The Energy Balance of Jatropha Plantation in Sun Biofuel Farm in Central Mozambique

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The Energy Balance of Jatropha Plantation in SunBiofuel Farm Located in Central Mozambique

By:
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ABSTRACT

Jatropha constitutes one of promising species suitable for providing oil for biodiesel production. So, looking for good practice and sustainable use of energy during Jatropha cultivation and lack of information about Jatropha in Mozambique, this study pretends to estimate the energy balance in Jatropha plantation in Sun biofuel farm, by calculating the energy indicators based on a life cycle approach in Sun Biofuel farm located in Manica province, Central Mozambique. Energy balance is a tool which can help to calculate all energy indicators in order to evaluate and analyse the energy efficiency, sustainability and environmental benefits. This study estimated the indicator of energy balance namely: energy input is the sum of all energy used during the process of Jatropha cultivation and oil production, energy output is the amount of energy produced, Net energy value can be calculated subtracting the energy output from the energy input, Energy productivity is the division of Jatropha produced by the respective input energy, specific energy is the division of energy input by Jatropha seed output and energy ratio is the energy output divided by energy input. Also data was collected on the farm of Sun Biofuel to estimate the sustainability of agricultural production of the company. The Jatropha production in Sun Biofuel farm (SBF) absorbed around 28 579 MJ/ha of energy during the production and 121 820 MJ/ha of energy gain as result of the all production. The total energy input was direct energy with 77% and Indirect energy with 23% used in Jatropha farm, and also the total energy input was divided into renewable with 26% and non-renewable with 74% of its contribution. The results revealed that the contribution of seed husks was (8%), woody products (38%), raw seed oil (30%), Shell (9%) and press cake (15%) of total energy output in Jatropha oil production farm. Net energy value (NEV), energy productivity, energy use efficiency and Specific energy was 93.241 MJ ha\(^{-1}\), 0.067 Kg MJ\(^{-1}\), 4.3 and 15.04 MJ Kg\(^{-1}\), respectively. According to these results the energy balance is positive and the energy use in Jatropha production is efficient.

**Key words:** Energy balance, Energy input and output, Jatropha Oil, Energy indicators
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ABBREVIATIONS

DAP – Diammonium Phosphate
EU – European Union
ENI – Ente Nazionale Idrocarburi
FA – Fat Acid
FFA – Free Fat Acid
FUNAE – Energy Fund
GHG – Green House Gas
HHV – High Heat Value
HVO – Hydrotreated Jatropha Oil
IMF – International Monetary Fund
JCL – Jatropha Curcas L
JME – Jatropha Methyl Ester
LPG – Liquefied Petroleum Gas
NEV – Net Energy Value
NEED – National Energy Education Development Project
PCB – Program of Biofuel Purchase
PNDB – Develop the National Biofuel Program
PROAGRI – Programa de Investimento no Sector Agrário
RSB – Roundtable on Sustainable Biodiesel
SADC – Southern African Development Community
SBF – Sun Biofuel
SVO – Straight Jatropha Oil
SGI – Synthetic Genomics Inc
Tcf - Trillion of Cubic Feet
TAG – Tri acyl glycerol
TSC – Total System Cost
TBO – Tree Borne Oilseeds
INDEX OF FIGURES

Figure 2.1: Mozambique Primary energy supply
Figure 2.2: Mozambique final energy consumption
Figure 2.3: Mozambique energy use by sector
Figure 2.4: Cahora Bassa dam site and Mphanda Nkuwa site
Figure 2.5: Number of districts electrified by national grid
Figure 2.6: Number of beneficiaries of PV systems
Figure 3.1: Jatropha from Sun Biofuel farm
Figure 3.2: Stage of Jatropha biodiesel production
Figure 3.3: Shows the emissions of the process
Figure 3.4: The biodiesel production chain
Figure 3.5: Total yield of Jatropha due to irrigation
Figure 3.6: Total yield of Jatropha without irrigation (MT seeds/ha)
Figure 3.7: Total yield of Jatropha with irrigation (MT seeds/ha)
Figure 3.8: The colours of Jatropha fruits changing from the green to yellow-brown
Figure 3.9: Sun Biofuel Company Location
Figure 3.10: Energetic components of Jatropha curcas
Figure 3.11: Direct sowing of the seed along planting row
Figure 3.12: Bulldozer removing roots (left) and piling the debris on farm boundaries (right)
Figure 3.13: Stumps are dug out by excavator (left) and heavy disc are hauled behind large wheel tractors to cut and invert the remaining roots, (right)
Figure 3.14: Light ripping at SBF farm
Figure 3.15: Thin grid to spread Jatropha fruits and Sheller to remove husk from Jatropha fruit
Figure 3.16: Machinery to crush seeds to extract oil (left), and filter press (right)
Figure 4.1: Location of research area map
Figure 4.2: Represents the steps of methodology of data collection
Figure 4.3: System boundary and stage of Jatropha oil production in SBF farm
Figure 5.1: Energy input analysis during Jatropha oil production
Figure 5.2: Represent the energy output from whole process of JME production per ha
Figure 5.3: Energy output analysis during Jatropha oil production
INDEX OF TABLES

Table 3.1: Describes some properties of Jatropha Oil

Table 4.1: Energy coefficients of farm machinery

Table 5.1: Represents the energy input of Jatropha in Sun biofuel farm

Table 5.2: Energy equivalent for the production means

Table 5.3: Data for energy output estimation

Table 5.4: Parameters of energy balance for conventional Jatropha production
# TABLE OF CONTENT

1. INTRODUCTION.......................................................................................................................... 1  
   1.1. Background .......................................................................................................................... 1  
   1.2. Problem Statement ............................................................................................................. 2  
   1.3. Aim .................................................................................................................................. 2  
   1.4. Objectives .......................................................................................................................... 2  
   1.5. Significance of the Study.................................................................................................... 3  
   1.6. Research Question ............................................................................................................. 3  
   1.7. Hypothesis .......................................................................................................................... 3  
   1.8. System Boundary and Structure of Thesis ........................................................................ 3  
2. LITERATURE REVIEW ................................................................................................................... 5  
   2.1. Energy Balance .................................................................................................................... 5  
   2.2. Energy System in Mozambique ............................................................................................ 6  
       a. Hydropower Potential ......................................................................................................... 7  
       b. Natural Gas ...................................................................................................................... 8  
       c. Mineral Coal .................................................................................................................... 8  
       d. Biomass ........................................................................................................................... 8  
       e. Renewable ....................................................................................................................... 9  
       2.2.1. Plans for Biodiesel Policy ............................................................................................. 10  
       2.2.2. Biofuel ....................................................................................................................... 11  
       2.2.3. Biodiesel .................................................................................................................... 11  
   2.3. Environmental Benefit from Jatropha Cultivation .............................................................. 11  
3. CULTIVATION OF JATROPHA CURCAS .................................................................................... 12  
   3.1. Jatropha Curcas Description ............................................................................................... 12  
   3.2. Cultivation and Production ............................................................................................... 12  
   3.3. Jatropha Production and Biofuel ....................................................................................... 15  
       3.3.1. Jatropha Biodiesel Production Chain .......................................................................... 16  
   3.4. Jatropha Yield and Harvesting ............................................................................................ 18  
       3.4.1. Jatropha Oil Extraction and Properties ....................................................................... 20  

VIII
The Energy Balance of Jatropha Plantation in SunBiofuel Farm in Central Mozambique

3.4.2. Global Impact of Jatropha Cultivation verse Food Security ........................................... 20

3.5. The Case of Sun-Biofuels Farm in Manica Province .............................................................. 22

3.5.1. Land Clearance and Preparation ......................................................................................... 24

3.5.2. Planting Maintenance and Harvesting .................................................................................. 24

3.5.2.1. Harvesting ....................................................................................................................... 25

3.5.3. Farm Machinery and Manpower (Man Labour) ................................................................. 26

3.5.4. Drying and Seed Cake Removal ......................................................................................... 27

3.5.5. Oil Extraction and Purification ............................................................................................ 28

3.5.6. Transportation .................................................................................................................... 29

4. MATERIALS AND METHODOLOGY ......................................................................................... 30

4.1. Research Area description ..................................................................................................... 30

4.1.1. Location .............................................................................................................................. 30

4.1.2. Climate ............................................................................................................................... 31

4.1.3. Research design ................................................................................................................ 31

4.1.4. Participants ........................................................................................................................ 31

4.1.5. Site selection ....................................................................................................................... 31

4.2. Choice of methods .................................................................................................................. 31

4.2.1. Literature review ................................................................................................................. 33

4.2.2. Observation ........................................................................................................................ 33

4.2.3. Data collection ..................................................................................................................... 34

4.2.4. Interview .............................................................................................................................. 34

4.2.5. Assumption .......................................................................................................................... 34

4.3. Data management and analysis ............................................................................................... 35

4.3.1. Data analysis ....................................................................................................................... 35

4.4. Analyses of Energy Indicators ............................................................................................... 36

4.4.1. Machinery Information ....................................................................................................... 37

4.5. Validity and reliability of data ............................................................................................... 37

4.6. Limitation ................................................................................................................................ 38

IX
The Energy Balance of Jatropha Plantation in SunBiofuel Farm in Central Mozambique

5. RESULTS AND DISCUSSION ............................................................................................................39
   5.1. Estimation of Energy Input ........................................................................................................39
   5.2. Estimation of Energy Output ......................................................................................................42
   5.3. Results of Energy Balance ........................................................................................................43
       5.3.1. Other Studies about Energy Balance .............................................................................44

6. CONCLUSIONS AND RECOMMENDATIONS .........................................................................45
   6.1. Conclusion ...............................................................................................................................45
   6.2. Recommendation ...................................................................................................................46
1. INTRODUCTION

1.1. Background

The availability of non-renewable resources is becoming limited and getting to the time that they will no longer exist. The inexistence of such resources will cause an increase of fuel price, thus creating many problems to the economy of many countries because of the high demand and negatively affecting the development of many countries. Therefore, a great change in oil price is notable, reaching amounts never seen in the last two decades. The increase of the global energy demand results from the population growth and industrial development [1]. The primary energy demand is about 13% of renewable energy sources in the world, and fossil fuels contribute with 80% of primary energy supply. Therefore, for the economy and environment to improve becomes necessary to minimize the dependence on petroleum demand fuels taking into account oil is the most consumed resource in the world [1].

Negative effects such as a depletion of fossil fuels, high level of atmospheric pollution and climate changes are related to the present system of energy supply. Currently Jatropha is considered as a feasible alternative source for diesel fuel production [2]. For example, the use of these fuels in diesel engines shows a decrease in GHG emission such CO, SOx, unburned hydrocarbons and particular matter during the combustion process. As the Mozambican government is committed to produce clean energy and mitigate GHG emission, it approved several projects to grow Jatropha to produce Biodiesel, whereby one of them was chosen to develop the study of energy balance in Sun biofuel farm in Manica Province.

Mozambique and many countries in the world are maximize the exploitation of renewable energy source as option to solve energy problems and may have a comparative advantage in growing biomass feedstock as sustainable alternative fuel to fossil fuels.

Up to date, 39 proposals related to biofuel investment were officially received by the Mozambican government, whereby 12 were related to bioethanol production and 26 to biodiesel production [3]. Hundred years ago, the solar energy was considered the main source of energy, which in few decades ago was shifted to fossil fuel hydrocarbons because of rapid growth of technology that allowed the excessive use of hydrocarbon fuels making the consumers highly dependent in the use of this kind of fuel. Thus, biodiesel constitutes an option fuel for diesel engine nevertheless it need the search for option of oil as energy source [4]. So, this study will be focusing on the energy balance, to estimate the energy input and output, net energy value, specific energy, energy productivity and energy use efficiency. The calculation of the energy indicators will help to analyse if the energy balance is positive or negative and will also help to see if Jatropha oil is reasonable option for a sustainable framework.
1.2. Problem Statement

The need to shift to the new forms of sustainable energy such as biofuels is presently becoming the core issue in political and scientific circles as well as in the community development. Both developed and developing nations face an urgent need for energy planning that is simultaneously broad based and context specific.

Locally produced biofuels can provide a set of advantages to a context tailored energy mix. Engineered biofuels would be a significant improvement over fuels. Most Mozambicans are currently using: firewood, charcoal, kerosene and diesel and most of the population lives in remote areas and low population density in the countryside where there is no electrical power available from the national network [5]. About 80% of the population satisfies their energy needs in biomass, and the wood fuel consumed by the rural area people and local communities is mainly obtained directly from the forest [6]. This study focuses on Jatropha plantation to produce biodiesel and will calculate all energy indicators to estimate and analyse the sustainability of Jatropha oil production in SBF Company.

The sustainability of Jatropha seed production and its consideration as an option for biofuels demands a positive energy output harvest from the farms or higher than the energy inputs used for production. On the other hand, the world is facing climate problems that need immediate change in the human behaviour in order to mitigate the emission of the greenhouse gas and the acidification potential.

1.3. Aim

The aim of this study is to calculate the energy indicators for the estimation of the energy balance in SBF farm for Jatropha oil production and to assess whether Jatropha constitutes a reasonable option for our biofuel sustainability framework based on the calculations of all energy input and evaluate all production system to verify if the energy balance is positive or negative. This work intends to do further investigation in order to get a deep understanding on the sustainability of Jatropha oil production against the fossil fuel. Using energy balance tools we can estimate the efficiency, sustainability, and to quantify all energy inputs and all energy output, and evaluate the environmental benefits of the whole production chain.

1.4. Objectives

The goal of this study is to estimate the energy balance in Jatropha plantation in Sun biofuel farm, by calculating the energy indicators, Net Energy Value (NEV); Energy Input and Energy Output; Energy Use Efficiency; Specific Energy and Energy Productivity, based on a life cycle approach.
1.5. **Significance of the Study**

Jatropha constitutes one of promising species suitable for providing oil for biodiesel production. This study addresses the life cycle assessment of Jatropha, with respect to environmental impact, acidification phenomenon and the efficiency of Jatropha oil production in Sun biofuel farm. The availability of funding from the government to promote Jatropha cultivation and lack of information about Jatropha in the country, made me to become interested in carrying out a deep research of Life Cycle assessment using energy indicators to estimate the energy balance in Jatropha cultivation farm for oil extraction aiming at producing biodiesel, which is vital because it will provide information to enable the understanding of the energy system for sustainability. Therefore, it will also help all Jatropha producers, biofuel developers, students, government workers to elaborate a good policy in the energy sector to enable good practice of Jatropha cultivation and to enrich with the know-how, information and sustainability of the crop and will contribute with a good manner for agriculture area and in particular to cultivate Jatropha, to improve the energy balance and how to use the energy efficiently in order to have higher achievements.

1.6. **Research Question**

- How can the energy balance of Jatropha oil production be calculated?
- How can we estimate the indicators of energy balance namely (Net energy value; energy input and energy output; Energy Use Efficiency; Energy productivity; Specific Energy)?
- Will energy input in Jatropha farm and oil extraction phase bring sustainable results in terms of energy output?

1.7. **Hypothesis**

The hypotheses of this study are:

- Jatropha oil production has a better energy balance and can be estimated using the respective formulas of energy indicators;
- Jatropha oil is reasonable option for our biofuel sustainability and has a positive energy output;
- Jatropha is expected to have higher energy output than energy input used during its practical cultivation;

1.8. **System Boundary and Structure of Thesis**

Most plantations in Mozambique are still in experimental stages, and do not have a real market for Jatropha. Many Jatropha cultivation of plantations with purpose of extracting its oil, do not belong to national companies but to foreign companies, that bring with them experiences of other countries that already have a long experience in the growth of this crop. This fact proves that Mozambique is a country with a large tract of fertile land but lacking in literature, reports, theses, and information related to the cultivation of
Jatropha. This study has been carried out in Sun biofuel farm located in Manica province, in Chimoio city namely in district of Gondola. The scope of the study is to estimate the energy balance in Jatropha plantation using energy indicators to verify the sustainability of the production crop.

This study is divided into six chapters. Chapter one is an introduction to the study, where the problem, aim, objectives, significant of the study, research question, hypothesis and limitation of the study are outlined. Chapter two is devoted to literature review about all stages of Jatropha cultivation. Chapter three presents the cultivation of Jatropha Curcas (LCA). Chapter four describes the material and methodology used to develop the research and data collection. Chapter five describes the results and discussion of Jatropha cultivation and production, while chapter six brings the conclusion and recommendation of the study.

This study was developed in Sun biofuel farm in two areas; i) Jatropha cultivation (Land preparation, Seedling production, planting, plantation operation, management, harvesting of tree trimmings, transport during all process of production and seed collection); ii) Extraction of Jatropha Oil (separation of seeds from husks, press cake for oil extraction, oil filtration). So, the limitation of this study will comprise the cultivation and oil extraction stage and the size of the area of study is 1 hectare.
2. LITERATURE REVIEW

2.1. Energy Balance

The agricultural production system of any crops is an extremely complicated process that requires meticulous care to ensure the growth of plants. The first thing to consider should be the preparation of the land, proceeding to sowing stage, tilling the land, proper use of fertilizers, pruning, irrigation in the whole process to the harvesting stage.

Regarding the agricultural production is indispensable to talk about investment and the yielding. No one can invest in a business without first analysing the cost benefit. And in this case, this research will analyse the study of energy used and the energy produced during the process of cultivation and production of Jatropha. But for its materialisation, a tool called energy balance should be used to allow the study of the energy analysis, efficiency, sustainability and environmental benefits. To estimate the energy balance is necessary to calculate all energy indicators (Net Energy Value (NEV); Energy Input and Energy Output; Energy Use Efficiency; Specific Energy and Energy Productivity) which will allow to have the numbers to give us the real pictures of the study.

The heat or radiation are forms of solar energy, which will not be taken into account in this study, as it is captured by the biomass during growth and in energy analysis is considered energetically free during the process cultivation [7]. During the process of cultivation, we have identified two types of energy, direct and indirect energy. Direct energy is composed by tractor, labour energy, diesel and other auxiliary machinery and the indirect energy is constituted by fertilizer and chemical and transport of seed. The sources of energy were also classified into renewable and non-renewable energy. Seeds, manure and human labour are parts of renewable energy while non-renewable energy is composed by chemical, diesel, fertilizers, machinery and oil refinery.

The Net energy can be calculated subtracting the output energy by the input energy. The energy use efficiency is a division of output energy by the input energy. Another approach for evaluating energy utilization in crop production is to calculate the specific energy dividing the input energy by the Jatropha seed output. Dividing Jatropha produced by the energy input we will have the energy productivity.

The total energy consumed in SBF farm during the cultivation process of Jatropha is called energy used or energy input which is divided as direct and Indirect energy whereby direct is composed by the human labour, fertilizer, seeds herbicides used directly in the farm, and the indirect energy is the energy used at the office to prepare all documents, computer process and accounting procedures.
2.2. Energy System in Mozambique

Mozambique holds considerable potential in energy source (water, natural gas, coal, biomass and renewable). Therefore, a large percent of these potential sources of energy is to satisfy the neighbour countries and international markets [8].

![Primary Energy Supply (2009)](image1)

**Figure 2.1:** Mozambique Primary Energy Supply.  
**Source:** Adapted by the author [9].

In the country approximately 5 percent of rural people have access to electricity from 14 percent of the country which has access to electricity, of those, a large part of household electrified live in urban areas [9]. According to figure 2.1 the primary energy supply is divided into 78% of biomass and waste which represent the most energy supply, 14% of Hydropower, 7% of Oil products and 1% of natural gas, while figure 2.2 shows the final energy consumption with 89% of biomass and waste representing the high consumption of energy, 10% of oil product and 1% of solar.

![Final Energy Consumption (2009)](image2)

**Figure 2.2:** Mozambique Final Energy Consumption.  
**Source:** Adapted by the author [9].
The residential sector occupies the main consumer of energy use in the country with 74%, the industrial sector with 19% and others which are showed in the figure 2.3.

![Energy Use by Sector (2009)](image)

**Figure 2.3:** Mozambique Energy Use by Sector.  
**Source:** Adapted by the author [9].

a. **Hydropower Potential**

The main source of energy in Mozambique is the hydropower, because the country has several and huge rivers and other natural resources to generate energy. The national electric energy system is predominantly generated from water, with a potential identified of 18.000MW, and of these only 2.300MW corresponds to the installed capacity, from which only the Cahora Bassa Hydroelectric Power owns 2075MW. The figure 2.4 shows the location of Cahora Bassa dam, and figure 2.5 represents the number of districts electrified by the national grid.

![Location of Cahora Bassa Dam and Mphanda Nkuwa site](image)

**Figure 2.4:** Location of Cahora Bassa Dam and Mphanda Nkuwa site.  
**Source:** [10].
The Energy Balance of Jatropha Plantation in SunBiofuel Farm in Central Mozambique

Figure 2.5: Number of districts electrified by national grid.
Source: Adapted by the author [11].

b. Natural Gas
In 1963 it was discovered in Inhambane Province (Pande and Temane) the potential of 3.59 Tcf of natural gas, which started its operation in 2004. At Rovuma Basin a potential of about 191 Tcf was discovered, the early operation is scheduled for 2018, by this time, Pande and Temane gas is being explored by Sasol pipeline with a length of 800 km connecting the Republic of Mozambique to the Republic of South Africa. At the country level, the natural gas is piped for industrial and domestic use, in an annual capacity of 3 million GJ [11].

c. Mineral Coal
The main coaling-station is located in the Province of Tete, namely in Moatize District. The potential is of about 25 billion tons, started being exploited by the mining company Vale and Rio Tinto in 2011, with an average annual volume of around 5.5 billion tones (coal coking and thermal). The starting of energy production from coal passes through realization of project of thermal power plants of Moatize, Ncondezi and Jindal.

d. Biomass
The potential of biomass is estimated in 2GW, and were more than 1.7 million hectares is allocated for plantation and features exceptional conditions in annual increment for plantation development [11]. The greatest plantation is in the Province of Zambezia, Sofala and Niassa then.

Biomass accounts for about 80% of the country’s energy needs. The resources include biomass, wood residues from conventional logging, industrial and agro-industrial waste and residual bagasse from sugar industries. Firewood and coal are the main source of energy in households in remote areas of the country.
The Energy Balance of Jatropha Plantation in SunBiofuel Farm in Central Mozambique

c. **Renewable**

The country has a huge potential in renewable energy resources whether solar, wind, geothermal, ocean and biomass including water mentioned above. The construction of small power plants based in renewable energy with emphasis on small hydro and solar and wind farms is a way to enjoy the abundance of these resources in the country.

➤ **Solar**

Solar energy plays an important role in the country’s energy matrix of Mozambique. The solar radiation average in the country is of 5kWh/m2/day, which favours for the employment of this energy source to generate energy through Solar Photovoltaic Systems (SSF) for electric power services. The figure 2.6 shows the Number of beneficiaries of PV systems.

![Figure 2.6: Number of beneficiaries of PV systems. Source: Adapted by the author [11].](image)

➤ **Wind**

Mozambique holds a wind potential (between 6-8 m/s) enough to produce electricity power in small and medium scale. The estimated potential is at 4.5 GW of this wind capacity whereby 1.1 GW has the potential for immediate connection to the network and about 230 MW are considered as projects with high potential. The provinces with the best resources are Maputo and Gaza where the registered average wind exceeds 7 meters per second and followed by Sofala, Cabo Delgado, Zambezia, Inhambane and Tete [11].

➤ **Geothermal**

Mozambique is crossed in its north-south direction by the East African Rift valley, causing changes in tectonic and increased geothermal gradient. The existing geothermal potential in the country, corresponding
The Energy Balance of Jatropha Plantation in SunBiofuel Farm in Central Mozambique

to 200 MW of which 20 MW are considered the priority. The biggest gradient is located in the District of
Lago, Niassa province, with thermal generation may need further study.

➤ Ocean

Oceanic energy includes wave energy, tide energy and oceanic thermic energy. In Mozambique has a good
potential for it exploitation. The country has a coast of 2800 km and the greatest oceanic potential is found
in the Province of Inhambane with about 10 kW/h/m and a tide that ranges from 3m to 3m of height [11].

➤ Fossil Fuels

The Geological and Geophysical studies indicate that an active petroleum system is present both in the
Rovuma and Mozambique delta [12]. Around 14.6% of total oil used in our country is imported, which the
bill is equivalent to US$270 million. Therefore, the country relies on imported petroleum and petroleum
products of 75% of its commercial consumption, and about 700,000 m3 of oil products is for domestic
consumption [13, 14].

In some provinces of Nampula, Cabo Delgado, Gaza, Zambezia, Inhambane, Sofala and offshore areas
considerable oil exploitation possibilities exist, and the variation of the oil price makes the country very
sensitive because of limited capacity of stoking. But to overcome this sensitive variation a lot of projects are
on-going to minimize the effect and to increase the capacity of stock [13].

2.2.1. Plans for Biodiesel Policy

Mozambique is a country that does not produce oil, which means that the oil used internally is all imported.
The use of fossil fuels is the main cause for atmospheric pollution. However, Mozambique intends to
implement a project to reduce the external dependence on imports of fossil fuels and reduce the pollution
of greenhouse gases blending biodiesel and fossil fuels.

The government commissioned a study to evaluate the biofuel stage and they conclude that Jatropha is a
promising crop to produce biodiesel and is necessary to develop further experimental studies by blending 5
to 10% of biodiesel and fossil fuels in the first phase [13, 15]. According to the same study, the country has
a huge extension of land arable, favourable climatic conditions of which 14% of lands are in use of 41.2
million ha.

According to the study of energy situation in Mozambique done in February 2010 by Cuvilas [13], revealed
that Petromoc Company, intends to cultivate Jatropha for purpose of biodiesel production to cover the
total petro-diesel consumption in the country by producing 226 million litres of biodiesel per year.
Therefore, the project will reduce the country’s fuel bill and will create around 800 jobs.
2.2.2. Biofuel

The term biofuel applies to all organics elements capable to generate fuel. Therefore, include both, solid, liquid, gaseous and gelatinous. According to [16], biofuels are fuels produced from organic matter (biomass), they are considered renewable sources and formed from animals compounds or vegetable, such as wood, sunflower, corn, cellulose, soybeans, sugarcane, Jatropha and others. Biofuels produced from those sources are biodegradable and environmental-friendly. In tropical countries biofuels are being used for heating and cooking and it are considered to have low emission of pollution and to be sustainable [17]. Biofuels can be blended in small quantities with fossil fuels to be used in combustion engines and in machines for transport.

2.2.3. Biodiesel

The biodiesel concept was discovered by Dr. Rudolf Diesel in 1885, when he built the first engine with the intention of putting it to work through fuel vegetable. The first demonstration was carried out in Paris in 1900 and surprised everyone when the machinery worked with any fuels available, including gasoline and peanut oil [18].

Biodiesel is a term used to describe fuel derived from organic matter. According to [17], biodiesel is fuel derived from renewable sources and is organic lipids, biodegradable, such as animal fats and vegetal oils and can replace part of diesel engines. It can be obtained from cotton, castor, algae, organic waste, sunflower and other vegetable oils (edible and non-edible), which is produced by trans-esterification process. Great variation of feed stocks can produce biodiesel [19], which in the recent past has received considerable attention worldwide.

2.3. Environmental Benefit from Jatropha Cultivation

According to the several studies Jatropha can be considered important because of its high energy value. It is a very resistant plant which can grow in any soil and in regions with different type of climates. Soil quality, sustainable use of energy, terrain, and climate are the main factors for Jatropha growth according to the consensus of different studies which have examined the correlation between natural condition, Jatropha production and environmental benefit [20]. Many countries in the world are doing their best to develop and promote the use of renewable energy as alternatives to replace the fossil fuels and minimize the pollution of atmospheric. Since Jatropha biodiesel is considered to have lower emissions of CO2 compared to the fossil fuel, it is also seen as alternative to replace fossil fuel due to the fact of helping in the mitigation of greenhouse gas, formation of acid rain and sustainable oil [20]. Therefore, by improving the environmental conditions and reducing the emissions promoting the use of renewable energy we are also improving the quality of life of people besides generating economics advantages for the country, as Mozambique is signatory of Kyoto Protocol.
3. CULTIVATION OF JATROPHA CURCAS

3.1. Jatropha Curcas Description

Many scientists tried to define the origin of Jatropha Curcas, L. (JCL), and up to now, the origins is still a controversy. Some studies defend that JCL originate from the naturalized country such as India, Africa, North America and Asia, however, its true origin is Central America [21, 22, 23].

Fossil fuels are the main sources of greenhouse gas pollution and to mitigate it an encouragement in order to cultivate Jatropha crops for biodiesel production is given and for this reason a lot of policy makers and investors in the world are willing to help for development of this area. Some researchers investigated the amount of oil extraction and concluded that it depends on the method of extraction and Jatropha seeds have non-edible oil, suitable for biodiesel production and produce around 27-40% of oil [17, 21, 24, 25].

Jatropha plant reaches a height of three to ten meters, it belongs to the Euphorbiaceous family and has a small tree or large bush and is very resistant to drought [24]. The perennial plant has a stem with branches growing from below, reaching maturity in five years and can have a life of more than 50 years and grows in different ways [26], see figures 3.1. Wind and water are the main cause of erosion, however, Jatropha has an advantage of having deep central root and lateral roots than are capable to help in the prevent of the erosion and fix the soil [17, 27].

![Figures 3.1: Jatropha from Sun Biofuel farm.](image)

3.2. Cultivation and Production

The cultivation of Jatropha is not complicated because of its facility to grow in tropical and subtropical regions, wastelands, sandy, saline soils and any terrain. This plant can flourish in poor soils and adapt itself to drought season. In order to cultivate Jatropha different steps should be followed, starting from land acquisition to the harvesting. After land preparation and remove all vegetation on the soil, many holes with dimensions 30 - 30 - 30 cm are open, with separation spacing from 2 to 5 cm in all sides, according to the fertilization, under the physical conditions of the soil, climate and treatments. The plantation of the slips is done with 20 cm depth [23].
Jatropha is a plant that requires a lot of care in case of large-scale cultivation. There is a range of procedures that should be taken into account for its cultivation, such as financial, political and social. Therefore, this crop occupies large area of land and its cultivation demands detailed knowledge of this plant in order to follow all procedures to ensure its health growth and producing the fruits in expected quantities. So, its production demands knowledge in the area and appropriate amount of energy used for all phases, starting from the preparation of land, plantation, irrigation, pruning, the amount of fertilizer used, transport, number of workers, harvest and besides enough knowledge on the amount of harvested products. All such parameters including environmental conditions should be considered for the sustainability of the production [28]. The mentioned activities contribute positively for a good modelling of Jatropha production.

The employment of mineral and organic fertilizers per plant serves to enhance the survival rate of the plant as (diammonium phosphate and solid compost) and will help to protect the plant from insects and growing healthy [29]. The employment of fertilizes will ensure good growth and health of the plant and good productivity will be ensured.

Jatropha tree produces huge amount of oval fruit and it contains 3 seeds with 1.2 cm width, 1.8 cm in length [30]. The perennial Jatropha can grow in any kind of land and without treatment [22, 31], it is also capable to grow in sub-humid and semi-arid climates [32]. The figure 3.2 below show many stages of Jatropha biodiesel production.
The design represents the stages of Jatropha biodiesel production. Jatropha biodiesel (JME), straight Jatropha oil (SVO), hydro-treated Jatropha oil (HVO) [32].

The Company that intends to cultivate Jatropha for the purpose of oil extraction for commercialization needs land for cultivation and one place for office work. The main activities will be done in the soil such as (land preparation, sowing, pruning, and irrigation, use of fertilizers, pesticides, harvest and so on), while the secondary activities which can also be called ancillary activities or products which usually take place at the office such as (economic activities, storage, accounting, acquisition of goods, purchasing, transportation,
human resource and others). Therefore, it means that the main activity depends entirely on secondary activities.

### 3.3. Jatropha Production and Biofuel

The research of Jatropha oil for biodiesel production in Mozambique should be a priority since the last decade a considerable amount of investment in this area was carried out by the government and some foreign companies to popularize the cultivation of Jatropha with purpose of commercialization. To have a good efficiency, the productivity should be higher meanwhile spending less input energy and cost, and to maximize the output energy a research in this area should be carried out in order to understand how it works [33]. According to some scientists, Jatropha can be a source of raw material for commercialization in the areas of biofuels, because the culture of Jatropha has a strong genetic characteristic, with a very strong quality of production, since it is treated and properly planted [34].

Jatropha is the plant that has characteristics to be one of the promising and the most productive bioenergy crops, concludes the leading US bioenergy research company Synthetic Genomics Inc (SGI) [34].

The figure 3.3 shows the process flow of manufacture of Jatropha biodiesel using feedstock, starting from Jatropha plantation stage to the biodiesel production.

![Diagram showing process flow of Jatropha biodiesel production](image)

**Figure 3.3:** Shows the emissions of the process.

**Source:** Adapted by the author and based on [2].
3.3.1. Jatropha Biodiesel Production Chain
Numerous studies and publications about benefits, problems of using vegetable oil as liquid engine fuel are taking place worldwide. Therefore, (micro-emulsification, pyrolysis, oil blends, straight vegetal oil and trans-esterification) are different ways to use vegetable oil as base for liquid engine fuel in the world. The end products of trans-esterification of Jatropha’s oil are the biodiesel (Methyl Ester) and glycerol which can be used in many industries as feedstock and can also be burned for heat and is an important by-product [33, 35-36]. During the process of biodiesel production from Jatropha oil there's always some end products which are the result of this process among them the waste, emission, glycerol, wood, Jatropha sheets, husks, kernel and Jatropha oil.
The Energy Balance of Jatropha Plantation in SunBiofuel Farm in Central Mozambique

Trans-esterified JCL oil or biodiesel is more efficient than pure JCL oil, is an energy consuming process, it does not only produce large percentage of oil from seeds but also permits an energetic use of end-products and by-products [24].
There are two ways to extract oil from the crops, namely, Chemical extraction using hexane or other chemical solvent and Mechanical extraction see figure 3.4. First alcohol is mixed with catalyst, and stirred to dissolve the catalyst, where alcohol and oil will be mixed together to react during 6 hours. The reaction will occur at temperatures between 50 to 60 °C and be neutralized by adding acids. To separate the biodiesel in the top and glycerine in the bottom there is a need to carry out a decantation process which will be followed by the washing.

3.4. Jatropha Yield and Harvesting

The yielding of Jatropha is subject to many factors among them the kind of soil, application of fertilizer, land management, rainfall, crop management and other ancillary conditions. The yielding might vary from the kind of soil planted to the treatment condition [32, 38].

The yield of Jatropha due to irrigation according to figure 3.5 in the first year is of 250 kg seeds/hectare, however on the sixth increased to 12000 kg seeds/hectare meanwhile the yield rain fed increased to 4000 kg seeds/hectare.
The higher production of the yield of Jatropha without irrigation varies from 0.4 MT seeds/hectares in the first year to 2.75 MT seeds/hectares in the fifth year, meanwhile the low seed production ranges from 0.1 to 1.10 MT seeds/hectares in the fifth year, see Figure 3.6.

![Figure 3.7: Total yield of Jatropha with irrigation (MT seeds/ha). Source: Adapted by the author [19].](image)

During the process of Jatropha cultivation, it is important to ensure a good growth of the plant to achieve the expected yield at the end. For that, there is a need to follow and control different issues related to the health of the plant such as nutrients, water, fertilizers, herbicides, pruning and others. Figure 3.7, shows the yield of Jatropha with irrigation with higher seed production in the first year with 2 MT seeds/hectares which increased to 12.5 MT seeds/hectares by the time it is five years meanwhile the low seed production ranges from 0.75 in the first year to 5.25 t/ha/year on the fifth year.

When the colours of the fruit are still green it means that the quality of oil is not so good, the best oil yield colour of fruits should shift from green to yellow-brown, and in this feature the seeds can be considered as mature. The seeds reach maturity when achieving 90 days after flowering [33]. See figure 3.8.

![Figure 3.8: The figure shows the colours of Jatropha fruits changing from the green to yellow-brown. Source: Sun Biofuel archive.](image)
3.4.1. Jatropha Oil Extraction and Properties

The process of oil extraction can be done using several methods, nevertheless, there are two most used methods to extract oil from Jatropha seed, which are mechanical and chemical extraction. So, 70-80% of oil available can be extracted using an engine driven screw press and 60-65% can be extracted using manual presses [21, 33]. Those methods are more appropriate and more used in developing countries especially in rural areas where small companies, private entities and Jatropha producers exist with a lot of experiences in the extraction of Jatropha oil.

According to some scientists, using chemical extraction is possible to reach around 4,000 tonnes/days, but extracting less than 200 tonnes of seeds/days will not be economical using this method [28].

Trans-esterification is a process of conversion of oil to biodiesel fuel, which depends on Jatropha oil extraction stage. Extracting more than 200 tonnes/day of Jatropha oil, during a year will extract around 73,000 tonnes, while the trans-esterification unit can be assumed to convert around 100,000 tonnes of biofuels/yr with around 95% efficiency of oil conversion to biodiesel [28]. Therefore, processing those amounts of oil extraction and biodiesel conversion the productivity will be viable and sustainable for the company.

Many of scientist indicates Jatropha seed as a promising crop for biodiesel production because of the properties of seed content, see the table 3.1.

<table>
<thead>
<tr>
<th>Component analysis of Jatropha seeds (wt per cent) as follows:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
</tr>
<tr>
<td>Protein</td>
</tr>
<tr>
<td>Fat</td>
</tr>
<tr>
<td>Carbohydrate</td>
</tr>
<tr>
<td>Fibre</td>
</tr>
<tr>
<td>Ash</td>
</tr>
</tbody>
</table>

**Jatropha oil mainly consists of tri-glycerides of:**

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oleic acid</td>
<td>34-45%</td>
</tr>
<tr>
<td>Linoleic acid</td>
<td>31-43%</td>
</tr>
<tr>
<td>Palmitic acid</td>
<td>14-15%</td>
</tr>
</tbody>
</table>

Source: [39].

3.4.2. Global Impact of Jatropha Cultivation Verse Food Security

In Mozambique the majority of people survive by dedicking themselves to food production. Even though 87% of food is produced by the majority of the people in the country because most them depend on the agriculture to survive, and as results the populations live under 1$ per day, and they are affected by the cyclic hunger and malnutrition [31].
Agriculture should be basis for a country development however, the reality is different. The lack of food production contributes for the increase of food prices in local markets and putting the people on the embarrassing situation of depending on the importation of food products, and as consequences life becomes more expensive and the people live below the level of poverty. Some methods and crops used in the agriculture can contribute negatively in respect to environmental impact and climate changes and affect our areas of production. This fact is advocated by some scientists who say that Jatropha is affecting seriously the food production, since it occupies large areas that once served as the cultivation of food. In this context, the agricultural production areas of the populations are being occupied by the large companies for Jatropha cultivation, thus, contributing for the shortage in the food production [40]. To overcome these problems of agricultural production and land occupation some studies suggest the involvement of good integrated approved policies in food security matter, energy and climate changes.

Different researches assert that biodiesel should not be seen as competitor of food production but as complementary production [23]. For instance, the population or the small Jatropha growers could grow food crops beside biofuels crops, which will lead to earn from both crops, increasing the cash flow, create source of energy and develop the multi- cultivation of crops [40].
Sun Biofuels Ltd was established in 2005 in Mozambique with purpose to cultivate Jatropha for biofuel production. Sun biofuel is the company based in UK (United Kingdom), operating in Manica Province, Chimoio City, along Beira corridor which links the port of Beira the landlocked countries such as Malawi and Zimbabwe [42]. The figure 3.9 above shows the location of Sun Biofuels Company.

3.5. The Case of Sun-Biofuels Farm in Manica Province

Gondola is a district of Manica province that goes along the border with Zimbabwe to the west of Mozambique. With a highest altitude of 2,436 meters we have Binga Mountain being the highest mountain in the country. During the rainy season the amount of rain is very high, making difficult the land communication with rural and semi-rural areas.

The Jatropha Alliance together with Partners for Innovation has implemented some sustainable projects dealing with biodiesel production in Mozambique. Existing sustainable frameworks have been reviewed and
analysed to identify the best suitable standards for this pilot project. The Roundtable on Sustainable Biodiesel (RSB) was considered as the most valuable instrument for the pilot project. A dedicated gap analysis at critical level revealed the status of the Jatropha producers with regard to the RSB standard.

In the previous conducted gap analysis, the SBF reached a very good score with 7.7 points out of 10, as SBF has put in place procedures and actions that ensure a sustainable operation of its business. For 31% of the RSB indicators SBF is already up to the RSB standard, taking into account that SBF started its operation before the RSB standard has been developed, this is really great. However, 69% of the RSB indicators further efforts to reach compliance need to be implemented [43].

Sun Biofuels Mozambique (SBF) is a vegetation oil company specialised in the oilseed plant, Jatropha curcas. Since 2009 SBF has planted more than 2000ha of Jatropha at Chimoio in Manica Province, Republic of Mozambique spreading it over the sites. With this amount of plantation, the aim was to reach the significant oil yield in 2012.

The figure 3.10 bellow shows the energetic components of Jatropha production from Jatropha plantation to oil extraction phase.

![Figure 3.10: Energetic components of Jatropha Curcas.](Source: Adapted by the author [44])

Two methods were chosen for this study, qualitative method and the use of secondary data collection. The qualitative approach was used to explore perceptions, experiences and practices of the company. The study used secondary data from literature review and data collected from the field which is a primary data to
understand the topic and establish the scope of the study. The use of secondary data was to complement the findings from the field.

Different methods used will allow to crosschecking and triangulation the data collected, contributing to the reliability and validity of the results. The technique used for data collection was verbatim transcript, field notes, researcher observation, semi-interview, researcher taken photos, follow-up of telephone calls.

3.5.1. Land Clearance and Preparation

All projects with purpose of oil production from Jatropha require acquiring land for plantation. In the first step the land should be cleaned and prepared for the plantation. Before starting with the land clearing it is crucial to first carry out the survey work. The data provided by the survey will be used to plan land clearing and subsequent land preparation procedures.

According to the guide of Jatropha Cultivation and Production in SBF farm [45], the degree of woody perennial re-growth determines the operation but the minimum requirement is a heavy disking (3 tone) with a 160 horse power wheel tractor. Punctures and pre-constructed contours are major factors which influence the productivity. In the same field small clumps of woody perennial re-growth must be slashed by hand or bulldozed into heaps for burning before disking can commence. The forest is cleared with machineries and manually, the trees are felled and the stumps are dug up to prevent re-growth of woody.

3.5.2. Planting Maintenance and Harvesting

Jatropha Curcas can be planted using two ways, direct sowing and seeding. But, as a plantation establishment policy, SBF has decided to establish all its plantations by direct sowing, see figure 3.11. Using direct sowing is possible to get immense advantages, including: a) to grow trees naturally from early stage, b) to avoid the disturbance of nursery operation, c) to avoid transplanting shock and d) to ensure tap root development. Nevertheless, there are some drawbacks of direct sowing including: a) requirement of excessive planting material (seed), b) failure of germination or proper rooting in some cases, and c) irregular stocking due blacking. However, the aforementioned drawbacks could be eliminated through proper management [45].
The Energy Balance of Jatropha Plantation in SunBiofuel Farm in Central Mozambique

Figure 3.11: Direct sowing of the seed along planting row. 
Source: [45].

The Use of direct sowing can constitute a method proper for improving the Jatropha establishment:

- Use of seeds with high viability (germination rate),
- Pre-treatment of seeds to ensure good germination and protection from pests and diseases,
- Good preparation of land to provide a good germination environment (soil may be scalped and cultivated),
- Preparation of seedlings to fill in vacant spots,
- Sowing 3 or 4 seeds (depending on germination rate) at each planting spot to minimize the risk of failure,
- Need for repeated sowing in case the germination fails.

3.5.2.1. Harvesting

In the Jatropha cultivation process the stage of harvesting is the most important because it here that companies or producers get the return on the investment for the production. Usually the harvesting of Jatropha process is done manually, pulling the fruit directly from the plant or shaking the branches of the plant. Shaking the branches of the plant is a very practical method because only the mature fruits are able to fall meanwhile the green fruits remain fixed on the branch.

The fruits reach maturity at 90 days of life, when it begins to change the colour from green to yellow-brown or brown colour. The fruits are not all ripe at same time, they get ripe gradually and therefore allowing the harvesting process to be done weekly [46].
3.5.3. Farm Machinery and Manpower (Man Labour)

During the preparation of land for cultivation of Jatropha Plant different kinds of machineries such as bulldozer were used to remove the roots and piling the debris, excavator to cut and remove trunks, heavy disc 3 tonne offset are hauled behind large wheel tractors to cut and to invert the remaining root systems for levelling the land, see figures 3.12 and 3.13 below.

![Figure 3.12: Bulldozer removing roots (left) and piling the debris on farm boundaries (right). Source: [45].](image)

![Figure 3.13: Stumps are dug out by excavator (left) and heavy disc are hauled behind large wheel tractors to cut and invert the remaining roots, (right). Source: [45].](image)

According to the figure 3.14 bellow, the tractor is ripping the soil but is not for amelioration purposes but is merely a tool to mark out planting lines. On these soils light ripping is good alternative but the ripper tine must be lifted out from the soil every 40 meters in a distance of 4 meters to prevent erosion. Although the alternative, low ridging, is preferred because it has numerous benefits; namely reducing weed competition, aerating of the soil, creating visible planting line and assists with maintenance operation [45]. Low ridging could be divided into two distinct operations based on soil properties. These are well-drained soils and seasonally wet soils. The direction of ridging shall be north-south except were slope and operational conditions dictate otherwise. During the operation of the pick production of the company, the maximum
contract of the workers was around 1500. Nevertheless, that number was drastically reduced because of the financial difficulties faced by the company.

![Figure 3.14: Light ripping at SBF farm. Source: [45].](image)

3.5.4. Drying and Seed Cake Removal

Some growers say that the seeds can be harvested when the colour of fruit is changing from green to brown, meaning that the fruits are reaching maturity. According to interviewee Shepherd Chiwundo after the harvest all fruits are dried out to remove the moisture until they find a gap to take out the seeds. The technique usually used is the open air sun drying. But in the case of SBF above the thin grid spread in free space as the Figures 3.15 (left) shows. Seeds are spread in the thin grid to permit the circulation of air in all direction during the drying process.

After the drying of all seeds, the husk removal process takes place. The husk can be removed manually and through machinery. The SBF Company removes husk using the machinery called Sheller, see Figure 3.15 (right).
3.5.5. Oil Extraction and Purification

The extraction of oil from seeds is the process to remove all liquid from Jatropha seeds. In order to extract oil different methods can be used; oil presses, oil expellers, traditional methods, hot oil extraction and modern concepts. The SBF Company extracts oil from Jatropha seeds using Oil Presses methods, as seen in figure 3.16 (left) below. The process of oil extraction is done by crushing the seeds in the expellers to remove oil and will be submitted to the filter to purify, but not refined at SBF Company.

Once the oil has been extract from the seed, impurities present in the oil are removed. The filtration systems are designed to remove particles, dissolved gas, acids and water. The equipment used for filtration is a filter press, but some of pieces had already been disassembled as shown in figure 3.16 (right).

**Figures 3.15:** Thin grid to spread Jatropha fruits (left), and Sheller to remove husk from Jatropha fruit (right).
**Source:** (Captured at SBF farm).

**Figure 3.16:** Machinery to crush seeds to extract oil (left), and filter press (right).
**Source:** (Captured in SBF farm).
3.5.6. Transportation

Transportation is one of key areas during the process of Jatropha cultivation. Daily, in the morning period a tractor carries workers from the office to the farms and in the afternoon brings them back. The round-trip distance is of 10 Km, meaning that the distance daily travelled by the tractor is around 20 Km. Also, some Land Cruiser vehicle from agriculture engineers circulated daily when supervising the work, transporting the agricultural material and involved in other related activities.
4. MATERIALS AND METHODOLOGY

This chapter presents the research design, the participants, instruments and the procedure of the research, the methodology and the instruments of the research used to carry out the data collection, its analysis, processing and interpretation in order to estimate the energy balance of Jatropha biodiesel in Sun Biofuels farm in Manica Province.

4.1. Research Area description

4.1.1. Location

SBF is located in Manica Province in central Mozambique, along the road linking Chimoio city and Manica district. Manica province has an area of 61,661 km² and a population of 1,359,923. Manica Province has a 12 districts (Tambara, Gondola, Macate, Guro, Machaze, Bárue, Chimoio, Manica, Sussundenga, Mossurize, Vanduzi and Macossa), where Chimoio City is the capital of the Province [95]. Figure 4.1 bellow shows the location map of the research area.

![Figure 4.1: Location of research area map. Source: [47].](image)

The SBF was established in 2005 in Mozambique with purpose to cultivate Jatropha for extraction of oil for commercialization. This company bought a large extension of land in Manica province particularly in the city of Chimoio along the road that connects the city of Chimoio and crossroads of Vanduzi. The choice of the province for Jatropha cultivation was due to favourable climate for the production and availability of land that allow the cultivation of various crops. Besides the production of Jatropha as the main crop, the company also cultivated various crops such as maize, beans, sunflower and sesame for commercial purpose.
4.1.2. Climate

The predominant type of relief is plateau and is here where is located the highest mountain of the country “Binga mountain” with a height of 2436 meters. The climate in the province is the humid tropical climate with a temperature ranging between 7⁰ and 28⁰, in which agriculture has become the main activity of the population in terms of survival because the climate and the rainfall favours for growing various kind of culture [47].

4.1.3. Research design

The research design is descriptive research since it is concerned with the description of the phenomenon. Qualitative and quantitative methods supported by the literature review approaches to meet the study objectives. Such methods were used to allow the collection of all possible data to achieve the objective of the study.

The researcher went to the field to confirm the hypotheses that Jatropha oil production has a better energy balance and can be estimated using the respective formulas of energy indicators, that it can be a reasonable option for our biofuel sustainability, that it has higher energy output than energy input used during its practical cultivation and that the lack of clear biofuels’ policies discourages promoters, investors and producers of Jatropha.

4.1.4. Participants

The study involved the interview of the General Manager, of the agronomist and of three former workers from the Sun Biofuels all in all to estimate the energy balance of Jatropha biodiesel in Sun Biofuels farm in Manica Province.

4.1.5. Site selection

Sun biofuel farm was indicated by local government based on all conditions for the development of this research, according to the aim of the study. The conditions are: To cultivate Jatropha and extract Oil from the seeds, which are the two area of the study. The scope of this research is to calculate all energy indicators for estimation of energy balance.

4.2. Choice of methods

The research used both primary and secondary data to meet the study objectives. The qualitative approach was used to explore perceptions, experiences and practices of the company stuff. The study used secondary data from literature review and primary data from the farm of SBF Company to understand the topic and establish the scope of the study. The use of secondary data was to complement the findings from the field.
The use of different methods allowed to crosschecking and triangulation of the collected data which ultimately contributed to the reliability and validity of the results. This combination allowed collecting most of the qualitative and secondary character information and creative data collection strategy [48]. All interviewers were conducted personally, using Portuguese, English and local language to communicate with the interviewee. The question for interviews were not prepared previously, were just asked question and some notes taken according to the observation and company background in the area of Jatropha oil production.

To achieve the study objectives, the method used was qualitative to have an idea of whole process of production, perceptions and practices staff from Sun Biofuel farm. The study used secondary data from literature reviews and primary data from the farm of SBF Company to understand the topic and establish the scope of the study, see Figure 4.2.

![Figure 4.2: Steps of methodology of data collection.](image)

The time spent walking in the fields was especially valuable in establishing individual perspectives, local knowledge, and issues peculiar to the farm. Visits to the sites were important to reach deeper understanding of the cropping systems [49]. Therefore, those methods used will help to conduct this research toward the objectives of the study which is to calculate all energy indicators to estimate the energy balance.
The aim of this study is to estimate the energy balance starting from Jatropha cultivation to oil extraction and filtration phase, see fig. 4.3 below.

![Diagram showing the stages of Jatropha oil production](image)

**Figure 4.3** – System boundary and stages of Jatropha oil production in SBF farm.

### 4.2.1. Literature review

The literature review was the key tool of data source to achieve the objectives of the study. Secondary data was obtained from the previous studies, books, scientific journals, internet, publications, and tours to the Sun-Biofuel farm as well as visits to some institutions such as Energy Fund and Ministry of Energy, and other data was supplied by some government organizations as the Ministry of Agriculture.

### 4.2.2. Observation

Observation was very important act in the data collection process because it allowed to learn directly from the object of the study, to have a clear picture of the object under the study, helping to have an answer to various questions and situations that exists in the field and also helping to make the crossroads of various information collected in the land and to have possible answers according to the data collected.

The observation in what regards a qualitative research was essential because it helped us to explore, to identify and to have deep information of the object under the study, helping to have the clear picture of all
process of Jatropha cultivation and oil production, also facilitating the researcher to achieve the objectives of the study, that is to estimate the energy balance by calculating all energy indicators. The observation act was considered by many scientists as a standard method that can be performed simultaneously with the interviews to allow and facilitate the acquisition of all possible data [49]. During tours to Jatropha plantations, it was possible to observe the size of the farm, machineries and the environmental work, how the company interacts with some workers.

4.2.3. Data collection

The technique used for data collection was verbatim transcript, field notes, researcher observation, unstructured interview, research taken photos, internet, follow-up telephone call and literature review which was useful because it was of a great helped in data collection that could not be found in the field. This technique of data collection contributed to collect most of data to achieve the objectives of the study which is to calculate all energy indicators in order to estimate de energy balance.

4.2.4. Interview

The interviews were carried out using open ended questions which allowed the respondents to give details and also for the researcher to come up with additional follow up questions and take some notes according to observation in order to understand the background of the farm. The time spent walking in the field was especially valuable in establishing individual perspectives, local knowledge, and issues peculiar to the farm. Visits to the sites were important to reach deeper understanding of the cropping systems. So, all this process helped the researcher to conduct the study to achieve the aim.

4.2.5. Assumption

The available information on the biofuel scheme was in somehow imprecise, vague and, in some instances, contradictory. Fundamental aspects, such as the actual method of Jatropha cultivation, the nature and scale of the oil extraction operations, and the precise uses for the subsequent biofuel, are almost entirely missing. In particular, the levels of mechanization, irrigation and artificial nitrogen (N), fertilizer application, if any, in Jatropha cultivation are not quantified. These and other details have a fundamental bearing on estimated total energy input, and also becomes difficult to make the energy balance calculation to estimate the efficiency of the production of Jatropha.

The absence of literature, reports and information about Jatropha cultivation in Mozambique, contributed negatively to gather and analyse information to elaborate this study. To achieve our goals, it was necessary to assume some data that are missing. Gaps induce generalization and assumption that lead to uncertainty. The hand-out of embodied energy collected in Jatropha farm during the survey missed a lot of important
information related to energy, in terms of quantity applied during the production. To overcome this situation other data were provided by various sources (Annexes 1 and 2). To calculate the energy indicators is necessary to use the energy equivalent which is in the (Figure 5.2). The electric engines can be found in the extraction unit, to remove oil from seeds, to shell and to filter, see figures 3.15 and 3.16. With 1000 kg of seeds, it is possible to extract 275 kg crude oil from Jatropha [50]. For this study was assumed 1900 kg/ha of seed yield. The quantities of energy output were also assumed, see (Figure 5.3).

The missing values in this research were undertaken from other studies that were conducted in similar areas to the study concerned. Although, the culture of study is not the Jatropha, but the cultivation activities are similar in terms of regions of agro-climatic.

4.3. Data management and analysis

The data from interview was manually recorded as notes in the discussion guides. The responses were recorded in respective spaces provided for each question on the note book. Other data was collected by direct observation of explanations which were either mentioned by the workers, or observed by the researcher. The data from observations was kept secure by taking pictures.

4.3.1. Data analysis

This work aims to study balance from the calculation of energy indicators. For this, it is necessary to develop a model for the analysis of data from life cycle assessment of Jatropha. Transparency, description, rigor, precision and procedures are characteristics attributed to the criteria for analysis [51]. Statistical numbers were considered as quantitative data, words and text were considered qualitative data, where those methods were used for data collection. The information gathered was crossed to obtain more accurate results. During data collection in the field, it was possible to observe various instruments and machinery on site, which facilitated somehow, makes the tracking of all energy inputs in the process of cultivation and production. However, the entries of all energy consumed during the process of Jatropha seed production were recorded, processed and analysed.

In this process, the power inputs of the human labour which is converted from hours of work to energy were recorded. In this case, the equivalent energy taken into account in this study was obtained from literatures and it varies considerably. However, the energy equivalent of human work for this study was assumed to be 1.96 MJ/ha.

The method of using primary and secondary data were applied and analysed after interpersonal communication in the field to collect all possible data and using secondary data available from various sources were the basis of the analysis. After the process of data collection, the computer was fundamental tool for the analysis of the data, because after release of the information collected at the computer, it
facilitated sorting, processing, analysis of data, calculation of energy indicators for the preparation of the table and graphs using Excel sheet.

For the calculation of energy indicators were used equations 4.1 to 4.4 [52].

The net energy, specific energy, energy use efficiency and energy productivity of Jatropha production are calculated using formulas below.

\[
NEV = \text{Energy Out (MJ)} - \text{Energy Input (MJ)} \tag{4.1}
\]

\[
\text{Energy use efficiency} = \frac{\text{Energy Output (MJha}^{-1})}{\text{Energy Input (MJha}^{-1})} \tag{4.2}
\]

\[
\text{Energy productivity} = \frac{\text{Seed Output (Kg ha}^{-1})}{\text{Energy Input (MJha}^{-1})} \tag{4.3}
\]

\[
\text{Specific energy} = \frac{\text{Energy Input (MJha}^{-1})}{\text{Seed Output (Kg ha}^{-1})} \tag{4.4}
\]

The Net energy can be calculated subtracting the energy output by the energy input. The energy use efficiency is a division of the energy output by the energy input. Another approach for evaluating energy utilization in crop production is to calculate the specific energy dividing the input energy by Jatropha seed output. The energy productivity is the division of Jatropha produced to the energy input in production.

\textit{i. Energy input}

Direct energy was the base for calculation of energy inputs (Human labour, Machinery and diesel) and indirect energy factors (Oil Extraction, fertilizers, Chemicals) involved.

\textit{ii. Energy output}

The total yield product was the base to calculate the energy outputs (Seed husks, raw seed oil, press cake, shells and woods). By multiplying the quantities by their corresponding energy value we can estimate the energy output [53].

4.4. Analyses of Energy Indicators

To reach the purpose of this study it is essential to calculate the energy indicators. Energy indicator is an important tool for the study of energy balance. The indicators selected for this study are: Net energy value,
specific energy, energy use efficiency and energy productivity, which can be calculated using equations 4.1 to 4.4 as aforementioned.

They vary depending on the subject and study area. In the process of cultivation and Jatropha seed production, the energy indicators help to estimate the consumption in each activity and calculate the energy efficiency throughout the production chain. The importance of using the energy indicators with a view to a good efficiency and good use of the equipment in the consumption of energy is directly linked to the environmental policies and economic factors of the institution. The use of indicators can help to define the good environmental practices, efficient use of energy and somehow improving the production process. See (Annex 3) for some information of field equipment’s.

4.4.1. Machinery Information

The equipment used in the cultivation process and Jatropha oil production was all taken into account in the data collection period. To estimate the energy balance is necessary to survey all agriculture equipment and all machineries involved in the production process and record all the characteristics of the fuel consumption, engine oil, its power, energy consumption, capacity production and hours of work per day, including the distance travelled by vehicles [54].

The Energy coefficients of farm machinery are illustrated in Table 4.2. This coefficient helps to calculate the energy of machineries in MJha⁻¹.

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass, kg</th>
<th>Life, h</th>
<th>Energy coefficient, MJha⁻¹</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor 70 Kw</td>
<td>4450</td>
<td>15000</td>
<td>42.3</td>
<td>[53, 55, 56]</td>
</tr>
<tr>
<td>Plough</td>
<td>600</td>
<td>2500</td>
<td>34.2</td>
<td>[56, 57]</td>
</tr>
<tr>
<td>Disc harrow</td>
<td>400</td>
<td>2500</td>
<td>22.8</td>
<td>[55, 56, 57]</td>
</tr>
<tr>
<td>Field cultivation</td>
<td>300</td>
<td>2500</td>
<td>17.1</td>
<td>[56, 57]</td>
</tr>
<tr>
<td>Row crop planter</td>
<td>470</td>
<td>2000</td>
<td>33.5</td>
<td>[57]</td>
</tr>
<tr>
<td>Sprayer</td>
<td>250</td>
<td>1500</td>
<td>23.8</td>
<td>[55, 56, 57]</td>
</tr>
<tr>
<td>Fertilizer distributor</td>
<td>300</td>
<td>2500</td>
<td>17.1</td>
<td>[57]</td>
</tr>
<tr>
<td>Row crop cultivation</td>
<td>300</td>
<td>2500</td>
<td>17.1</td>
<td>[57]</td>
</tr>
<tr>
<td>Combined harvester</td>
<td>12500</td>
<td>3000</td>
<td>594.6</td>
<td>[55, 57]</td>
</tr>
<tr>
<td>Trailer</td>
<td>1500</td>
<td>15000</td>
<td>14.3</td>
<td>[57]</td>
</tr>
</tbody>
</table>

4.5. Validity and reliability of data

There was one kind of approach which was used to validate data. The validation involved comparing three different sources of information. The sources were the interviews responses, direct observations, and lastly secondary data obtained from literature review.
It was considered to validate the interpretations deduced from the study through peer review and getting expert opinions from agriculturists. However, this was not possible due to limitations of time available to be in the field.

In the process of data collection primary data, secondary data, field observation, interviews, report and credible information from government institution are the strategy used to improve the truth of the information collected crossing the data to avoid contradictory information and give more credibility the data [49].

4.6. Limitation
Data collection was carried out at Sun-Biofuel farm in 2012. At the beginning of the same year the company closed doors because of lack of funding. This situation contributed negatively for the process of data collection in the field, because most of agricultural experts had been dismissed from service. The data collection was limited to Sun-biofuel farm, which means, the study is geographically limited to this enterprise farm. The lack of information related to life cycle of Jatropha in the country contributed negatively to the development of this work; even in the SBF Company they didn't give us all data because they claimed it to be confidential information. When I was looking for the information about biodiesel production during the last five years, the Ministry of Energy said that the information available is not for sharing to singular people, it is for government institution. So, this work was developed using information found on the internet, newspaper and in some books from other countries.
5. RESULTS AND DISCUSSION

5.1. Estimation of Energy Input

The study took place in Sun biofuel farm in Manica Province during 2012. To develop a scientific character study there are materials and information to be provided for research and must be acquired on the farm, in place of the study, ensuring the reliability of the information and this is one of the appropriate methods and recommended to develop this type of study [58]. Farmers’ responses were obtained through farm visits over one-year period and consisted of several in person interviews with producers. It should be noted that the data used in this study corresponds to 1 hectare and it’s of one year. During the site visit all machinery were not working because of lack of funding, and was also possible to see some old machineries as, Sheller, Filter press, Machinery to crush, Tractors, cars Land Cruiser as some pictures taken in the site show.

The survey for assessing the energy consumption covered the information about energy inputs included labour, machinery, fuel, chemical application, fertilizers, irrigation, weeding, pruning, harvesting, spraying, oil extraction, filtration and electricity use, whereas output assessment considered Jatropha yield value. The size of the study was 1 hectare whereby the value of input and output energy was calculated using standard energy equivalents, and the collected input and output data were both converted to unities of energy before analysis. The energy coefficient used for energy input and output in Jatropha farm production applied in this study is illustrated in the Table 5.2 bellow, where most of data was locally collected at Sun biofuel farm during site visit and interviews.

Due to differences in energy calculation methods the energy equivalent is different according to the conditions of the local of study [58]. So, the aim of this study is to estimate the energy balance by calculating all energy indicators (energy input, energy output, Net energy value, energy productivity, specific energy and energy use efficiency) in Jatropha farm of SBF Company located in Manica Province, which will be done using formulas and information from table 5.1 adapted from SBF handout, annex1 and 2. The energy consumed in oil extraction phase was estimated to be 688.5 MJ and 1000 kg of seeds can yield 275 kg of crude oil of Jatropha [50].

We used several references to determine the value of various energy equivalents. After energy inputs and outputs were determined by using energy equivalents, see table 5.2, the energy indicators were calculated and are presented in Equation (4.1) to (4.4) in chapter four.
Table 5.1: Represents the energy input of Jatropha in Sun-biofuel farm.

<table>
<thead>
<tr>
<th>Agriculture MJ/ha</th>
<th>26909.39</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Labour</td>
<td>7019.72</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>5003.96</td>
</tr>
<tr>
<td>Land preparation</td>
<td>637.84</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>4772.01</td>
</tr>
<tr>
<td>Irrigation</td>
<td>25.4</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>128.26</td>
</tr>
<tr>
<td>Fertilization application</td>
<td>564.48</td>
</tr>
<tr>
<td>Potassium</td>
<td>103.69</td>
</tr>
<tr>
<td>Pruning</td>
<td>1072.51</td>
</tr>
<tr>
<td>Chemical Application</td>
<td>626.84</td>
</tr>
<tr>
<td>Harvesting</td>
<td>486.08</td>
</tr>
<tr>
<td>Herbicide</td>
<td>595.1</td>
</tr>
<tr>
<td>Loading/discharging</td>
<td>51</td>
</tr>
<tr>
<td>Pesticide</td>
<td>31.84</td>
</tr>
<tr>
<td>Transportation</td>
<td>63.45</td>
</tr>
<tr>
<td>Diesel (MJ/ha)</td>
<td>8024.42</td>
</tr>
<tr>
<td>Seeding</td>
<td>234.16</td>
</tr>
<tr>
<td>Land preparation with machinery</td>
<td>4920.93</td>
</tr>
<tr>
<td>Oil Refinery</td>
<td>69.42</td>
</tr>
<tr>
<td>Weeding machinery</td>
<td>1544.4</td>
</tr>
<tr>
<td>Spraying</td>
<td>6.23</td>
</tr>
<tr>
<td>Irrigation</td>
<td>145.06</td>
</tr>
<tr>
<td>Pest control</td>
<td>728.06</td>
</tr>
<tr>
<td>Spraying</td>
<td>6.34</td>
</tr>
<tr>
<td>Weeding Herbicide</td>
<td>1646.41</td>
</tr>
<tr>
<td>Transportation</td>
<td>1407.75</td>
</tr>
<tr>
<td>Weeding manual</td>
<td>1419.64</td>
</tr>
<tr>
<td>Oil Extraction</td>
<td>2352.53</td>
</tr>
<tr>
<td>Other</td>
<td>15.68</td>
</tr>
<tr>
<td>Machinery</td>
<td>5551.92</td>
</tr>
<tr>
<td>Oil pressing</td>
<td>469.02</td>
</tr>
<tr>
<td>Land preparation with machinery</td>
<td>1065.91</td>
</tr>
<tr>
<td>Filtration</td>
<td>873.02</td>
</tr>
<tr>
<td>Weeding machinery</td>
<td>1166.92</td>
</tr>
<tr>
<td>Electricity use</td>
<td>591.53</td>
</tr>
<tr>
<td>seeds transportation</td>
<td>793</td>
</tr>
<tr>
<td>Agriculture MJ/ha</td>
<td>28579.3</td>
</tr>
<tr>
<td>Weeding ring</td>
<td>1317.12</td>
</tr>
<tr>
<td>Irrigation</td>
<td>60.00</td>
</tr>
<tr>
<td>Spraying</td>
<td>1.57</td>
</tr>
<tr>
<td>Transportation</td>
<td>188.1</td>
</tr>
<tr>
<td>Fertilizing application</td>
<td>959.3</td>
</tr>
</tbody>
</table>

Source: (adapted from SBF hand-out, annex 1 and 2).

During the Jatropha seed production quantities of consumed energy corresponds to the input energy which are classified into direct and indirect. Human labour was also used in this study with their respectively equivalent energy applied in several areas of production. Equivalent energy is estimated taking into consideration the number of workers involved in all activities of Jatropha seeds production. For this study were used various methods of data collection in different areas of activities for Jatropha seed production such as interviews, hand-outs from SBF company and bibliographic revision (see table 5.1), where the data was obtained from multiplication of energy equivalent by the quantities applied. The input and output energy were provided by various sources see table 5.2 and 5.3 bellow.
The Energy Balance of Jatropha Plantation in SunBiofuel Farm in Central Mozambique

Table 5.2: Energy equivalent for the production means.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Energy equivalent (MJ unit-1)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Input</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human labour (h)</td>
<td>1.96</td>
<td>[7, 52, 59]</td>
</tr>
<tr>
<td>Machinery (h)</td>
<td>62.7</td>
<td>[7, 52, 59]</td>
</tr>
<tr>
<td>Diesel fuel (L)</td>
<td>56.31</td>
<td>[7, 52, 59]</td>
</tr>
<tr>
<td>Chemical fertilizer (Kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>66.14</td>
<td>[52, 59]</td>
</tr>
<tr>
<td>B. Phosphate (P2O5)</td>
<td>11.1-12.44</td>
<td>[52, 59]</td>
</tr>
<tr>
<td>Potassium (K2O)</td>
<td>11.15</td>
<td>[52, 59]</td>
</tr>
<tr>
<td>Farm yard manure (Kg)</td>
<td>0.30</td>
<td>[7, 52, 59]</td>
</tr>
<tr>
<td>Chemicals (Kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herbicide</td>
<td>237.9</td>
<td>[7, 52]</td>
</tr>
<tr>
<td>Pesticide</td>
<td>199</td>
<td>[52]</td>
</tr>
<tr>
<td>Irrigation water (m3)</td>
<td>1.02</td>
<td>[52, 60]</td>
</tr>
<tr>
<td>Electricity</td>
<td>11.9</td>
<td>[7]</td>
</tr>
</tbody>
</table>

The table 5.2 represents the value of energy equivalent to calculate all energy input applied during all process of Jatropha production.

The total consumed energy in Jatropha farm was 28.579 MJ/ha. The top three energy inputs were related to diesel, human labour and machinery which consumed 28%, 25% and 19% of the total energy inputs, respectively. Diesel energy was mainly consumed and has been used for land preparation, cultural practices, Irrigation, transportation and generator for electricity in case of blackout, see also (fig. 5.1).
5.2. Estimation of Energy Output

<table>
<thead>
<tr>
<th>Item</th>
<th>Quant. Kg/ha</th>
<th>E. value MJ/Kg</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed husks</td>
<td>600</td>
<td>16</td>
<td>[44]</td>
</tr>
<tr>
<td>Raw seed oil</td>
<td>900</td>
<td>39.8</td>
<td>[44]</td>
</tr>
<tr>
<td>Press cake</td>
<td>1000</td>
<td>18.8</td>
<td>[59, 60]</td>
</tr>
<tr>
<td>Shells</td>
<td>1000</td>
<td>11.1</td>
<td>[44, 59, 60]</td>
</tr>
<tr>
<td>Woody products</td>
<td>3000</td>
<td>15.5</td>
<td>[44, 60]</td>
</tr>
</tbody>
</table>

Table 5.3: Data for energy output estimation

The table 5.3 summarizes the information of quantities and energy value of all products collected.

The energy outputs, was calculated using following item: seed husks, raw seed oil, press cake, shells and woody products as shown in the table above. According to the table 5.3, the multiplication of energy value by quantities will results in output energy of the system. During the data collection was not possible to get all data needed for the study, therefore, to overcome this situation was assumed the value of seed yield as 1900 kg/ha.

![Energy Balance of Jatropha Plantation](image)

**Figure 5.2**: Represent the Energy output from whole process of JME production per ha.

Co-products are the results of all outputs which come from Jatropha cultivation. So, for this study was defined output the seed husk, raw seed oil, press cake, Shells and woody products. All those energy output can be calculated from multiplication of quantities of each product by respective energy value.
The distribution of percentage of the energy output from different co-products is shown in figure 5.3. The main contribution of energy output was wood products (38%), followed by raw seed oil (30%), press cake (15%), shells (9%) and seed husk (8%).

5.3. Results of Energy Balance

All energy indicators selected for this study of Jatropha production in SBF Company in Manica Province are calculated and tabulated in Table 5.4.

<table>
<thead>
<tr>
<th>Items</th>
<th>Unit</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Input</td>
<td>MJ ha(^{-1})</td>
<td>28 579</td>
</tr>
<tr>
<td>Energy Output</td>
<td>MJ ha(^{-1})</td>
<td>121 820</td>
</tr>
<tr>
<td>Seed output</td>
<td>Kg ha(^{-1})</td>
<td>1900</td>
</tr>
<tr>
<td>Energy use efficiency</td>
<td>-</td>
<td>4.3</td>
</tr>
<tr>
<td>Specific energy</td>
<td>MJ Kg(^{-1})</td>
<td>15.04</td>
</tr>
<tr>
<td>Energy productivity</td>
<td>Kg MJ(^{-1})</td>
<td>0.067</td>
</tr>
<tr>
<td>Net Energy Value</td>
<td>MJ ha(^{-1})</td>
<td>93 241</td>
</tr>
</tbody>
</table>

When studying flow in agricultural systems, it is important to develop an investigation of energy balance to estimate the sustainability and efficiency of the production [7].

The table 5.4 shows the results of all energy indicators chosen in this study of Jatropha oil production. As the NEV formula simply subtracts inputs from outputs, the biologically based products such as Jatropha biodiesel can have positive net energy values as 93.241 MJ because solar energy used for plant growth is not accounted for in the equation. The energy use efficiency (energy output/energy input) in Jatropha production was 4.3 which shows that energy production was higher than energy utilization, which mean that the energy production of Jatropha is considerable efficient in terms of energy use. Another approach for
evaluating energy utilization in crop production is to calculate the specific energy (energy input/seed output), in Jatropha farm it was 15.04. The energy productivity (seed output/energy input) in Jatropha farm was 0.067 see Table 5.3. To highlight the value of seeds output was assumed as 1.900 kg/ha.

5.3.1. Other Studies about Energy Balance

Some authors developed a deep research about energy balance in different farms and with different crops, in order to assess the sustainability of framework oil production. Below there is comparison of different results of studies which calculated all energy indicators selected for this study, being therefore possible to find positive and negative results on energy balance. Therefore, this study has almost the same scope, which is to estimate the energy balance of Jatropha oil production, using the same energy indicators.

Comparative study on energy during the research in potatoes farming in New Zealand were 62300 MJ ha⁻¹ of the energy input while other potatoes studies found 81624.96 and 102432.99 MJ ha⁻¹ of energy input and output respectively [52]. In Iran the energy ration of wheat crops was calculated as 1.44 and 3.38 for irrigated land while other study found 1.25 in the same country [52].

The energy productivity of cotton – 0.06, sugar beet – 1.53, tomato – 1.0 are documented in different literatures and the calculation of net energy of potato is 34913.07 MJ kg⁻¹ and specific energy 2.62 MJ kg⁻¹ [58]. In Turkey was developed a research of different vegetables and field crops and were estimated the specific energy of wheat – 5.24, Cotton – 11.24, Water melon – 0.97, tomato – 1.14, melon – 0.98, maize – 3.88 and sesame – 16.21, while in Iran the specific energy was reported as 8.96 and 15.83 MJ kg⁻¹ in irrigated and dry land [58]. Therefore, according to the several researchers the variation of differences energy indicators in term of numbers is because of different methods of cultivation, practices, climate and soil, those items vary from regions to regions and it can directly affect the output production. While the results of the current study revealed that Jatropha production in SBF farm, under current management practices, is energy efficient.

The energy consumed in this farm was a total of 28.579 MJ/ha and the energy output was estimated in 121.820 MJ/ha. The Net energy value (NEV), energy productivity, energy efficiency and Specific energy were 93 241MJ ha⁻¹, 0.067 Kg MJ⁻¹, 4.3 and 15.04 MJ Kg⁻¹, respectively. The positive number of the energy balance indicators obtained in this study can be attributed to various reasons. One important reason for the positive energy is high level of technology including efficient machineries and irrigation pumps which consume less energy, because there was no need for so much irrigation due to the kind of land of the region. Choosing better machinery operation to reduce excessive usage of diesel fuel, more accurate utilization of fertilizers can help the company for more efficient and sustainable production.
6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusion

The objective of this research was to estimate the energy balance calculating all energy indicators in Jatropha farm of SBF Company located in Manica Province in the district of Gondola. The overall energy balance of Jatropha oil production was calculated using all energy indicators mentioned in this study and assessing the sustainability framework of Jatropha production which can contribute to provide useful information to help in the implementation of management strategies in order to improve the energy efficiency, sustainability and a friendly environment.

According to the results of all energy indicators of this study it was concluded that in the agriculture phase to cultivate Jatropha to produce oil, was used the energy from human labour – 7019.72 MJ/ha (25%), Machinery – 5551.92 MJ/ha (19%), Fertilizer – 5003.95 MJ/ha (18%), Chemical Application – 626.84 MJ/ha (2%), Diesel – 8024.42 MJ/ha (28%) and Oil refinery – 2352.53 MJ/ha (8%), which is promising and a challenging way to produce and converting Jatropha seed into oil energy.

The total energy applied in SBF farm during Jatropha oil production was estimated in 28579 MJ/ha and the energy output obtained from the production was 121820 MJ/ha which means that the energy input was used efficiently and brought sustainable result for the whole production. During the calculation was possible to find out the contribution of seed husks was (8%), woody products (38%), raw seed oil (30%), Shell (9%) and press cake (15%) of total energy output in this farm. Net energy value (NEV), energy productivity, energy efficiency and Specific energy was 93 241 MJ ha\(^{-1}\), 0.067 Kg MJ\(^{-1}\), 4.3 and 15.04 MJ Kg\(^{-1}\), respectively. These findings indicated that the net energy for Jatropha production has positive values, because the energy was used efficiently.

Fossil fuels are indicated as the main source of emission of greenhouse gases, causing major damage to the environment by creating global warming, acid rain, melting, floods, storm and other disasters. However, to mitigate these effects, biodiesel is mentioned as a potential viable to substitute the fossil fuels providing very low emissions and taking the advantage of being environmentally friendly and having a very high energy potential, which somehow can help in the stability of power system. For the country, the biofuels will help to reduce the external dependence on oil imports, lower import costs and will contribute in reducing greenhouse gases. For governments, the study will help to inspire policy makers to draw up biofuels plans that promote the cultivation of Jatropha in sustainable and efficient way. The research will also contribute to help all Jatropha producers in terms of information and sustainability of the crop.
6.2. Recommendation

The researcher recommends:

➢ To promote the cultivation of Jatropha crops for oil production in the country;
➢ To increase more research on Jatropha energy balance in the country for suitable, efficient and sustainable production in the future; and that
➢ Efforts should be carried out for efficient use of energy input during Jatropha cultivation, which can lead the country one step closer to the sustainability of agricultural production.
The Energy Balance of Jatropha Plantation in SunBiofuel Farm in Central Mozambique

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The Energy Balance of Jatropha Plantation in SunBiofuel Farm in Central Mozambique


The Energy Balance of Jatropha Plantation in SunBiofuel Farm in Central Mozambique


The Energy Balance of Jatropha Plantation in SunBiofuel Farm in Central Mozambique


# ANNEXES

## ANNEX 1: Raw Data from SBF farm

<table>
<thead>
<tr>
<th>Activities</th>
<th>Man Days/ha</th>
<th>Energy quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizing (Man Days/ha)</td>
<td>36</td>
<td>Fertilizing (MJ/ha) 564.48</td>
</tr>
<tr>
<td>Harvesting Manual (Man days/ha)</td>
<td>31</td>
<td>Harvesting Manual (MJ/ha) 486.08</td>
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<tr>
<td>Others (Man days/ha)</td>
<td>1</td>
<td>Others (MJ/ha) 15.68</td>
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<td>Pest Control (Man days/ha)</td>
<td>46.428</td>
<td>Pest control (MJ/ha) 728</td>
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<tr>
<td>Planting, sowing (Man Days/ha)</td>
<td>7</td>
<td>Planting, sowing (MJ/ha) 109.76</td>
</tr>
<tr>
<td>Ploughing (Hours/ha)</td>
<td>14</td>
<td>Ploughing (MJ/ha) 478.8</td>
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<tr>
<td>Pruning Man (Days/ha)</td>
<td>68.4</td>
<td>Pruning (MJ/ha) 1072.512</td>
</tr>
<tr>
<td>Ridging (Hours/ha)</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Ridging (Man Days/ha)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Transport (Hours/ha)</td>
<td>1.5</td>
<td>Transport (MJ/ha) 63.45</td>
</tr>
<tr>
<td>Weeding Herbicide (Man Days/ha)</td>
<td>105</td>
<td>Weeding Herbicide (MJ/ha) 1646.4</td>
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<tr>
<td>Weeding Rings (Man Days/ha)</td>
<td>84</td>
<td>Weeding Rings (MJ/ha) 1317.12</td>
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<tr>
<td>Weeding Manual (Man Days/ha)</td>
<td>90.53846154</td>
<td>Weeding manual (MJ/ha) 1419.643077</td>
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<tr>
<td>Weeding Mechanical/mowing (Hours/ha)</td>
<td>29.66666667</td>
<td></td>
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<tr>
<td>Weeding Mechanical/mowing (Man days/ha)</td>
<td>9.714285714</td>
<td>Weeding Mechanical mowing (MJ/ha) 1166.92</td>
</tr>
</tbody>
</table>
ANNEX 2: Raw Data from SBF farm

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Quantity per unity area (ha)</th>
<th>Total energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity in Sheller and crusher (MJ/t)</td>
<td>49.71</td>
<td>591.549</td>
</tr>
<tr>
<td>Energy used in irrigation (MJ/ha)</td>
<td>231.33 [58]</td>
<td>235.9566</td>
</tr>
<tr>
<td>Nitrogen (MJ/kg)</td>
<td>72.15</td>
<td>2546.895</td>
</tr>
<tr>
<td>N Application rate (kg/ha)</td>
<td>35.3</td>
<td>128.2564</td>
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<tr>
<td>Phosphorus (MJ/kg)</td>
<td>10.31</td>
<td></td>
</tr>
<tr>
<td>P2O5 application (kg/ha)</td>
<td>12.44</td>
<td></td>
</tr>
<tr>
<td>Potassium (MJ/kg)</td>
<td>9.3</td>
<td>103.695</td>
</tr>
<tr>
<td>K2O application (kg/ha)</td>
<td>11.15</td>
<td></td>
</tr>
<tr>
<td>Herbicide (MJ/kg)</td>
<td>238</td>
<td>595</td>
</tr>
<tr>
<td>Herbicide application rate (kg/ha)</td>
<td>2.5</td>
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</tr>
<tr>
<td>Pesticide MJ/kg</td>
<td>199</td>
<td>31.84</td>
</tr>
<tr>
<td>Pesticide application kg/ha</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Seed (MJ/kg)</td>
<td>65</td>
<td>234</td>
</tr>
<tr>
<td>Seed rate (kg/ha)</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>Spraying</td>
<td>6.23 [58]</td>
<td>6.23</td>
</tr>
</tbody>
</table>
### ANNEX 3: Field operations – Implements [54]

<table>
<thead>
<tr>
<th>Field operation</th>
<th>Implement</th>
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</thead>
<tbody>
<tr>
<td>Ploughing, at a depth of 25 cm</td>
<td>Plough, 3 furrows of 35 cm width</td>
</tr>
<tr>
<td>Disc harrowing</td>
<td>Disc harrow, 3 m width</td>
</tr>
<tr>
<td>Fertilizer application (ammonium phosphate N=28 Kg/ha, P2O5=41.4 Kg/ha)</td>
<td>Fertilizer distributor, 500 kg capacity</td>
</tr>
<tr>
<td>Applying pesticide (0.16 kg/ha)</td>
<td>Sprayer, 500 L capacity</td>
</tr>
<tr>
<td>Cultivating – pesticide incorporation</td>
<td>Field cultivator, 3 m width</td>
</tr>
<tr>
<td>Sowing seed at 3.5 kg/ha</td>
<td>Row planter, furrows</td>
</tr>
<tr>
<td>Hoeing for weed control</td>
<td>Row crop cultivator, furrows</td>
</tr>
<tr>
<td>Hoeing manually for weed control</td>
<td></td>
</tr>
<tr>
<td>Harvesting</td>
<td>Combine harvester, furrows</td>
</tr>
</tbody>
</table>

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