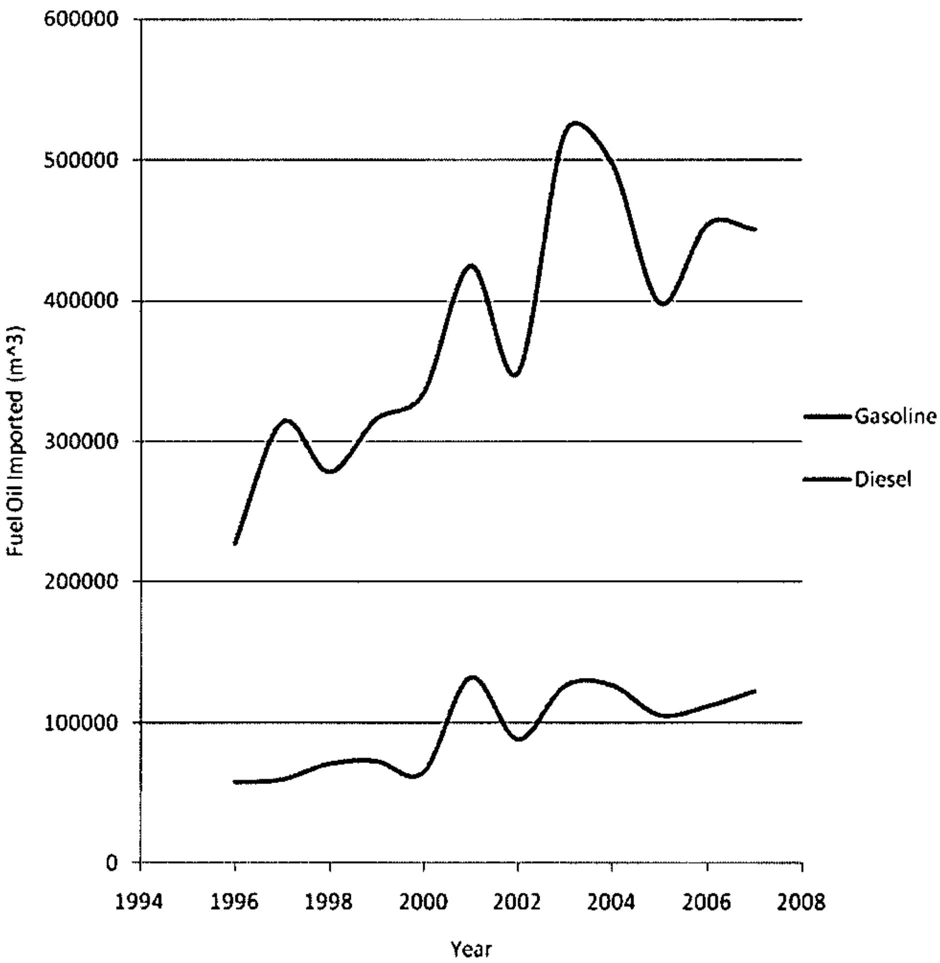

Figure 4.3: Balance of fuel oil import in Mozambique[11].

[11] Graphic adapted by the author based on data from Ministry of energy, 2006

4.3. Biomass

The majority of Mozambican households rely on biomass for their main fuel supply. In rural areas, the burden of collecting firewood falls almost entirely on women as does the health impact of cooking in smoke filled kitchens. Urban growth is creating a huge demand for charcoal and firewood and putting pressure on surrounding ecosystems. In Mozambique, 85% [Ministry of energy, 2006] of energy consumption is from wood. Seventy percent of rural households use firewood as an energy source. Charcoal has high energy density, is easy to transport, use and store, so it is the energy source most used in urban area. Both charcoal and firewood are highly gendered fuels, with the labor and responsibility primary given to the females in the house. As it is usually used in enclosed spaces, presenting health hazards from exposure to smoke and particulates.

The use of biomass fuels, leads to deforestation, constitutes a health hazard, and is responsible for the deaths of millions of people in developing countries such as Mozambique.

Biomass fuels release a large quantity of PM_{10} particles, particles with a diameter of less than ten microns [Smith, K.R.at *al*, 2000]. Because these particles are so small, they can infiltrate the lungs and respiratory system, causing severe health problems. Poor ventilation in residences, inefficient cooking stoves, and frequent use of the fuels exacerbate the potential for adverse effects.

Biomass fuels also pose other threats to the welfare of those who use them. In developing countries energy can cost up to a third of a family's income, taking money away from other potential uses. Women often spend three hours per day gathering firewood, sometimes walking several miles to obtain it. In addition to harming women's joints and backs from carrying heavy loads over long distances, gathering firewood takes away time and opportunity that could be put to better use.

In 2006, firewood consumption in Mozambique was about 275000 TJ and charcoal less than 25000 TJ [Ministry of Energy, 2006].

5. The roll of cleaner fuels for development

5.1. Health improvements

Smoke from biomass contains a large number of pollutants and known health hazards. Cooking over open fires emits pollutants that cause 3.5 to 4 million deaths a year globally, half of them children [Ezzati at *al.*, 2002]. A shift from firewood/charcoal to clean fuels can greatly reduce indoor air pollution, thus dramatically improving family health as showed in figure 5.1

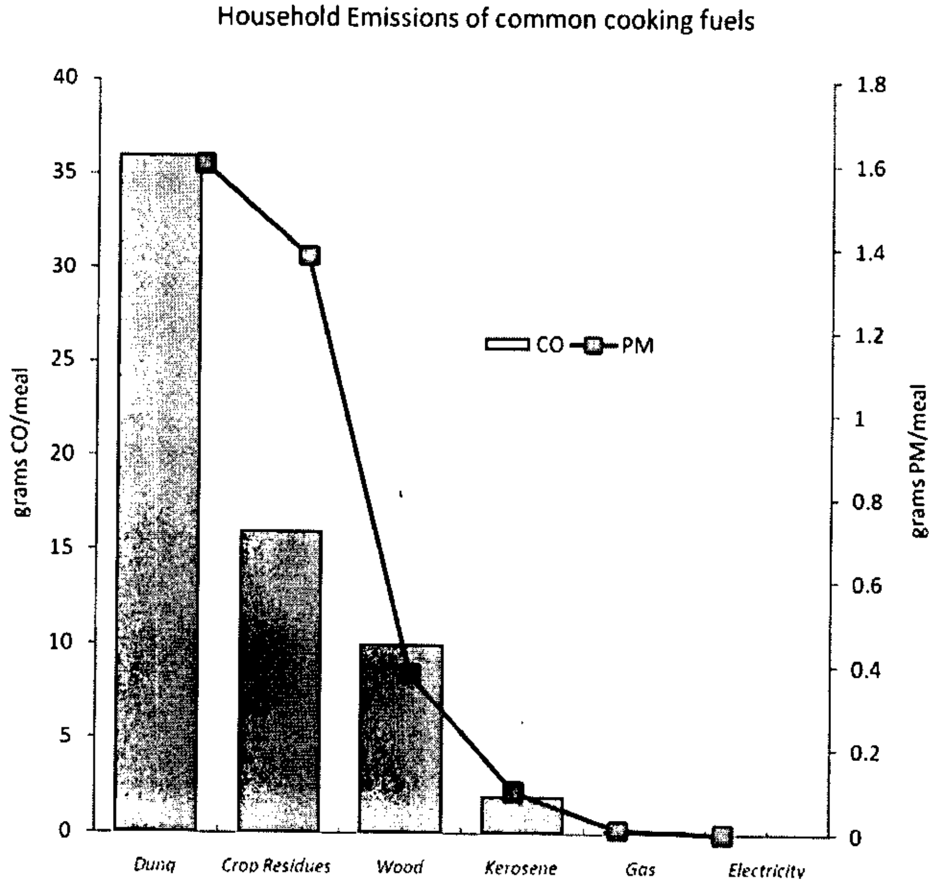

Figure 5.1: Household emissions of common cooking fuels[12].

[12] Source: Smith at *al*. 2000

5.2. Quality of life enhancement

Many rural households find much of their time and disposable income going to obtain energy. Fuel wood dependence is especially hard on women and children. Time spent collecting firewood is one factor that limits the social and educational development of children – particularly girls in Mozambique where the literacy rate is about 48%. Many women carry 20 kilograms of wood an average of five kilometers a day. This not only takes a toll on their bodies but consumes time that could be spent on more life-enhancing activities.

5.3. Rural economic development and poverty alleviation

Modern energy services are critical in the battle against poverty. Economic development is the only realistic means of permanently lifting the poor out of extreme poverty. Every sector of the economy can be enhanced by sufficient, reliable, and affordable modern energy services.

5.4. Human Development Index

The UN Human Development Index (HDI) is an index combining normalized measures of poverty, literacy, education, life expectancy, childbirth, and other factors for countries worldwide. A transition to modern source of energy can improve the Human Development Index of poor countries (Martinez, D.; Ebenhack, B. 2008).

6. Technology and facts about biofuels

6.1. Biofuels technology

The biofuels considered in this thesis are Bioethanol Biodiesel and Biogas

6.1.1. Bioethanol

Ethanol production from biomass is well know and established technology and is related to a decades. The process includes sacharification followed by fermentation and finally distillation takes place. In some biomass like sugar cane, sugar beet, the process occurs just in two steps fermentation and distillation. But in crops like corn, wheat and cassava, sacharification takes place in order to break down the starch. The process consists basically in convert the starch in sugar by enzymatic or acid hydrolysis. After sacharification, fermentation takes place to convert sugar into alcohol by adding different organisms like bacteria or yeast. This process produces ethanol with high water content and to have increase ethanol content a series of distillation must carried out.

Three steps ethanol conversion (sacharification, fermentation, distillation) can result in low alcohol yield per unit mass of biomass; this because the last step of the process depends on high yield of the first and second steps. In order to have high efficacy in distillation process maximum sacharification and fermentation must be guaranteed. From this point this is one disadvantage of using starch crops like corn, wheat, cassava for ethanol production.

6.1.2. Biodiesel

Biodiesel is produced by chemical reaction from vegetable oil, waste frying oils and animal fat with an alcohol such as methanol. The reaction requires a catalyst, usually a strong base such as sodium (cheaper) or potassium (expensive) hydroxide, and produces new chemical compounds called methyl esters and glycerin.

The main crops used for this purpose are soybean, coconut oil, sunflower, Jatropha and rapeseed. The process start with oil extraction from crops, this process can be performed in two ways: Mechanical extraction followed by chemical extraction using hexane or other chemical solvent. The reaction between oil and alcohol occur at temperatures between 50 t0 60 °C where alcohol is mixed with catalyst first, stirred vigorously to dissolve the catalyst. After that vegetable oil is added to the reactor for time 1 to 6 hours and the reaction is neutralized by adding acids after 6 hours of reaction. Decantation is carried out to separate the biodiesel in the top and glycerin in the bottom followed by washing.

The ratio Oil/alcohol depends on the amount of various fact acids in the oil and varies from 11.3% for rapeseed oil (canola) to 16.3% for coconut oil[13].

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[13] Source: Liberty Vegetable Oil Company. www.libertyvegetableoil.com/products.html. accessed: 07/30/2008

Vegetable oils with high free fatty acid content are more expected to produce soap (saponification) instead to produce biodiesel (esterification), to avoid saponification reaction more alcohol is used per volume of oil.

Another interesting factor in esterification process is the degree of mixing between the alcohol and triglyceride (TG) phases. TG and alcohol phases are not miscible and form two liquid layers upon their initial introduction into the reactor. Variations in mixing intensity are expected to alter the kinetics of the transesterification reaction. [Noureddini, H.; Zhu, D. 1997].

6.1.3. Biogas

Biogas is produced when organic matter is degraded in the absence of oxygen. This anaerobic decomposition process occurs naturally in biomasses that contain large quantities of water as well as in wetlands, lake bottoms and deep in soils. Anaerobic digestion occur in two basic steps: acidification process where complex organic wastes, proteins, amino acids, carbohydrates fats and oils are broken down into voltaic acids. The voltaic acids produced in this stage are used by Methane-forming bacteria to convert them into methane. In the waste water treatment industry, anaerobic digestion has long been used as a means of reducing the amount of organic matter which must be treated.

Environmental concerns about the effects of many industry waste streams are resulting in stricter regulations. Consequently, industries are being forced to clean

up their discharges. Since anaerobic digestion reduces the amount of organic waste and produces methane, a valuable fuel, it is becoming more and more attractive the idea of producing energy from waste.

The amount of biogas produced is determined by the temperature of the system, the volatile solid content in the biomass, and the efficiency of the converting them to biogas [Pimentel [b], D. at *al.* 2007]. For biogas production from cattle manure the efficiency is between 18% to 95%. Theoretically, a 100% efficiency digester would produce 625 liters of biogas from every 1 kg of volatile solids added [Pimentel [b], D. at *al.* 2007].

6.2. Facts about biofuels

6.2.1. Air pollution

Pollution from biofuels comes from three main phases: agriculture phase; bio-refinery phase and transportation and distribution phase. The choice as to how to generate the energy necessary to run the operation dictates the amount and nature of any significant pollutants.

For example appreciable improvements can be achieved if we use solar or wind power in ethanol production instead of using coal fired facility.

The replacement of native vegetation with biofuels feedstock and subsequent cultivation of the biomass can change the amount of carbon stored in biomass and soils and consequently changes the amount of carbon dioxide removed from

or emitted to the atmosphere compared to the assumed baseline [Kammen at *al.* 2008]. The agricultural phase appears to be the major contributor of greenhouse emissions [Searchinger [a], at *al.* 2008; Fargione, J. at *al.*, 2008; Kammen at *al.* 2008].

Biofuels are normally transported in diesel-powered trucks that emit black carbon which has a very strong global warming effect Kammen at *al.*, 2008]. During this process, amounts of pollutants are released for every mile travelled.

6.2.2. Land use and soil degradation

We are faced by increasing oil prices day after day. This spurs in, expansion of crop-based biofuels production throughout the world and consequently displaces native ecosystems and existing agricultural food production. Change in land use and vegetation clearly affect physical parameters such as reflectivity [Marland, 2003; Fedemma, 2005]; evapotranspiration and flux of sensible and latent heat that affect the absorption and disposition of energy at the surface of the earth.

Among the implications of extensive biofuel feedstock production, at both the large and small scale, soil erosion is the most serious Damage to the land can occur by sheet erosion; wind erosion and water erosion [Pimentel [a], at *al.*2007].

Currently, soil erosion is one of the most serious environmental problems faced by agriculture throughout the world. In Brazil soil erosion from sugar cane cultivation is 31 tons/ha/year [Pimentel [a], at *al.* 2007] which is 30 to 60 times

greater than the sustainability of agricultural soils. In the United States, wind erosion accounts for about 13 tons/ha/year [Pimentel [b], at *al.* 2007].

Currently 5.0 million ha of land are used worldwide to produce 18.9 billion liters of ethanol equivalent to just only 1% of the petroleum demand in the U.S. each year [Pimentel [a], 2007]. In Europe production of biodiesel rose 10 million tons [EBB, 2007] in 2007 which means it used approximately 7 million ha of land.

18.2 million hectare will be required in 2010 [EBB, 2007] at EU-15 level from biofuel production. This would require 24 percent of the total EU-15 arable land to be dedicated to producinge biofuels crops. Since the production of biofuels is expected to increase, more land will be needed to grow biofuel crops.

6.2.3. Greenhouse Gases Emissions

The arguments that biofuels reduce greenhouse gasses emissions are not entirely true. Recent studies show that corn-based ethanol, instead of producing a 20% saving in GHG emissions, nearly doubles greenhouse emissions over 30 years. In addition, increases in greenhouse gas emissions occur for 167 years from land use change. If switchgrass is grown on U.S. lands formerly devoted to corn, emissions increase by 50% [Searchinger [a] at.*al.*, 2008]. Soy biodiesel increases greenhouse gas emissions by 158% over 30 years [Searchinger [b], 2008]. In another study, CO_2 emissions are estimated to be17 to 420 times higher than the

annual GHG reductions these biofuels provide by displacing fossil fuels if rainforests, peatlands, savannas or grassland land are converted to grow biofuel crops [Fargione at. *al*., 2008].

From table 6.1 we conclude that soil and vegetation contain large amounts of carbon approximately 2.7 times the carbon in the atmosphere [Fargione, at *al*. 2008]. This carbon is released through land use changes such as deforestation and conversion of native ecosystems to cropland. Forty-three percent of land used for grain in 2004 will be needed for production of bio-fuels by 2016 in the U.S. [Searchinger, at *al*.2008]. This means that land currently storing CO_2 could be turned into cropland to support the increased demand for bio-fuels. Depending on the type of land converted, there could be an increase in CO_2 emissions due to a reduction in carbon benefit of the native land. Using land that is already used as cropland does not have as negative effects however. Land use changes to native ecosystems in places like the US, Indonesia, China, Brazil and Africa could create large greenhouse gas emissions.

Table 6.1: Estimates of global carbon stocks in vegetation and soil to 1 m depth[14]

Biome	**Area**	**Global Carbon Stocks (Gt C)**		
	10^9 ha	Vegetation	Soils	Total
Tropical forest	1.76	212	216	428
Temperate forest	1.04	59	100	159
Boreal forest	1.37	88	471	559
Tropical savannas	2.25	66	264	330
Temperate grassland	1.25	9	295	304
Desert and semi-deserts	4.55	8	191	199
Tundra	0.95	6	121	127
Wetlands	0.35	15	225	240
Croplands	1.6	3	128	131
Total	**15.15**	**466**	**2011**	**2477**

[14] Source: Bolin, B. at *al.* 2000.

6.2.4. Water level and contamination

Over 1.2 billion people do not have access to safe water and 40% of humanity does not have access to water to meet their daily needs [CA, 2007].

Currently the production of biofuels is estimated to be 39000 million liters [Charlotte, 2008]. At least 11 to 12 million ha of land and 100 Km^3 of fresh water are used. In the process of biofuels production water is required at two stages: The agricultural phase and in the biorefinary phase. In China, 2400 liters of water are used for irrigation just to produce 1 liter of ethanol and 3,500 liters of water /1 liter of ethanol is the ratio for India [Charlotte, 2008].

Growing crops for biofuels is likely to have significant regional and local impacts. Shifting land from an existing crop (or non-crop plant species) to a crop used in biofuels production has the potential to change irrigation water use, and thus the availability of local water.

Mozambique a country with a predominantly tropical climate, has physical water scarcity in the southern part of the country and economic water scarcities in the central and northern parts of the country. This is one of key issues for biofuels production from high water consuming crops like sugar cane, soybeans and coconut.

Figure 6.1 shows how necessary irrigation is for productivity, even for crops claimed to be less water consumptive such as Jatropha. We can see exponential

growth in productivity for irrigated crops after 5 year and at least we reach saturation productivity case for unirrigated crops after 5 years. So there is no question that, as with other crops, water context is critical.

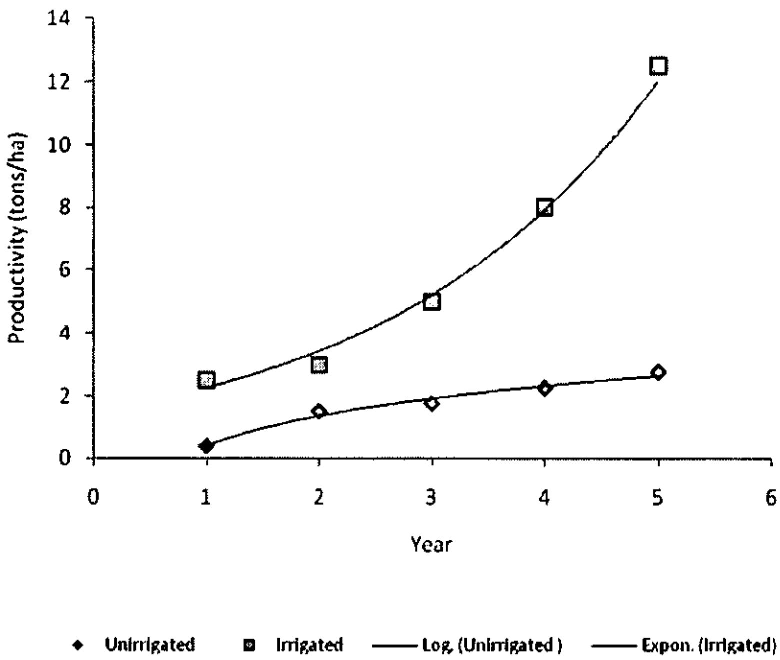

Figure 6.1: Influence of irrigation in Jatropha productivity.[15]

[15]Center for Jatropha promotion. Promoting farming for future fuel. Growing diesel fuel Plant. http://www.jatrophabiodiesel.org. accessed: 07/30/2008

Another issue related to biofuels production is waste. Approximately 11 liters of waste water are produced per 1 liter of ethanol produced from sugar cane and corn, this wastewater also contains a biological oxygen demand (BOD) of 18,000 to 37,000 mg/l [Pimentel [a], at *al.* 2007]. In order to remove and or treat this sewage effluent more energy and dollars are needed. The cost of processing the effluent was reported to be 4 kWh/kg of BOD [Pimentel [a], at *al.* 2007}. The two major areas for higher water consumption associated with biodiesel production are the esterification process with methanol and the production of chemical fertilizers.

Most of the water used during esterification is for washing the products to remove soap and catalyst. [Pate et.*al.* 2007]. An estimated 3 liters of water is used per liter of biodiesel produced. Biodiesel has the potential to produce waste water discharges of high BOD, grease, and oils since it uses chemical compounds like hexane for oil extraction from the seeds; sodium or potassium hydroxide as catalyst in esterification reaction and fresh water to separate biodiesel from glycerin by washing. Wastewater, potentially high in biochemical oxygen demand is problematical because decomposition can consume all of the dissolved oxygen in water, suffocating aquatic animals.

6.2.5. Energy density

By definition, Energy density is the amount of energy stored in a given system or region of space per unit volume, or per unit mass. The energy density of ethanol is less than the energy density of gasoline and as the energy density of biodiesel also is less than the energy density of diesel (table 6.2), meaning that a greater volume (and mass) must be carried to provide comparable cruising ranges in vehicles. This also translates to greater time consumption in fueling vehicles. Consequently, the miles per gallon of biofuels are less than the miles per gallon of fossil fuels in the same proportion of low heating values. In Mozambique, where the fuel distribution infrastructure is not well developed, it is highly problematic to decrease the cruising range of vehicles, as one cannot depend on finding fueling facilities everywhere.

Table 6.2: Low heating values of biofuels and fossil fuels[16]

	Diesel	Biodiesel	Gasoline	Bio-ethanol
LHV (MJ/kg)	42	38	43.4	26.9

[16] Source: Raymond, et, *al.* 2004; GREET Transportation fuel cycle analysis model developed by Argonne national laboratory.2007.

A barrel of crude oil after remove from the ground and refinery process yields approximately 122 liters of transportation fuel (gasoline, diesel and jet fuel). Some of the petrochemicals products made from a barrel of crude oil include all plastic, nylon, rayon, polyester, cosmetics, and detergents.

Table 6.3:Mass balance of barrel of crude oil under American conditions[17]

1 Barrel of crude oil (169.1 liters)					
Transp.fuel (liters)		By-products (liters)			
		Heating oil	Heavy fuel oil	LPG	Petrochemical products
Gasoline	72.5	6.6	6.7	6.5	27.5
Diesel	34.9				
Jet fuel	14.4				

[17] Source: Minerals year book, U.S. Bureau of mines. 1980; What fuel are made from crude oil. http://www.eia.doe.gov. Accessed: 7/30/2008.

6.2.6. Impact on food consumption

Studies performed by Rosegrant at *al.* (2006) showed substantial price increase in cassava, sugar, oil crops and grains, Brown (2006) relate the corn price increases in the U.S. Biofuels production may compete with food crops and have significant negative impacts on food security, this because for large scale commercial biofuels production will be necessary land and water available in order to have high agricultural yields (tons/ha) and my take place on lands that would be suitable for food production.

In countries like Mozambique with more than 80% of the population living in rural areas and dependent in agriculture of subsistence, weak system of irrigation, low annual rainfall, and only 3 million ha of land suitable for irrigation there is no doubts about the negative impact of biofuels production for large commercial scale.

One of the impacts on food security is through impacts on access to land for people who depend on land-based agricultural livelihoods [Cotula, L. at *al.*2008] like in Mozambique. As biofuels begin to push up prices of food and people are hence most in need of land for production, poor people's access to that land is liable to be weakened [Cotula, L. at, *al.* 2008]. Land destined for rice production was shifted to sugarcane production in the Wami Basin (Tanzania).

7. Objectives

The objectives of this study are as follows:

Perform a life cycle assessment of biofuels in Mozambique by:

- Estimating a net energy value of biofuels,
- Evaluate water requirement and land availability,
- Evaluate Greenhouse gas emissions due to land use changes

Synthesis of ethanol from cassava waste,

- Provide direct observations of the life cycle factors
- Compare the ethanol potential from raw cassava to that from cassava waste

8. Methodology

8.1. Synthesis of ethanol from cassava waste

Cassava residue, starch-processing waste from cassava plant was used as a raw material in ethanol production. The experiment was performed into two steps (1) enzymatic hydrolysis, the step in conversion of starch to fermentable sugar, and (2) ethanol fermentation, the step in conversion of fermentable sugar to ethanol by turbo yeast.

Two scenario were investigated, ethanol production form cassava skin, and ethanol production from cassava juice and the results are showed in table 8.1. Detailed explanation of the methodology can be found in Bioethanol production from Cassava: A Sustainable Energy Source for Mozambique?
Author: Steven Kraft, 2007. Steven studied cassava fermentation using barley malt as source of enzyme break down starch into sugar and turbo yeast to ferment sugar into ethanol, and obtained alcohol content of 7% in volume.

Procedures, Materials and Equipment[18]

The materials necessary for brewing a beer or fermented alcoholic beverage are quite simple. Adapting the typical tools to this specific problem, the following items employed for making cassava waste alcohol were as follows [Kraft, S. 2007]:

- Cassava (raw root with skin)
- .Malted barley (crushed)
- Yeast (powdered)
- Thermometer (in degrees Celsius)
- Beakers (various sizes)
- Flakers (various sizes)
- Test tubes
- Graduated cylinders (various sizes)
- Mortar and pestle
- Knife (for cutting cassava root)
- Hot plate
- Digital balance
- Triple-beam balance

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[18] Detailed explanation about procedures, enzymatic and fermentation process can be found at Kraft, S. 2007. "Bioethanol production from Cassava: A Sustainable Energy Source for Mozambique?" Master thesis in Chemical Engineering. University of Rochester.

- ❖ Coffee filters
- ❖ Funnel
- ❖ Gas chromatograph
- ❖ Temperature controller
- ❖ 10% ethanol solution (for reference with gas chromatograph)

Optimal Procedure

The procedure describe below was prepared by Steven Kraft in 2007 when he produced ethanol from cassava (Master thesis in Chemical Engineering).

- 175 mL of liquid waste and 75 mL of skin waste
- Added 60 grams barley and 150mL to crushed cassava
- Heated solution to 45 °C. holding temperature for 15 minutes while stirring continuously.
- (Repeated previous step at 56 °C, 65 °C, and 70 °C.')
- Heated to 80. to discontinue enzymatic activity
- Cooled mixture from 35 °C to 40 °C. Quickly
- Added 3.29 g "Turbo Super Yeast" and allowed to ferment for 24 hours.
- Filtered using coffee filter to remove solids
- Finally ethanol content determination using GC

Table 8.1: Ethanol content in cassava waste

	Alcohol content (%)	
	Cassava juice	Cassava skin only
Experiment 1	4.98	2.87
Experiment 2	5.16	2.88
Average	**5.1**	**2.9**

8.2. Technical assessment

Goal and scope definition

The goal is to perform a life cycle assessment of biofuels produced from crops, agriculture by-products and waste.

System boundary

The system boundary of biofuels production was set up to identify the exchange of the system with the environment in terms of net resources inputs and outputs. The three main segments involved in biofuels production are assumed to be:

a) **Agricultural phase**–land preparation, cultivation harvesting and processing of feedstock.

b) **Biorefinery phase**- Conversion of feedstock into biofuels.

c) **Transportation phase**- Transport of fertilizers, feedstock and produced biofuels.

Two scenarios will be investigated:

Scenario I: This scenario addresses the production of biofuels from crops. Three main phases (Agricultural phase, Biorefinery phase and Transportation phase) will be analyzed.

Scenario II: This scenario examines the production of biofuels using waste, by-products of agriculture and sugar cane molasses. Two main phases will be studied. Biorefinery phase and transportation phase.

Life-cycle assessment

Life-cycle assessment (LCA) is a process to evaluate the resources consumed and environmental burdens associated with a product, process, package, and activity. The LCA process encompasses the identification, quantification and evaluation of resources usage, as well as environmental impacts across all stages of the life cycle as illustrated in figure 8.1. Not only does LCA provide a whole picture of resource consumption and environmental burdens but it also can help highlight specific areas where technological innovation or strategic policy is need.

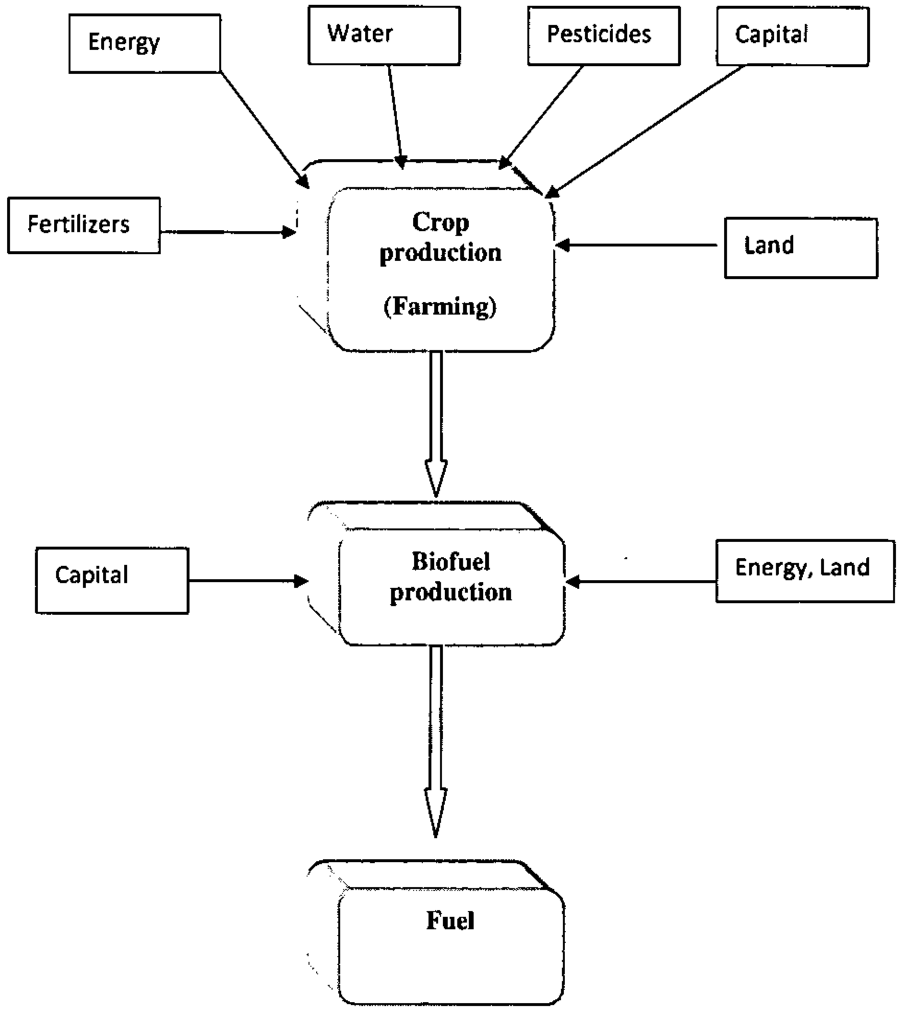

Figure 8.1: General Biofuel pathway[19]

[19] Adapted by the author from Kammen, at *al.*, 2007

Major assumptions simplifications

Performing a complete and thorough LCA requires a large amount of information regarding the processes involved in whatever is being evaluated. To create a good model, the information must be detailed, accurate, up to date and from a reliable source.

LCA studies in biofuels production in developing countries like Mozambique are very difficult compared to developed countries, where the agriculture and biofuels industries are standardized, heavily regulated and large amounts of data exist.

For example there are many scientific papers published on biofuels production LCA by scholars like David Pimentel, Tad Patzek, Daniel Kammen , Alexander Farrell; Isaias Macedo, Marcelo D. Oliveira and others from the USA, Brazil, Europe and Asia .

Excellent records have been kept regarding the resources required for preparation and fertilization of field crops, resources used in harvesting and processing the crops, and finally the resources used to truck the biofuels to their final destination. Finding the analogous information for Mozambique is difficult because:

- The agricultural sector is not mechanized or standardized;
- There is no production of biofuels in Mozambique currently.

Thus, finding good estimates of necessary data has proven to be difficult. Therefore, many of the values used are informed assumptions, estimates, and values adapted from sources like Mozambican sugar cane, vegetable and soap industries.

8.2.1. Net energy value

Governing Equations and Principles

The following definitions are shared among many studies, including the following papers:

- "Assessment of greenhouse gas Emissions in the Production and Use of Ethanol in Brazil. Government of Sao Paulo, Secretariat of the Environment, 36p" [Macedo at *al.* 2004];
- "Ethanol production: Energy and Economic Issues Related to U.S. and Brazilian Sugarcane" [Pimentel, D.; Patzek, T. 2007];
- "Ethanol Can Contribute to Energy and Environmental Goals" [Farrell, 2006] incorporated into their EBAMM model; "Full Chain Energy Analysis of Fuel Ethanol from Cassava in Thailand" [Nguyen, at *al.*2007].

Net Energy Value is the difference between the energy content of biofuels and the amount of net energy inputs in the fuel production cycle (both fossil and non-fossil). The solar energy absorbed by crops through photosynthesis is considered free, and thus is not taken into account.

$$NEV(MJ / L_{fuel}) = OutputEnergy(MJ_{fuel} / L_{fuel}) - InputEnergy(MJ_{Imput} / L_{fuel}) \quad (8.1)$$

Output Energy is the energy contained in the fuel plus energy contained in the co-product [Farrell, at *al*.2006].

$$\begin{aligned} OutputEnergy(MJ / L_{fuel}) &= FuelEnergy(MJ / L_{fuel}) \\ &+ Co-productEnergy(MJ / L_{fuel}) \end{aligned} \quad (8.2)$$

Input energy is the sum of the energy required to create all of the inputs. This includes the energy needed to cultivate the crop, the energy required to refine and process the crop into fuel; and finally the energy required for transport, storage and distribution. The equation for Input energy is shown in equation 8.3:

$$Input\ Energy\ (MJ_{Inmput}\ /\ L_{fuel}) = \frac{Agric.Energy\ (MJ_{Input}\ /\ ha)}{NetYield\ (L_{fuel}\ /\ ha)} + Biorefiner\ yEnergy\ (MJ_{Input}\ /\ L_{fuel}) + Transp.Energy\ (MJ_{Input}\ /\ L_{fuel}) \tag{8.3}$$

Definition of Inputs and Outputs

The agricultural energy cited in equation 8.3 is comprised of embodied energy, farm direct energy, farm labor energy, farm machinery energy and inputs packaging energy. Embodied energy is comprised of farm inputs, multiplied by their respective application rates. These include fertilizers, soil amenities, herbicides, insecticides and seeds.

Farm labor energy has been a matter of controversy. Some published papers use a TCF method and a value of 2.3 MJ/h derived for human labor energy equivalent. Others use an LSSE method recommended by Odum, H.T.1983. This method consists of estimating a person's energy input by multiplying its cost by the average energy to monetary unit ratio or energy intensity of the country. For a country like Mozambique where agricultural laborers are located in rural areas where the access to electricity is a mere 2.5%, the LSSE method is not suitable. I

am assuming the TFC method to be the most appropriate method for Mozambique.

Biorefinery energy is energy that is required to produce biofuels from the harvested crops. This energy is the sum of inputs from electricity, fossil fuel, biomass energy, process water, effluent water energy and embodied energy.

Transport and Distribution is energy used in transporting all inputs and outputs. This phase is divided in three categories:

Category 1: Fertilizers

- Step 1, From manufacturing plant to distribution;
- Step 2, from distribution centers to retailers;
- Step 3, from retailers to farms.

Category 2: Crops

- From field to farm collection areas?
- From farms to processing plants

Category 3: Biofuels

- Step 1, biofuel s from factories to oil refinery
- Step 2, biofuels from oil refineries to gas station.

Specific assumptions and estimates:

Since Mozambique's government is considering a series of projects to produce biofuels and recently studies show that the country could produce 40 million liters of bio-diesel and 21 million liters of bio-ethanol per year [African Economic Outlook, 2008], my calculations will be in that range of production level.

An ethanol plant will be located in Massingir District (Gaza Province) 300 km away from Maputo City and 150 km away from National Road number 01. It will produce 100,000 liters of ethanol per day. The site was chosen because of water availability from Massingir dam, natural gas availability from the Chokwe district (100 km away from Massingir District), and available agricultural land. Note however that the Massingir dam has a storage capacity of 2.84 $km^{3.}$ And water for used for irrigation is 2.13 km^3.

Also I assumed that a biodiesel production plant producing 100,000 liters of biodiesel per day will be located in the same place as the ethanol plant.

A plant for producing molasses ethanol from molasses residues will be located 10 km away from two sugar cane plants in the southern part of Mozambique, 75 km away from Maputo City. The same location is suggested for a plant producing biodiesel from cotton seed.

Annual production of ethanol and biodiesel will be determined by annual production of molasses and cotton seed. In Mozambique 90,000 tons of molasses are produced annually (INA, 2007) and half of it is produced in the southern part of the country (Xinavane Sugarcane and Maragra Sugarcane).

Agricultural phase

- Sugarcane productivity is 75 tons/ha. (INA, 2007);
- Cassava productivity is 15 tons/ha. (INE [a], 2007);
- Jatropha productivity is 2 tons/ha average value from Achten, at *al.* 2008;
- The amount of applied fertilizers; pesticides and herbicides are the average of values from studies by Pimentel, Patzek, Shapouri, de Oliveira, Thu Lan, Wang, Grabosk, and Kammen).
- The steps involved in this stage includes land preparation; planting, fertilization; weed control; and harvesting;
- Tractors and others machinery (diesel machinery) will be used for this phase;
- I make the assumption that cassava uses less pesticides, herbicides, insecticides, and irrigation water; than Jatropha, sugarcane and coconut oil.

Biorefinery phase

- The steps involved in this segment include liquefaction; sacharification; fermentation; distillation/dehydration in case of cassava based ethanol; and fermentation, distillation/dehydration in case of sugar cane ethanol.
- For biodiesel production the main step is esterification followed by decantation to separate the biodiesel from glycerin and finally washing to remove the residual glycerin in the biodiesel.
- In the case of cassava, the by-products (distilled mash; cassava dried peel) will be used as an energy resource for the distillation process phase as well as is the sugarcane bagasse.
- I assumed electricity and natural gas as the main sources of energy inputs. The natural gas will piped from the nearest take off poin (Chokwe).
- The high density polyethylene pipeline for transporting gas is estimated to be 100 km long– from Chokwe take-off point to Massingir

Transportation phase

The three main items requiring transport in biofuels production are fertilizers, crops and biofuels. In this phase the main transport will be by trucks, having payloads of 1-35 tons in round trip distances.

- Transportation of Fertilizers

- From manufacturing plants to distribution centers, distance travelled 600 km (South Africa-Maputo) using 4 trucks with payload of 35 tons,1 trip
- From distribution centers to retailers, distance travelled 310 km (Maputo City to Massingir) by 2 trucks of 35 tons each, 2 trips;
- From retailers to farms, distance travelled 10 km, 2 trucks of 7 tons each, 2 trips.

- Transportation of crops
  - Crops from farms to storage facilities, distance travelled 10 km by 2 trucks of payloads of 35 tons; 7 trips;
  - Crops from storage facilities to biofuels plant, 1 km, 2 trucks of 8 tons in payloads and 7 trips.

- Transportation of biofuels
  - Biofuels from plant to oil refineries (will be transported by 8 diesel trucks having payloads of 20 tons to Maputo City, 310 km) 1 trip.
  - Gasohol from refineries to gas stations (maximum distance travelled 500 km), 4 diesel trucks of 20 tons of payloads and 1 trip.

The results are showed below from table 8.2 to table 8.8 as well as few modeled scenarios illustrated in figure 8.2 to figure 8.8.

Table 8.2: Energy balance for Ethanol production[20] in MJ/L

	Cassava Ethanol	Sugarcane Ethanol	Molasses Ethanol
Agricultural Phase (MJ/L)	4.15	6.80	0
Refinery Phase (MJ/L)	15.02	3.28	3.25
Transportation Phase (MJ/L)	4.12	4.12	3.18
Total Input(MJ/L)	19.17	12.88	5.12
Total output(MJ/L)	23.5	25.8	21.2
NEV(MJ/L)	**4.33**	**12.92**	**16.08**
NER	**1.23**	**2.00**	**4.14**
Total land needed (ha)[21]	**12,121**	**6,165**	**0**

[20] Calculations were based on data from Pimentel at *al.* 2007; De Oliveira at *al.* 2005; Macedo, I.C. at, *al.* 2004; Ngueyn, T.L.T. at, *al.*2007.

Table 8.3:Energy balance for Biodiesel[22] production in MJ/L

	Jatropha	Sunflower	Cotton Seed
Agricultural Phase (MJ/L)	22.3	24.1	0
Refinery Phase (MJ/L)	11.86	10.404	10.404
Transportation Phase (MJ/L)	2.07	2.07	3.18
Total Input(MJ/L)	36.2	36.6	13.6
Total output(MJ/L)	46.2	48.3	41.2
NEV(MJ/L)	**10**	**11.7**	**27.6**
NER	**1.3**	**1.3**	**3.03**
Total Land Used (ha)[23]	**67,000**	**72,000**	**0**

[21] Assumed annual production of 40,000,000 liters of ethanol with sugar cane volumetric yield of 6488 $L_{ethanol}$/ha ; 3300 $L_{ethanol}$/ha for cassava.

[22] This calculation was based on data from Kallivroussis, L. at *al.* 2002; Pimentel, D. at *al.* 2007; Prueksakorn, K. at *al.* 2006.

[23] Assumed annual production of 40,000,000 liters of Biodiesel with volumetric productivity of 600 L/ha and 550 l/ha for Jatropha and sunflower respectively.

Table. 8.4: Natural resources input for biofuels production

	Land (ha)	Water (10^6 m^3)
Sugarcane ethanol	6,165	133.3
Cassava ethanol	12,121	73
Molasses ethanol	0	0.02
Sunflower biodiesel	72,000	0.12
Jatropha biodiesel	67,000	0.12
Cotton seed biodiesel	0	0.0405

Sensitivity analysis and optimization

The results presented in tables 8.1 and 8.2 come from educated assumptions and estimates of some variables. From these estimates different sensitivity analyses were conducted to determine the effect on the process of variables that had some degree of uncertainty, and to identify any operating specifications within an individual process that could be modified to improve the net energy value. The greatest variables between LCA of biofuels studies are:

- farm yield
- nitrogen application rate
- nitrogen energy
- refinery yield
- refinery energy

Influence of volumetric yield in net energy value[24].

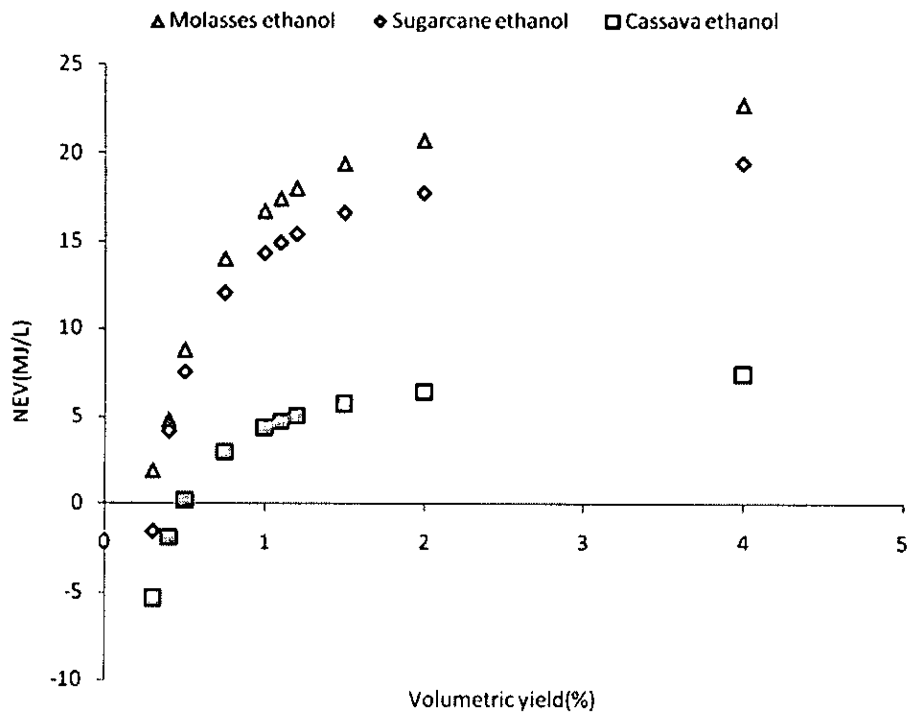

Figure 8.2: Net energy value as function of volumetric yield for ethanol.[25]

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[24] Volumetric yield as a product of field yield and refinery yield: $\left(\frac{kg}{ha}\right)*\left(\frac{l}{kg}\right)\Rightarrow\left(\frac{l}{ha}\right)$

[25] Graphic created by the author

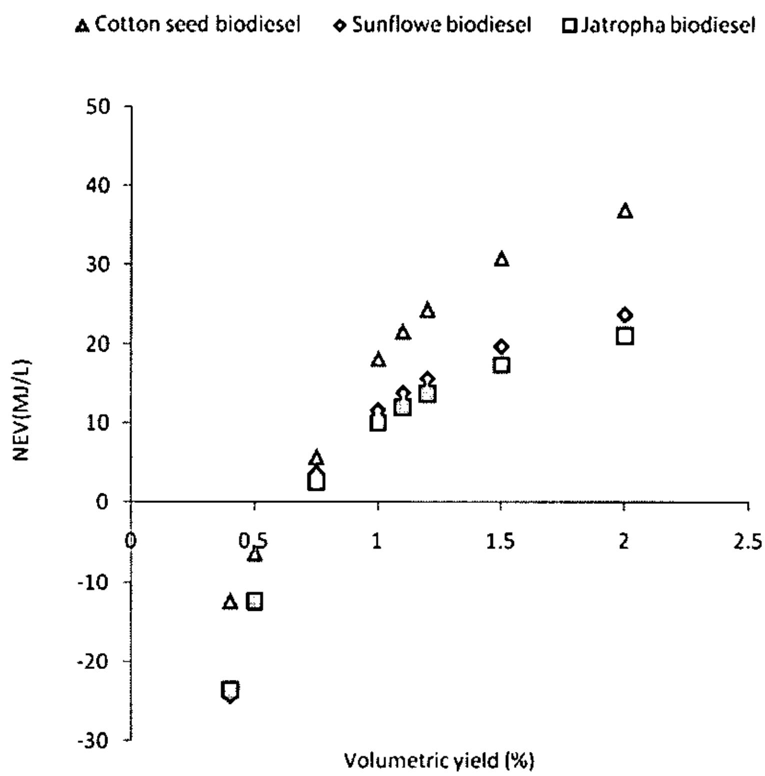

Figure 8.3: Net energy value as a function of biodiesel volumetric yield

Influence of nitrogen application rate in net energy value.

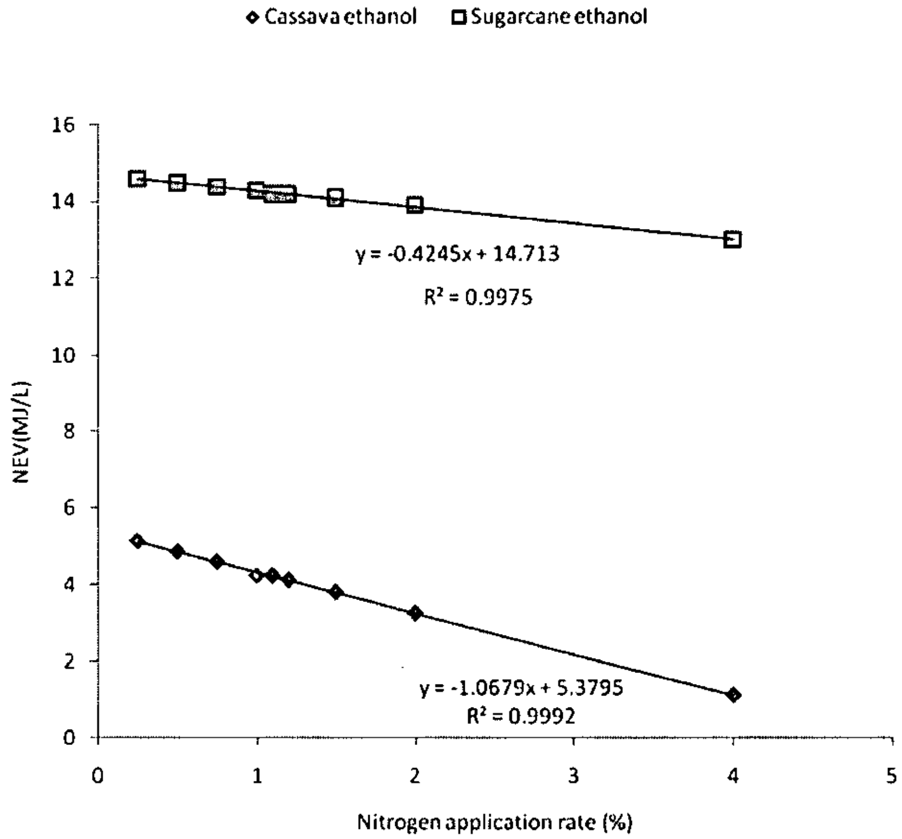

Figure 8.4: NEV as function of nitrogen application rate for ethanol

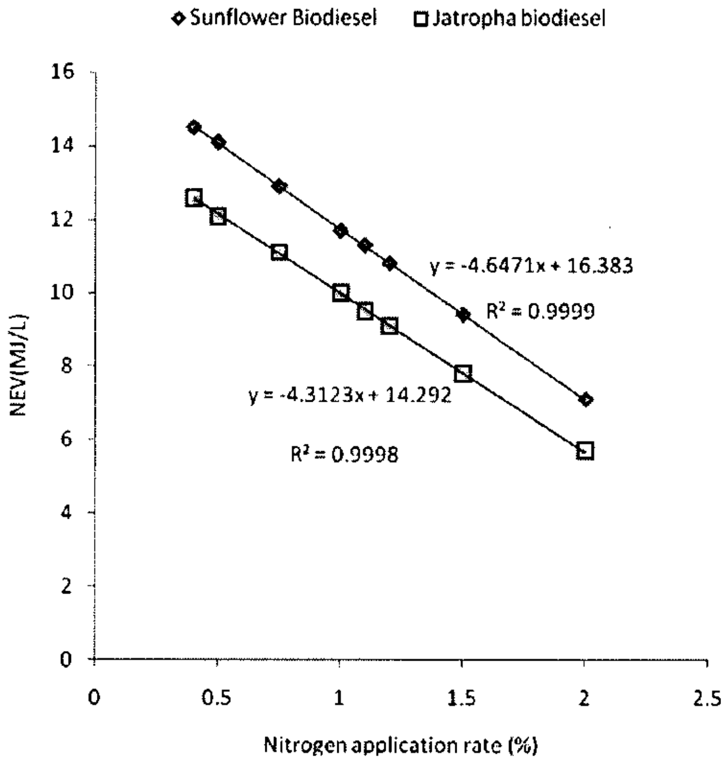

Figure 8.5: NEV as function of nitrogen application rate for biodiesel

Influence of energy input in refinery phase

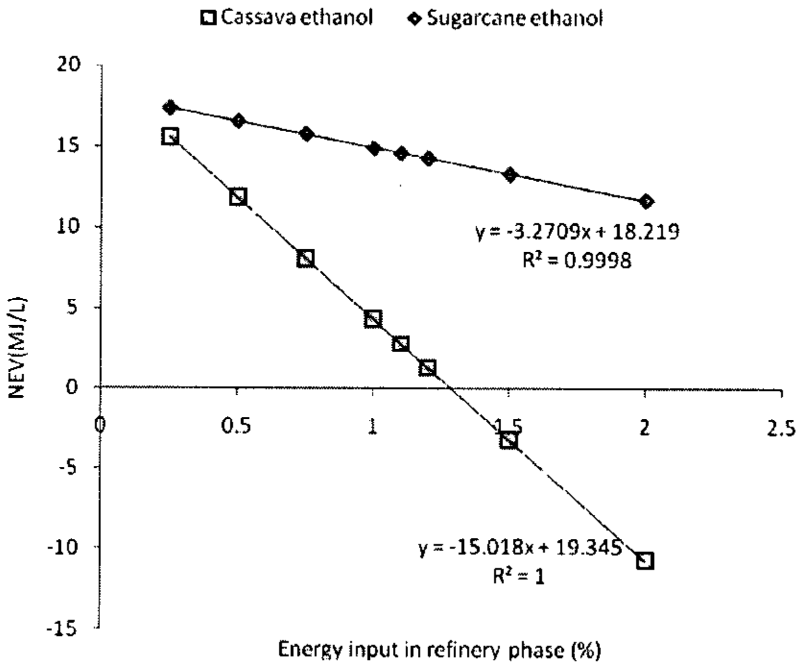

Figure 8.6: Effect of energy input (refinery phase) in Net energy value of ethanol

Table 8.5: Energy balance for biogas production from brewery waste

Human labor (MJ)	46
Electricity (MJ)	17035
Cement foundations;30 years life (MJ)	5.3
Steel: gas collector , other equipment with 30 years life (MJ)	2119.9
Pumps and motors (MJ)	3
Steel trucks/tractors for transportation ;10 years life (MJ)	605.7
Petroleum for transport; 20 km radius (MJ)	1989.7
Total Input(MJ)	**21804.5**
Methane Yield (L/kg dry mass)[26]	361
LHV (MJ/L)[27]	0.0239
Total output(MJ)	**133953.3**
NEV(MJ)	**112148.7**
NER	**6.1**

[26] Average value obtained from Jain at *al.* 1995; Neves, L. at *al.* 2006

[27] Pimentel [b], D. at *al.* 2007.

8.2.2. Water balance

Water balance involves water required to grow the crops and water used in bio-refinery phase.

$$(Water\,Biofuel)_i = (ETm)_{crop_i} * (Land\,Used) + (Water.refinery) * \Pr oduction$$

(8.5)

$(Water\ Biofuel)_i$	Total water required to produce biofuels from crops	[m^3]
$(ETm)_{crop_i}$	Water requirement for maximum production	[m^3/ha]
$(Total\ land\ )_{prod.crop_i}$	Total land used to produce crops	[ha]
$(Waterref\ .)_{proc.crop_i}$	Water requirement in bio-refinery phase	[m^3/L]
$\Pr oduction$	Biofuel production per year	[L]

Table 8.6: Water required in biofuels production

Crop	Agricultural phase m^3/ha[28]		Refinery phase (m^3/L)[29]
	Min.	Max.	
Sugarcane	15000	25000	0.25
Cassava	5000	7000	0.004
Jatropha	10000	15000	0.003
Sunflower	6000	10000	0.003
Molasses	-	-	0.002
Cotton seed	-	-	0.003

[28] Source: FAO. Crop water management. http://www.fao.org/ag/agl/aglw/cropwater. accessed: 6/26/2008

[29] Source: Pimentel[a] at *al.* 2007; Pate at.*al.* 2007.

Cost of water

Taking as example the use of water from Massingir dam, we can evaluate the cost of water as total investment in dollars, dam capacity (m^3) and life time of the dam (years).

Table 8.7: water cost evaluation

	Agricultural phase[30]	Refinery phase [31]	Total ($/year)
Sugarcane	624,097.7	37,962.1	**662,060**
Cassava	368,111.4	607.3	**368,719**
Jatropha	0	455.5	**455.5**
Sunflower	0	455.5	**455.5**
Molasses	0	14,236	**14,236**
Cotton seed	0	205	**205**

[30] Jatropha and sunflower were assumed not irrigated crops.

[31] 100,000 liters per day, 300 days per year for Sugar cane, cassava, Jatropha and sunflower. The costs for Molasses and cotton the calculations were based in annual production of molasses and cotton seeds times refinery yield.

8.2.3. Land balance

To estimate future land areas available for growing biofuels feedstock for energy production, the equation below is proposed.

$$A_0^{agric} = A_t^{foodfeed} + A_t^{comercrops} + A_t^{unused} \tag{8.4}$$

A_0^{agric} Total available agricultural land in country in base period [ha]

$A_t^{foodfeed}$ Agricultural land area requirements in country for domestically produced food and feed for year t [ha]

$A_t^{comerc.crops}$ Agricultural land area in country required for commercially produced crops[32] for year t [ha]

A_t^{unused} Agricultural land areas in country unused in year t [ha]

[32] Commercial crops are assumed to be cotton, cash nut, sugarcane, tea, citrus, copra, tobacco and sunflower.

Country-wide agricultural land area required for domestically produced food and feed for year t.

To determine the land needed for food production, land use data was collected from FAOSTAT 2006, and National Institute of Statistics. The reference years were 1990 to 2005. After plotting land use as function of time, we found quadratic function correlations. Since this is a limited source, for future uses, the best correlation is a function with saturation point. Hyperbolic tangent was chosen to be appropriate function witch describe the saturation phenomena in natural resources use such as land.

Three scenarios were proposed to be the next future land use for food production as showed in figure 8.4.

Scenario A: It is assumed that the saturation point in land use for food production will occurs in 2014, and maximum land use will be 12.2 million ha in 2069.

Scenario B: Saturation begins in 2034 and is complete by 2069, the maximum land use is about 17.6 million ha.

Scenario C: Saturation begins in 2044 and complete by 2069, 24.8 million ha will be used for food production.

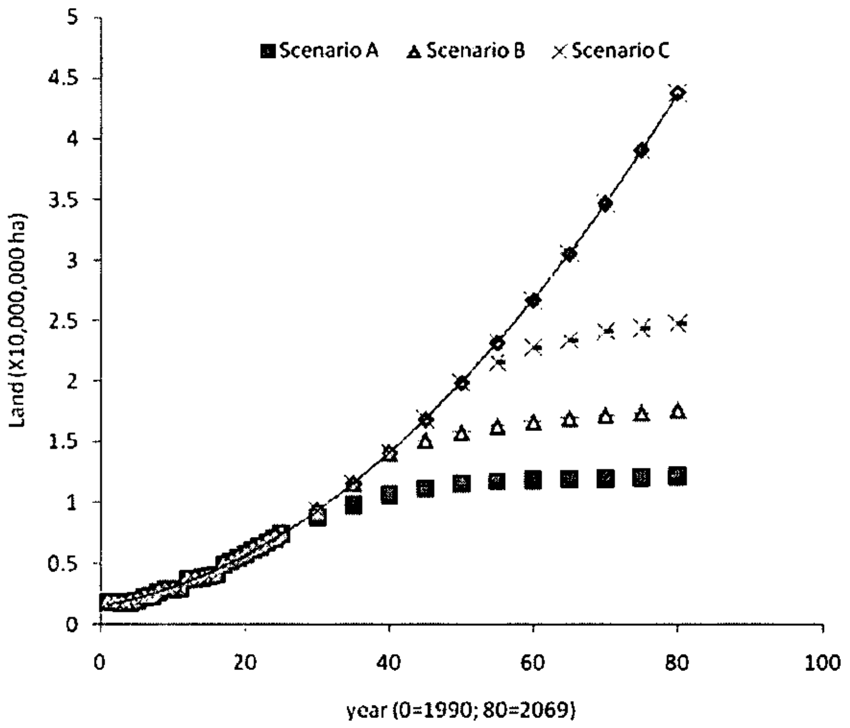

Figure 8.7: Land use profile for food production in Mozambique[33]

[33] Graphic created by the author base on data from FAOSTAT 2006, INE 2008

Agricultural land area in country required for Biofuel production

The rapid spread of commercial biofuel production may result in losing access to land and water in poorer groups, and in rural population which depend on it (case of Mozambique). In these contexts, the spread of commercial biofuel crop cultivation can have major negative effects on local food security and on the economic, social and cultural dimensions of land use.

Taking into consideration ethical and moral issues associated with land for food, as we can live with a minimum of energy resources but we can't live without adequate food resources, [Cotula, at *al.* 2008] Governments must develop robust safeguards in procedures to allocate land to large-scale biofuel feedstock production where they are lacking and even more importantly to implement these effectively.

Resources like land water must given priority for food and feed production. In order to do that I propose a mathematical model described in equation 8.4.

Similar calculation should be than for water in places where water is shortage like in southern region of Mozambique.

In this equation, the only land that can be shifted into biofuel production is the land allocated for commercial crops and unused land from the overall equation 8.4. and also the decision to shift land used for commercial crops to land used for biofuels production can be a function of production cost and demand between

biofuels and commercial crops or the ratio between $\left(\frac{\$ Invested}{\$ Revenue}\right)_{Biofuel}$ compared to $\left(\frac{\$ Invested}{\$ Revenue}\right)_{Comercial crop}$.

Thus, the land balance for biofuels can be written by the following equation:

$$(Land\ Biofuels)_t = \alpha * A_t^{comerc.crops} + \beta * A_t^{unused} \qquad (8.5)$$

$-1 \le \alpha \le 1;\ 0 \le \beta \le 1$

α: Coefficient of shifting from commercial crops to biofuels crops and vice versa.

β: Coefficient of utilization the unused land

$\alpha > 0$: There is some land can be converted to biofuels crops $\left(\frac{\$ Invested}{\$ Revenue}\right)_{Biofuel} > \left(\frac{\$ Invested}{\$ Revenue}\right)_{commercial crop}$

$\alpha = 0$: There is no land can be converted to biofuels crops

$\left(\frac{\$ Invested}{\$ Revenue}\right)_{Biofuel} \approx \left(\frac{\$ Invested}{\$ Revenue}\right)_{commercial crop}$

$\alpha < 0$: There is some land to be converted from biofuels crops to commercial crops

$$\left(\frac{\$Invested}{\$Revenue}\right)_{Biofuel} < \left(\frac{\$Invested}{\$Revenue}\right)_{commercial\,crop}$$

Agricultural activity in Mozambique is primarily for subsistence. So priority must be given to land availability for food production. Commercial cropland must be less than land devoted to food production in a country like Mozambique where more than 50% of the total population lives under $1 per day.

$$A_t^{commercial\,crops} = \varphi * A_t^{food\,production} \qquad (8.6)$$

$$0 < \varphi < 1$$

Combining equations 8.4, 8.5 and 8.6 we obtain the final equation for land available for biofuels crops.

$$(Land\ Biofuels)_t = \beta * A_0^{Agric.} + [\alpha * \varphi - \beta * (1+\varphi)] * A_t^{food\,fed} \qquad (8.7)$$

For Mozambique we can assume:

$A_0^{Agric.} = 36{,}000{,}000\ ha$	Total land available for agriculture
$\alpha = 0.1$	20% of land dedicated for commercial crops can be shifted to biofuels crops in the near term.
$\beta = 0.4$	40% of untapped land could be devoted to biofuels crop production in the near term.

$\varphi = 0.6$ The land dedicated to commercial crops should be less than 60% of land dedicated to food production.

From these assumptions the land availability for biofuels crops is shown in the figure below.

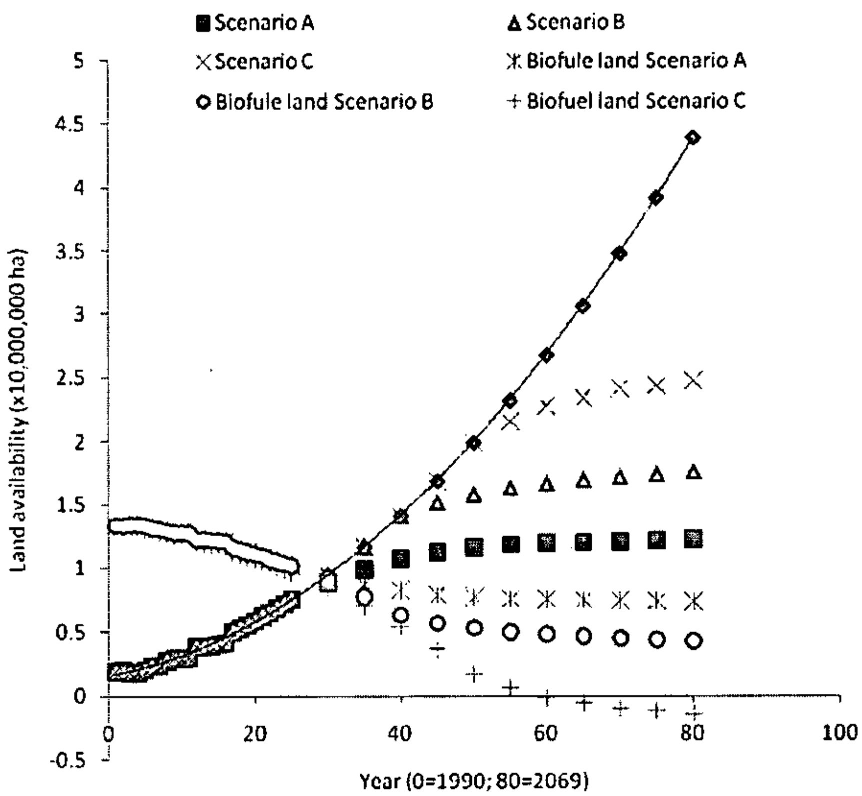

Figure 8.8: Land use profile for food and biofuels crops in Mozambique[34].

[34] Created by the author

8.2.4. Emissions from land use changes

The evaluation of greenhouse gases emissions will be performed in land use change by converting native ecosystem for biofuels crops production. [Searchinger [b], 2008] since any productive land dedicate to growing biofuels is land that would otherwise already support plant growth for years, and so long as people do not reduce the amount of food they consume, is inevitable that virgin land like forest or grassland land will be converted to biofuels crops.

Assuming tropical forest and tropical savannas as the main land types in Mozambique and using data from tables 6.1; 8.1 and 8.2 we evaluated the greenhouse gas emissions in terms of CO_2 equivalent.

Table 8.8: Greenhouse gas emissions from converting of native ecosystem to biofuels production in terms of CO_2 equivalent (10^6 tons).

	Tropical forest	Tropical savannas	Temperate grassland
Cassava ethanol	2.95	1.78	2.95
Sugarcane ethanol	1.5	0.904	1.5
Sunflower biodiesel	17.5	10.6	17.5
Jatropha Biodiesel	16.3	9.83	6.3

From table 8.8 we can conclude that there is huge amount of Greenhouse gas released from land use change if Mozambique engages in biofuels projects.

The question is how many years are needed to repay the carbon debt if Mozambique engages in Biofuels projects?

In order to address this accurately, it is essential to have thorough and reliable carbon flux assessments. The authors who simply claim that carbon released in burning biofuels can be considered zero, due to the purported Closed Carbon Cycle, make it very difficult to establish reliable carbon flux assessments. It is

imperative to evaluate fully the carbon uptake and release rates for each prospective biofuel and then to use those data to calculate the time for the repayment of carbon debt related to land use changes.

Assuming the methodology developed by Fargione, J. et, *al.* 2008 , I evaluate the time to repay biofuels carbon debt due to land use change.

Assumptions:

I assumed annual carbon repayment of soybean equal to sunflower and Jatropha and the annual carbon repayment of corn equal to the cassava, due to approximate life time (except for jatropha). The results are showed below in table 8.9.

Table 8.9: Time to repay biofuel carbon debt (years)[35]

	Tropical forest	Tropical savannas	Temperate grassland
Cassava ethanol	203	122	202
Sugarcane ethanol	25	15	25
Sunflower biodiesel	270	165	270
Jatropha Biodiesel	270	163	105

[35] Calculations based on data from Fargione, J.et, *al.* 2008

9. Discussions

9.1. Ethanol from cassava waste

Experimental production of ethanol from cassava waste compares somewhat favorably to ethanol production from raw cassava (approximately 5% from the juice compared to 7% from the raw crop). A comparison of their LCA costs and benefits shows the waste stream to have some advantages over the raw crop stream. It is clear that the land use and energy consumed in the agricultural production phases can be ignored if the cassava is produced primarily as a food crop and only the waste streams from the food processing of cassava are tapped for fuel production.

The large water consumption in agricultural irrigation of cassava crops is attributable then to the food production, not strictly to the fuel production from the waste.

9.2. Life cycle assessment

The results in tables 8.2; 8.3; and 8.5 show that biofuels in Mozambique can be energy efficient as indicated by a positive NEV. This positive value result from an exclusion of the solar energy stored in the biomass from the terms "energy inputs".

Of the total energy inputs in ethanol conversion molasses ethanol has less energy input compared to sugarcane and cassava ethanol. The same trend is observed in biodiesel conversion, where cotton biodiesel appear to have less energy input compared to sunflower and jatropha biodiesel.

Energy input in biorefinery is less in sugarcane because sugarcane plant is self efficient. It uses bagasses as source of energy for steam production in boilers and generate electricity in co-generation process.

High net energy return is observed in Molasses ethanol; cotton biodiesel; and biogas from brewery waste with values of 4.14; 3.03 and 6.1 respectively. Interesting is, all those are agriculture by-products and waste.

Sugarcane is 1.8 times more water intensive than cassava ethanol and is 2 times less land intensive than cassava (table 8.4).

Jatropha and sunflower are the most land intensive compared to sugarcane and cassava. If irrigated, those crops can be water intensive as well because they use much land compared to sugarcane and cassava.

Biodiesel crops (table 8.8) are 8 time greenhouse gas intensive in tropical forests; 10 times more intensive in savannas and 5 times more intensive in grass land compared to ethanol crops. Consequently the time to repay the carbon debt is almost long compared to ethanol crops.

As figures 8.2; 8.3; 8,4; 8.5; 8.6 indicate some important factor contributing to the variation in NEV estimates are values of the magnitude of farming energy inputs, volumetric yield and energy input in refinery phase. Notable are Nitrogen application rate(greater difference is noted between cassava and sugarcane); conversion rate associated with agricultural yield.

10. Conclusions and recommendations

10.1. Ethanol from cassava waste

Considering the energy input, land, and water, ethical and moral issues associated of using cassava on ethanol production the ethanol production from cassava residue is promising and challenging way of converting agricultural waste to energy. It could help to reduce greenhouse gas emission due land use change, reduce at least 23% or more of energy input in cassava ethanol plant. Utilization of cassava waste for ethanol production could provide the most effective use of natural resources.

In addition more technical research (effect of P^H, temperature of fermentation, enzyme) on optimization of ethanol production my help to increase the ethanol conversion from cassava waste.

10.2. Life cycle assessment

Cassava waste can be used as raw material in ethanol conversion.

Agricultural by-products, brewery waste and sugarcane by products are the most favorable source of biofuels. They provide high net energy return, insignificant natural resources input (land and water) and zero greenhouse gasses emissions due to land use change.

Mozambique has potential to produce 22,500,000 liters of ethanol and 13,500,000 liters of biodiesel per year without devoting even 1 ha of agricultural land. Mozambique can replace 14% of gasoline imported and 3% of diesel imported only by producing biofuel from agriculture by- products;

Total amount of greenhouse gas emissions will depended on the type of lands converted, type of biofuels produced.

Biodiesels are greenhouse gas intensive, land intensive and if irrigated can be water intensive this because of low agricultural yield.

There is no enough water to supply water consumptive crops like sugarcane in south region of the country. Use Massingir dam as source of water for biofuels production is a disaster and the consequence of that is hunger for more than 1,200 million people.

If Mozambique engages in biofuels production using food crops, the amount of greenhouse gas emitted will be between 0.9 to 17.5 Mt due to land use change and will be necessary 15 to 270 years to repay this carbon debt.

For Mozambique with a large number of poor people reliant on agriculture, the first priority should be given to effective use of existing agricultural wastes for energy generation (tables 8.2; 8.3; 8.4; 8.5). This option provide additional revenue for poor rural communities, they produce food and energy at same time.

The success of biofuels is depending in crops that yield much higher amount of energy per hectare (higher volumetric yield), or higher amount of energy per unit of water input. In other hand, biofuels to not have impact in food must use fewer natural resources (land and water).

Biofuels must be focus on food crops that generate by-products that can be used for biofuels, and create varieties that generate larger amounts of by products.

In country like Mozambique more investment needed in agriculture to increase productivity of food crops, since this would escape additional land and water for the production of biofuels.

Natural resources management is required (figures 8.7; 8.8) in order to have good balance between food security and energy generation.

Extrapolating beyond the Mozambican case study, it is apparent that LCA studies of biofuels should be expanded to account for all resource inputs more accurately. First, it is critical to account accurately for all primary energy inputs to the system

and all of the benefits derived. To do this accurately, land use, carbon debts from land transformation, and water demands must be accounted for properly. This is a challenging accounting process, both in that the systems are highly variable and that some of the inputs themselves are dissimilar.

Mozambique offers a relatively favorable scenario for biofuels in that the agricultural systems are not highly mechanized, labor is cheap, and commercial energy sources are relatively expensive. Nevertheless, the LCAs undertaken in this study suggest that full energy, resource and economic accounting are generally not favorable for dedicated biofuel crops. The balances are much more favorable for waste streams. While this conclusion clearly limits the total contribution potentials for biofuels, the balance of benefits to costs appears to be much more favorable.

It is also clear that context is extremely important in thorough LCA. For instance, the distances from points of collection to bio-refineries and the availability of fresh water are critical factors.

It is recommended that further work strive to develop robust metrics to compare the costs of dissimilar resource inputs and outputs (land, water, energy, carbon…), so as to provide results that can be used directly for decision-making about various biofuel options.

It is also recommended that multiple case studies be conducted in which detailed data are developed on the local agricultural systems, the water availability and the

magnitude, compositions and current dispositions of agricultural and other biotic waste streams.

The comprehensive contextual data should be used in thorough LCAs to develop context-specific analyses of the potential contributions to energy needs and resource requirements for desirable biofuels.

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