The Biodiesel Value Chain as a Development Tool for Smallholder Farmers in Rural Mozambique

Carolina Onsbring Gustafson

Erik Englund
Abstract

As one of the poorest countries in the world Mozambique has a great need of development, especially among smallholder farmers within the agriculture sector which constitutes 80% of the population. Previous research, as well as the government of Mozambique, has identified a great potential for biodiesel production in Mozambique. This study investigated if it is possible to carry out a socially, environmentally and financially sustainable biodiesel production chain as a development tool for smallholder farmers in rural Mozambique. The study also investigated if the biodiesel value chain can be used for poverty reduction, how it best can be designed, and what structures need to be changed.

The study was carried out by a study of previous literature, a field study in Mozambique, and by developing a scalable model for scenario simulations of the biodiesel production chain. In the model the biodiesel value chain was defined by a number of modules, and for each module different scenarios were defined for further tests and analysis. The model simulated the total production of biodiesel from one hectare of land over a ten year period from both jatropha and coconut trees, and for each defined scenario the cost, energy use, and CO2 emission both for the total value chain and for each activity was calculated. The energy ratio was also calculated for each analyzed scenario.

The most suitable design of the biodiesel value chain was found to be the use of smallholder farmers with advanced farming technique for growing the biodiesel crops, in combination with an advanced extraction facility with high extraction rate. As end market the local market for vegetable oil was found completing the whole value chain as the best design to full fill the requirements of sustainability. Whether the biodiesel should be sold at the southern African market or at the EU market was found to depend on the market prices and possible tax exemptions at the point of sales.

The results showed that the total cost of producing one liter of vegetable oil from jatropha is 0.43 USD/liter, and 0.60 USD/liter for coconuts. The energy use for producing one liter of vegetable oil from jatropha is 0.00544 GJ/liter, and 0.00868 GJ/liter for coconuts. The CO2 emission from production of one liter of vegetable oil from jatropha is 0.741 kgCO2/liter, and 1.190 kgGJ/liter from coconuts. The energy ratio for producing one liter of vegetable oil to the local market is 6.51 for jatropha excluding utilization of byproducts, and 13.14 including utilization of byproducts. For producing one liter of vegetable oil to the local market is 4.16 for coconuts excluding utilization of byproducts, and 5.02 including utilization of byproducts.

By an analysis of the results taking the social, environmental and financial aspects in consideration it was found that it is be possible to use the biodiesel value chain to reduce poverty in Mozambique in a sustainable way. The systems that were found in need of changes were the systems for education and information sharing, the systems for collecting the feedstock, the systems for use of byproducts, and the systems for regulation and taxes.
Sammanfattning

Som ett av världens fattigaste länder är Mozambique i stort behov av utveckling, speciellt av småjordbrukare vilka utgör 80 % av befolkningen. Både tidigare forskning och den Mozambikanska regeringen har identifierat en stor potential för produktion av biodiesel i Mozambique. Denna studie har undersökt huruvida det är möjligt att konstruera en socialt, miljömässigt och finansiellt hållbar biodieselproduktionskedja som ett medel att utveckla småjordbrukare på den Mozambikanska landsbygden. Studien undersökta även huruvida värdekedjan för produktion av biodiesel kan användas för fattigdomsbekämpning, hur det bästa utförandet av värdekedjan är designad och vilka strukturer som behöver förändras för att göra detta möjligt.


Resultaten visade att den totala kostnaden för att producera en liter vegetabilisk olja från jatropha är 0,43 USD/liter och 0,60 USD/liter för kokosnötter. Energianvändningen för att producera en liter vegetabilisk olja från jatropha är 0,00544 GJ/liter och 0,00868 GJ/liter för kokosnötter. Koldioxidutsläppen från produktion av en liter vegetabilisk olja från jatropha är 0,741 kgCO2/liter och 1,190 kgCO2/liter från kokosnötter. Energikvoten för att producera en liter vegetabilisk olja för den lokala marknaden är 6,51 för jatropha om restprodukter inte tas tillvara, och 13,14 då restprodukter tas tillvara. För att producera en liter vegetabilisk olja för den lokala marknaden är 4,16 för kokosnötter om restprodukter inte tas tillvara, och 5,02 då restprodukter tas tillvara.

Genom en analys av resultaten, med hänsyn till sociala, miljömässiga, och finansiella aspekter, befanns det möjligt att använda värdekedjan för biodiesel för att minska fattigdom i Mozambique på ett hållbart vis. De system som befanns i behov av förändring var systemen för utbildning och informationsspridning, systemen för att samla in råmaterial, systemen för användning av restprodukter, samt systemen för beslutsprocesser och skatter.
# Table of Contents

Abstract ................................................................................................................................. 2  
Sammanfattning ......................................................................................................................... 3  
Table of Contents ....................................................................................................................... 4  
Nomenclature ........................................................................................................................... 6  
Figures .................................................................................................................................. 7  
Tables ..................................................................................................................................... 8  
1. Introduction .......................................................................................................................... 9  
   1.1. Statement of Problem ......................................................................................................... 9  
   1.2. Background ...................................................................................................................... 9  
   1.3. Purpose .......................................................................................................................... 10  
   1.4. Thesis Statement ............................................................................................................. 10  
   1.5. Delimitation .................................................................................................................... 10  
   1.6. Objectives ...................................................................................................................... 10  
   1.7. Disposition ..................................................................................................................... 11  
2. Mozambique ......................................................................................................................... 12  
   2.1. Land Rights .................................................................................................................... 12  
   2.2. Food Security .................................................................................................................. 12  
   2.3. Poverty Reduction .......................................................................................................... 14  
      2.3.1. Family Farming ........................................................................................................ 14  
      2.3.2. Outgrower Schemes ................................................................................................. 15  
3. The Biodiesel Value Chain in Mozambique ........................................................................... 17  
   3.1. Farming .......................................................................................................................... 18  
      3.1.1. Large Scale Farming .................................................................................................. 18  
      3.1.2. Small Scale Farming ................................................................................................. 19  
   3.2. The Regulatory Process .................................................................................................. 20  
   3.3. Processing ...................................................................................................................... 21  
      3.3.1. Peeling and Dehusking ............................................................................................. 21  
      3.3.2. Feedstock Drying ..................................................................................................... 21  
      3.3.3. Oil Pressing - The Extracting Process ....................................................................... 22  
      3.3.4. Oil Refining ............................................................................................................... 22  
   3.4. Trading .......................................................................................................................... 22  
      3.4.1. Feedstock Trading .................................................................................................... 23  
      3.4.2. Vegetable Oil Trading ............................................................................................... 25  
      3.4.3. Biodiesel Trading ...................................................................................................... 25  
   3.5. Transportation ............................................................................................................... 25  
      3.5.1. Transportation of Feedstock .................................................................................... 26  
      3.5.2. Transportation of Vegetable Oil and Biodiesel ........................................................... 26  
      3.5.3. Storing ........................................................................................................................ 27  
   3.6. Markets ........................................................................................................................... 27  
      3.6.1. Domestic Market for Vegetable Oil and Biodiesel .................................................... 29  
      3.6.2. International Market for Vegetable Oil and Biodiesel .............................................. 30  
      3.6.3. Market for Byproducts ............................................................................................... 30  
4. Method .................................................................................................................................. 31  
   4.1. Main Structure of the Model ........................................................................................... 31  
   4.2. The Flows in the Model ................................................................................................. 34
5. Result
5.1. Farming Module Scenarios ................................................................. 45
  5.1.1. Cost Result of Jatropha Farming Scenarios ................................. 45
  5.1.2. Energy Result of Jatropha Farming Scenarios ............................ 46
  5.1.3. CO2 Result of Jatropha Farming Scenarios ................................. 47
  5.1.4. Cost Result of Coconut Farming Scenarios ................................. 48
  5.1.5. Energy Result of Coconut Farming Scenarios .............................. 49
  5.1.6. CO2 Result of Coconut Farming Scenarios ................................ 49
5.2. Extraction Module Scenarios ........................................................... 50
  5.2.1. Cost Result of Jatropha Extraction Scenarios ............................. 50
  5.2.2. Energy Result of Jatropha Extraction Scenarios ......................... 51
  5.2.3. CO2 Result of Jatropha Extraction Scenarios ............................ 52
  5.2.4. Cost Result of Coconut Extraction Scenarios ............................. 52
  5.2.5. Energy Result of Coconut Extraction Scenarios .......................... 53
  5.2.6. CO2 Result of Coconut Extraction Scenarios ............................ 54
5.3. Jatropha and Coconut Refining Module Scenarios ............................. 54
  5.3.1. Cost Result of Jatropha and Coconut Refining Scenarios ............ 55
  5.3.2. Energy Result of Jatropha and Coconut Refining Scenarios .......... 55
  5.3.3. CO2 Result of Jatropha and Coconut Refining Scenarios ............ 55
5.4. Results of the sensitivity analysis of the model ............................. 56
  5.4.1. Jatropha costs sensitivity analysis ......................................... 56
  5.4.2. Jatropha energy input sensitivity analysis ................................ 57
6. Result Analysis .................................................................................... 59
  6.1.1. Total Cost of the Biodiesel Value Chain .................................. 59
  6.1.2. Total Energy Use in the Biodiesel Value Chain .......................... 60
  6.1.3. Total CO2 Emission from the Biodiesel Value Chain ................. 60
  6.1.4. Energy Ratio for the Biodiesel Value Chain .............................. 61
6.2. Discussion .......................................................................................... 63
6.3. Conclusion ......................................................................................... 66
  6.3.1. Recommendations .................................................................... 66
7. Further research .................................................................................... 68
8. References ........................................................................................... 69
**Nomenclature**

- **B** = Total Embedded Energy Input for the Biodiesel Production Value Chain [GJ/l]
- **BF** = Total embedded energy input for farming [GJ/kg]
- **BFP** = Embedded energy input for preparing and maintaining land [GJ/kg]
- **BR** = Total embedded energy input for refining [GJ/kg]
- **BRR** = Embedded energy input for refining [GJ/kg]
- **C** = Total Cost of Biodiesel Production Value Chain [USD/l]
- **CE** = Total cost of extraction [USD/kg]
- **CED** = Cost of drying and storing feedstock [USD/kg]
- **CEM** = Cost of trading oil to oil market [USD/kg]
- **CEO** = Cost of storing oil [USD/kg]
- **CEP** = Cost of oil pressing [USD/kg]
- **CES** = Cost of storing presscake [USD/kg]
- **CET** = Cost of trading presscake to market [USD/kg]
- **CF** = Total cost of farming [USD/kg]
- **CFH** = Cost of harvesting feedstock [USD/kg]
- **CFP** = Cost of preparing and maintaining land [USD/kg]
- **CFS** = Cost of processing and storing feedstock [USD/kg]
- **CFT** = Cost of trading feedstock to feedstock market [USD/kg]
- **CR** = Total cost of refining [USD/kg]
- **CRD** = Cost of storing diesel [USD/kg]
- **CRR** = Cost of oil refining [USD/kg]
- **CRT** = Cost of trading diesel to market [USD/kg]
- **D** = Total Diesel Input for the Biodiesel Production Value Chain [l/l]
- **DE** = Total diesel input for extraction [l/kg]
- **DET** = Trading diesel energy input [l/kg]
- **DF** = Total diesel input for farming [l/kg]
- **DFH** = Diesel input for harvesting feedstock [l/kg]
- **DFP** = Diesel input for preparing and maintaining land [l/kg]
- **DFT** = Diesel input for trading feedstock to feedstock market [l/kg]
- **DR** = Total diesel input for refining [l/kg]
- **DRT** = Diesel input for trading diesel to market [l/kg]
- **E** = Total Electric Input for the Biodiesel Production Value Chain [kWh/l]
- **EE** = Total electric input for extraction [kWh/kg]
- **EEP** = Electric input for oil pressing [kWh/kg]
- **EES** = Electric input for drying and storing feedstock [kWh/kg]
- **ER** = Total electric input for refining [kWh/kg]
- **ERR** = Electric input for refining [kWh/kg]
- **ME** = Mass flow of extraction [kg]
- **MED** = Drying and storing feedstock [kg]
- **MEM** = Trading point [kg]
- **MEO** = Oil pressing [kg]
- **MEP** = Feedstock to oil pressing [kg]
- **MER** = Oil to refineries [kg]
- **MES** = Oil to storage [kg]
- **MET** = Oil to trading [kg]
- **MF** = Mass flow of farming [kg]
- **MFH** = Harvesting feedstock [kg]
- **MFP** = Planting and maintaining feedstock [kg]
- **MFS** = Processing and storing feedstock [kg]
- **MFT** = Feedstock to feedstock market [kg]
- **MR** = Mass flow of refining [kg]
- **MRM** = Trading diesel to markets [kg]
- **MRR** = Oil refining [kg]
- **MRS** = Diesel to storage [kg]
- **MRT** = Oil to refining [kg]
Figures

Figure 1: Food security ................................................................. 13
Figure 2: The biodiesel value chain ...................................................... 17
Figure 3: Stakeholders in the biodiesel value chain .................................. 18
Figure 4: The trading system for family farmers in Mozambique .............. 23
Figure 5: The trading system for family farmers with collection points ........ 24
Figure 6: Industrial farm trading system .............................................. 24
Figure 7: Price differences relative to port of entry of fuel ....................... 29
Figure 8: The main structure of the model ........................................... 32
Figure 9: The interface where different input variables can be changed to simulate different scenarios ... 33
Figure 10: Data generated from a run of a the model ................................ 34
Figure 11: The models mass flow with the three modules, and its 15 activities ........................................................... 35
Figure 12: The models cost flow with the three modules, and its 14 activities ........................................................... 35
Figure 13: The models diesel flow with the three modules, and its five activities ........................................................... 37
Figure 14: The models electric flow with the two modules, and its three activities ........................................................... 38
Figure 15: The models embedded energy flow with the two modules, and its two activities ........................................................... 39
Figure 16: The start of the farming module with mass flow, cost flow, diesel flow, and embedded energy flow, different activities, sub-activities, and input variables ........................................................... 40
Figure 17: Cost for coconut biodiesel sold to the EU .............................. 62
Figure 18: Cost for jatropha biodiesel sold to the EU .............................. 62
Figure 19: Energy input for coconut diesel sold to the EU ....................... 62
Figure 20: Energy input for jatropha biodiesel sold to the EU ................... 62
Figure 21: CO2 emissions for coconut biodiesel sold to the EU .................. 62
Figure 22: CO2 emissions for jatropha biodiesel sold to the EU .................. 62
Figure 23: Energy ratio for the biodiesel value chain ................................ 63
Figure 24: Sustainability criteria .......................................................... 65
Tables

Table 1: Breakdown of petroleum prices in Mozambique ................................................................. 28
Table 2: Breakdown of petroleum taxes in Mozambique .................................................................. 28
Table 3: End user price of petroleum in Mozambique ..................................................................... 28
Table 4: Farming scenarios .............................................................................................................. 43
Table 5: Extraction scenarios .......................................................................................................... 43
Table 6: Refining scenarios ............................................................................................................. 44
Table 7: Farming costs for jatropha .................................................................................................. 46
Table 8: Energy inputs for jatropha farming ..................................................................................... 47
Table 9: CO2 emissions for jatropha farming .................................................................................. 47
Table 10: Cost of coconut farming ................................................................................................... 48
Table 11: Energy input for coconut farming ....................................................................................... 49
Table 12: CO2 emissions for coconut farming .................................................................................. 50
Table 13: Cost of jatropha extraction ............................................................................................... 51
Table 14: Energy input for jatropha extraction ............................................................................... 52
Table 15: CO2 emissions for jatropha extraction ............................................................................. 52
Table 16: Cost of coconut extraction ............................................................................................... 53
Table 17: Energy input for coconut extraction .................................................................................. 54
Table 18: CO2 emissions for coconut extraction ............................................................................... 54
Table 19: Cost of refining ............................................................................................................... 55
Table 20: Energy input for refining .................................................................................................. 55
Table 21: CO2 emissions for refining .............................................................................................. 56
Table 22: Jatropha costs sensitivity analysis .................................................................................... 57
Table 23: Jatropha energy input sensitivity analysis ......................................................................... 58
Table 24: Total cost of the biodiesel value chain ............................................................................. 60
Table 25: Total energy use in the biodiesel value chain ................................................................. 60
Table 26: Total CO2 emissions from the biodiesel value chain ....................................................... 60
Table 27: Energy ratio for the biodiesel value chain ....................................................................... 61
1. **Introduction**

The introduction chapter will give a presentation of the background of this study, the purpose, and the questions to be answered. The introduction chapter will also state the objectives and describe the delimitations of the project, and the structure of the report will also be described in the disposition part.

1.1. **Statement of Problem**

In the global energy sector of today there is a big interest for investments into biodiesel production. The government of Mozambique believes that investments into biodiesel can be a way to improve the country’s future prospects. There is however a lack of literature on how the biodiesel value chain in Mozambique is structured and how it works. There is also a lack of research into how investments in, and incomes from, the biodiesel value chain can be used as a rural development tool. (Alves, 2011)

1.2. **Background**

Mozambique, a Sub-Saharan African country (UN, 2011) and a former Portuguese colony, is one of the world’s poorest countries with an average income of 370 USD per year and person. The country experienced a 16 year civil war that ended in 1992. The war destroyed much of the country’s infrastructure and business structures (UNICEF, 2011). In Mozambique 80% of the population works within the agricultural sector (IDFC, 2011), of which 57% are below the national poverty line (World Bank, 2011.a). Around 90% of the farmers in the agricultural sector in Mozambique are smallholder farmers (IIASA, 2011), i.e. farmers with limited resource endowments relative to other farmers in the sector (Dixon, Tanyeri-Abur, & Wattenbach, 2011). The productivity at the smallholder farmers’ farms is very low. Increasing the productivity at the farms is therefore a priority in order to reduce poverty (IIASA, 2011).

As the debate over climate change and fuel supply security has intensified, and the price of fuel has gone up, the interest for renewable fuels has been increasing in recent years. Many countries have mandates on mandatory blending of biodiesel into petroleum diesel. The EU has for example decided on a mandatory target of 5.75 % blending of biodiesel into petroleum diesel. These regulations, in combination with a public awareness of the environmental problems associated with petroleum fuels, have created an increasing demand for biodiesel (EU, 2006).

Mozambique has been identified as a country with a very big potential for biodiesel due to its relative political stability and political freedoms (EIU, 2011), a relatively good business climate (World Bank, 2011.b), favorable climate conditions (Englund & Claise, 2011, p.19-22), and a vast amount of unused agricultural land (CIA, 2011). This biodiesel potential is largely unutilized today, but the government of Mozambique, who started to promote biofuels in 2006-2007, has set as a goal to prioritize biodiesel production as a mean to increase investments and incomes, and also to achieve a sustainable development of the country (AllAfrica, 2011).

Mozambique’s need for income opportunities for rural communities, and the country’s unused agricultural potential, makes the increased international demand for biodiesel hugely interesting. The Government of Mozambique believes that the biodiesel value chain can improve the living conditions in rural communities. (Adebo, 2010) Most of the biodiesel investments in Mozambique have until today...
been concentrated on large scale projects. Many of these projects have however had limited success in promoting rural growth, with low or unpaid salaries, and withheld promised community investments. There are also several more risks with investments into large scale than small scale biofuel projects, such as concerns with food security and land grabs (UNAC, 2009).

1.3. Purpose

The purpose of this study was to investigate whether biodiesel crops can be grown to reduce poverty, and if the production chain can be designed in a socially, environmentally, and financially sustainable way. The study aimed to further investigate how the biodiesel value chain can be designed to best benefit smallholder farmers and other rural stakeholders to promote rural development with respect to the sustainability obligatory. The purpose was to take into account the current conditions in Mozambique in order to use as many of the existing structures as possible, and to investigate what structures need changes in order to make the biodiesel value chain sustainable.

1.4. Thesis Statement

Is it possible to use the biodiesel value chain as a mean to reduce poverty in a socially, environmentally, and financially sustainable way in Mozambique, and how can the biodiesel value chain best be designed?

1.5. Delimitation

This study is delimited to analyze the value chain of biodiesel production in Mozambique using jatropha and Coconuts as biodiesel crops. All oil rich crops can be used for biodiesel production, but jatropha and coconuts were the crops with highest interest and highest potential in Mozambique. The study is delimited to investigate the primary activities of the value chain, hence only the process activities for the mass flow will be investigated. The analysis of these activities will further be delimited to cover the costs, the energy use and the CO2 emissions. The study will be delimited to cover the currently existing conditions and potential technical structures in Mozambique and will therefore not investigate possible risks such as political risks, thefts, economic development, or the development of the world market for oil.

1.6. Objectives

- Identify methods for reducing poverty with commercial means in rural areas in Mozambique
- Identify the current baseline conditions and situation of social development in rural Mozambique
- Identify currently existing technologies and structures for the biodiesel value chain in Mozambique
- Investigate which structures have to be developed and which additional technologies are needed to design a sustainable biodiesel production chain in Mozambique
- Define the biodiesel production chain, the flows of feedstock, cost, and energy, and its activities
- Define different scenarios for the biodiesel production chain
- Model the mass flow of the feedstock for the total production of biodiesel
- Calculate the total cost and the cost of each activity of the biodiesel production chain for the different scenarios
- Calculate the total use of energy and the use of energy for each activity use in the biodiesel production chain for the different scenarios
- Define the energy ratio of the biodiesel production chain’s end product and for the accumulated energy in each module for the different scenarios
- Calculate the total CO2 emission and the CO2 emission from each activity from the biodiesel production chain for the different scenarios
- Investigate which input variables have the largest impact on the total cost, and the total energy use of the biodiesel value chain.

1.7. Disposition

This report is divided into two main parts. The first main part consists of the two chapters; the “Mozambique” chapter and the “The Biodiesel Value Chain in Mozambique” chapter. In this part the qualitative findings from the literature study and from the field study are presented. The purpose of this part is to describe the current conditions in Mozambique, and to describe the biodiesel production chain with its different required activities.

The second main part of this report consists of the two chapters; the “Method” chapter and the “Result” chapter. In the “Method” chapter the design of the technical model, the definition of the different scenarios, and the construction of the sensitivity analysis are described. In the “Results” chapter the results from the sensitivity analysis, the results from running the scenarios in the model, and an analysis of the results are presented and discussed. The purpose of this part is to present the results generated from the model and the analysis of the quantitative results.

After the two main parts of the report the “Conclusion” chapter follows. In this chapter the whole study is analyzed and conclusions from both the main parts of the study are presented. The purpose of this chapter is to connect the literature study, the findings from the field study and the results and analysis from the technical part of this study, to answer whether it is possible to create a sustainable biodiesel production chain in Mozambique and how it best can be designed.
2. Mozambique

In this chapter the current baseline conditions and situation of social development in rural Mozambique, with respect to the different situations and instances that have a relation and potential impact on the biodiesel value chain and rural development, are presented. Through a literature study, and through interviews, needs and opportunities for development of rural family farmers in Mozambique have been identified.

2.1. Land Rights

All land in Mozambique is owned by the government, and since no land areas can be bought by any private person, company, or organization, farmers can not own the land of their farms. In many other countries farmers use their land as collateral in order to get loans and credits. The farmers in Mozambique do not have that opportunity and their chances to get credits for investments for their farming activities are limited. The land rights in Mozambique are, instead of rights to own land, built on a system with land use rights. Depending on different conditions and circumstances it is possible for land users such as farmers to acquire a contract that gives the user the right to use the land. This agreement is called a DUAT. It is also possible for other legal entities to acquire a DUAT, for example commercial companies that are aiming to start or expand their business. Although the regulations vary between different types of legal entities and the regulations of getting a DUAT is often more rigorous for larger commercial companies than for small family farmers. But, on the other hand, the capabilities to acquire DUAT’s can sometimes be low for family farmers in rural areas due to the low education level, unawareness of their rights, and low literate levels (USAID, 2007).

2.2. Food Security

Mozambique is one of the poorest countries in the world, and as a consequence of the civil war the country of Mozambique is also underdeveloped regarding its infrastructure (Trading Economics, 2011). As a cause of the low income and the lack of effective infrastructure, malnutrition is a major problem for the people in Mozambique. Up to 44 % of the children in Mozambique are suffering from chronic malnutrition (WFP, 2011), and about 52 % of the total population are suffering from under nourishment (FAO, 2011). This leads to a situation where a big part of the population does not reach their full physical potential. This in turn makes it difficult for many of the Mozambicans to develop productive businesses or manage hard full time jobs. Many households are therefore in need of an extra income to turn the negative trend (SR, 2011).

Because of globally increasing food prices, climate change, and a growing population there has, both in media and in each related academic discipline, been a strong debate concerning biofuel production from grown crops regarding food supply. One of the most discussed theories is that; production of bio fuel decreases the food supply of a country. Argumentation used to establish that theory is that; land for food production is used for fuel crops (UNAC, 2011). Another alternative theory concerning the impact on food supply from biofuel production holds that production of biofuel increases the food supply. The most commonly used argument in this discourse holds that biofuel production activities generate an increased income for the farmers. It is also commonly discussed that the biofuel production process could benefit the farmers through increased access to technology, information and better access to market (Neves, 2011).
The concept of food security is often misunderstood, and the term is often seen as a synonym to access to food. But the definition of food security is broader, and the concept is, in addition to access to food, also containing production of food and use of food. The reason is that, to achieve a sustainable food supply, there has to be a continuing production of food in order to obtain a supply of food and secure access to food. And to benefit from the access to food, usage of the food has to be carried out. Only having a batch of food transported to an area will in the short term initially increase the access to food, but not necessarily strengthen the food security. On the other hand, having a biofuel farm will not increase the local food production, but it could increase the access to and use of food for its workforce through a creation of a local market and ability to pay, and therefore strengthen the food security (Gouveia, 2011).

![Figure 1: Food security](image)

Figure 1: Food security

Mozambique has an area of 78 600 000 ha, which is about twice the size of Sweden, and a population of 23.4 million, which makes Mozambique a sparsely populated area. About 5.7% of the land area is cultivated, and about 49.6% of the land is forest area (World Bank, 2011c). A large part, approximately half of the land area in Mozambique, is used as pastures for cattle. Almost none of that area is fenced since cattle are supervised or tied when pastured (De Arauj, 2011a). The average of cultivated land per person is 0.2 ha (FAO, 2011). Mozambique is only using a small part of the potential arable land area for food production, and there is still a large potential of increasing the productivity of the cultivated land since the yields are currently very low (De Arauj, 2011 a.). Even though Mozambique has plenty of uncultivated fertile land the percentage of imported food of the used food in Mozambique is high (CSM, 2011).

It is clear that the question of how biofuel production affects food security is highly complex. Since the number of variables, of how biofuel production is operating in the communities, is extremely high, there is no unambiguous answer on what impacts biofuel production has on food security. In addition, the number of different strategies to carry out the production process and arrange the value chain is many, which increases the uncertainty of how the biofuel production affects the food security. As a result of the many interpretations of the different variables’ impact on food security, the opinions of different stakeholders are differing a lot. The Mozambican government has for example promoted the production of biofuel and biofuel feedstock farming as a developing tool, some NGOs are against biofuel production in developing countries and some NGOs think biofuel production can strengthen the food supply, profit making businesses are promoting different strategies for how the biofuel value chain should be designed and carried out, different associations take different positions (UNAC, 2011), and different researchers have different theories. One thing that is however clear is that the there is a need of further research in order to find a social, financial, and environmental long term sustainable design of the biofuel production value chain that will positively affect the food supply (Alves, 2011).
2.3. Poverty Reduction

Mozambique is considered by many as one of Africa’s few aid success stories due to its sustained growth, peace, and stability after the civil war ended (Renzio & Hanlon. 2007, p.2). The influx of Official Development Assistance, ODA, has hence been very large. Last year the Swedish government aid agency, SIDA, contributed 609 million SEK in ODA to Mozambique (SIDA, 2011), amounting to around 1% of Mozambique’s GDP (IMF, 2011). In 2009, 20% of Mozambique’s GDI was made up of ODA (World Bank, 2011a). The average ODA for the sub-Saharan countries is 2.9% of GNI (OECD, 2011). The ODA is distributed to different causes such as fighting HIV, building schools, improving living conditions of farmers, and also to budget support (SIDA, 2011).

The government of Mozambique, GoM, has together with the International Monetary Fund, IMF, developed an action plan, the Action Plan for the Reduction of Absolute Poverty, PARPA II. The action plan aims to reduce the level of absolute poverty in Mozambique. The plan includes ideas of how to increase farming productivity, decrease bureaucracy, and improve the education system and health service. The focus of PARPA II is to increase productivity in small, micro, and medium sized enterprises, and to work on the lowest level of the government, the district level. (IMF, 2007)

When it comes to rural development PARPA II has determined factors that are crucial for the development of rural areas. PARPA II emphasizes the complex relationships between smallholder farmers, other paid workers in rural areas, and the national and international markets as important to consider in issues regarding poverty reduction. It is also determined that it is crucial that the national economic growth will be inclusive for the rural population to benefit from the financial development, and for investments to be done in rural areas. PARPA II also stressed that the Government of Mozambique needs to invest in improving rural production, infrastructure, and institutional services. (IMF, 2007)

2.3.1. Family Farming

In the agricultural sector in Mozambique around 90% work in the family farming sector (IIASA, 2011). The average family farm in Mozambique has 1.2 ha of arable land (FAO, 2005) and consists of 4-5 people. The productivity of these farms is often very low. (De Arau, 2011a).

There are several causes for the low productivity of the family farms. The low rate of mechanization, the low access to tools, lack of irrigation, and the limited access to markets for both inputs and outputs, all contribute to a low productivity. As a result of the farmers’ low income, very few family farms have access to technology such as tractors. But even though the use of simple tools with extremely low cost, such as long handles for plough equipment, can increase productivity and reduce back injuries, many farmers also lack this type of tools. Due to the laws for land collateral in Mozambique credit is sparse and very hard to obtain for family farmers. This further complicates obtaining the necessarily tools to increase productivity (De Arau, 2011a).

The farmers’ limited access to the market has several consequences. If the farmers manage to produce a surplus over their subsistence farming, they have no market, or only a limited market, to sell their products on. There is also a lack of accurate price information, and the lack of infrastructure complicates the transportation of products to the closest markets. If the farmer manage to reach the market and sell their products they are therefore likely to get a price that undervalues their products. Another problem for the farmers is that they have inadequate access to inputs as well. This means that they have limited opportunities to buy better seeds, pesticides, and fertilizers that could increase their productivity. Since
Mozambique is a sparsely populated area, some farmers in remote areas could have 5-10 km to their closest neighbor, further complicating the market access issues (De Arauj, 2011.a).

In Tanzania, a similar but slightly more developed and more densely populated country than Mozambique, a study was conducted on how the information flow in rural areas work. The study found that there is a lot of information available in research institutions, universities and other public bodies, but very little of this is accessible to farmers. It was found that farmers obtained almost all their information through local means, such as neighbors and friends. The study identified the need to map the current knowledge, a stimulation of a local knowledge demand, and the adoption of new and differentiated communication means as a way to make the information flow more available (Lwoga et. al, 2011). A similar study in Mozambique that focused on the institutional framework for information sharing came to similar conclusions. The study found that information exists to a large extent, but the information sharing is largely informal and it can many times be hard to know who has the information, and how it could be obtained (Norfolk & Ribeiro, 2006).

One of the consequences of the market issues in Mozambique is the high transaction costs, i.e. the sum of all costs associated with an exchange, including marketing. These costs arise due to the lack of information, enforcement, market regulations, market failures, and lack of credit. If the transaction costs are high the incentives to sell products on the market will be less for farmers since the price they will obtain will be substantially below the nominal market price. These transaction costs that are especially evident in Sub-Saharan Africa are therefore a major barrier for smallholder farmers to access the market (Delgado, 1999, p.167-168).

### 2.3.2. Outgrower Schemes

An increasing number of academics, NGOs, and aid organizations have started to promote outgrower schemes as a way to reduce poverty through better market access for smallholder farmers. Outgrower schemes can take different forms and shapes. In general they can be described as some sort of vertical integration, through a long or a short term contract, between a landowner and a trader or processor (FAO, 2007). Outgrower schemes are hence a way to link smallholder farmers to global markets and international companies (Felgenhauer & Wolter, 2011). In some instances the buyer guarantees a minimum price beforehand, sometimes they buy for current market prices, and sometimes they buy for a set price. The outgrower company can provide the farmers with credits, inputs such as fertilizers and pesticides, technology and tools, and information and education. Other outgrower schemes can arrange for the basic logistics of buying the product (Brüntrup, 2006).

The outgrower companies are in general well suited to act as creditors since they can enforce the credit by deducting the debt from the farmer’s sales. This is a form of collateral that other credit institutes cannot easily use, which also makes the cost of default lower for outgrower companies than for banks. The contract for the credit can be arranged at the same time as the contract for the feedstock purchase, which lowers the administrative and transportation costs. These aspects eliminate a lot of the transaction costs normally associated by smallholder farmer’s credits (Key & Runsten, 1999, p.383-384).

Outgrower companies can also act as insurers. The market prices for cash crops are often volatile which can be a major problem for smallholder farmers. The farmers’ access to contracts, such as futures, to secure a certain price for the crop is very limited and expensive. There is also almost no possibility to insure against bad yields due to for example bad weather or natural disasters such as floods. The outgrower companies can due to their geographic spread and access to financial markets provide insurance to farmers through a contract below the spot market price. Since natural disasters, bad yields,
and market volatility usually affects the poorest farmers the most, providing insurance can be crucial to improving their opportunities and reducing their risks (Key & Runsten, 1999, p.385-386).

One type of outgrower scheme in Mozambique uses a system where the trader and the landowner agree on a price, quantity, and time of delivery before the start of the agricultural season. The trader then provides the inputs to the farmers, such as fertilizers and pesticides. The inputs are given to the farmers on credit, and are deducted from the price of the final deal. If the farmer chooses to sell to someone else they are allowed to do that, but they have to repay the trader (De Arauj, 2011.a).

Roger Peltzer, the Vice-President for the Africa-Department of the government owned development investment bank DEG, mean that the outgrower schemes have positive effects beyond the increase in access to markets, credits, and to inputs for the farmers. The outgrower schemes also affect the communities’ incitements in a positive way, where the local entrepreneurs are encouraged and rewarded. The outgrower schemes produces an environment where the conditions for an efficient organization are created, where productivity is increased, and where environmental concerns are more taken into account (Peltzer, 2011). The incitements for outgrower schemes can hence be a way to transfer assets from the international market to the farmers without creating the transaction costs through the wrong incentives that other asset transfers, such as aid, risks doing (Delgado, 1999, p.170).

There are however risks with outgrower schemes. Primarily there’s a risk with non-compliance from both parties. If the price and quantity is agreed upon in advance, the farmer might sell the feedstock to another trader if the price goes up, and if the price goes down the trader might renegotiate or buy from some other farmer (Peltzer, 2011). The best way to prevent this is to work to build up the long term confidence and trust of both parties. This demands a long term commitment by the outgrower company. Some companies report that it can take up to five years to set up a functioning supply chain in the outgrower sector in Africa (Felgenhauer & Wolter, 2011).
3. The Biodiesel Value Chain in Mozambique

In this chapter the current capabilities and constraints of the biodiesel value chain in Mozambique, found and investigated in this study, is described and illustrated. As seen in figure 2 the main steps in the biodiesel value chain in Mozambique are the farming process, the extraction process, and the refining process. Figure 2 also shows the value chain’s connection to the end consumer of the vegetable oil and the biodiesel.

Figure 2: The biodiesel value chain

All the steps in the biodiesel value chain described above already exist in Mozambique. Despite that, the different processes do not always cooperate with each other in a desirable way, and at the same time the transaction costs can be very high. What has been identified by this study as one of the weak links in the value chain is the flow of information. In general the problem is bigger closer to the farmer in the value chain, but as experienced by this field study, the problem with information sharing is evident and a problem in the whole Mozambican society.

As illustrated in figure 3 there are many stakeholders to consider in the biodiesel value chain. With the increasing debate of food security and climate change, the scope of NGOs and other opinion makers have increased drastically for the biodiesel value chain. For a biodiesel value chain to be successfully sustainable all the issues addressed by the different stakeholders have to be taken into careful consideration. The negative effects from the biodiesel production chain viewed in figure 3 are effects that could be negative for some, or all, of the stakeholders in the value chain, and the positive effects are effects that can be positive for some, or all, of the stakeholders. These effects are often complex and not necessarily independent on each other. For example the negative effect of land grabs could potentially lead to the positive effects of income opportunities and CO2 reductions.
3.1. Farming

This study encountered biodiesel companies working with two different types of crops for biodiesel production in Mozambique, namely jatropha and copra. These two crops were both used in small scale production, and also produced in large scale. Because of different use of different farming technology the farming practices differed significantly between the small and large scale production.

3.1.1. Large Scale Farming

This study only identified one successful large scale farming biodiesel company, Sun Biofuels. At the time for the field study Sun Biofuels had a production of 3000 ha of jatropha plants, and were looking to expand to around 11 000 ha (Gouveia, 2011). This project was cited by a variety of people as possibly the most successful large scale biodiesel production company in Mozambique.

One of the main problems for Sun Biofuels was to acquire more land to expand the farm on. As primarily the concerns over food security have grown, the local communities, government, NGOs, and other stakeholders have become more and more vocal in their critique of, and more reluctant to approve, land use for biofuel production (Gouveia, 2011).

According to a farmers union, UNAC (2009), the workers at Sun Biofuel's farm were paid the minimum wage. According to interviews conducted by them it was also apparent that the workers at the farm work 9 hours per day, which is one hour longer than legally allowed in Mozambique.

Sun Biofuel's jatropha farming was done with the help of fertilizers, pesticides, irrigation, and machinery such as tractors. The farm employed around 600 permanent workers and another 600 seasonal workers. The company expects to get yields of around 5 tons of jatropha per hectare and year, five years after plantation (Gouveia, 2011).
According to Sun Biofuels their jatropha farming project had several positive externalities. Sun Biofuels’ investments into their jatropha farming project had led to better access to market also for the local family farmers that were not involved in the jatropha farming project. The employment opportunities at the jatropha farming project had created incomes that generated a demand for products locally, which stimulated the local business environment. Since Sun Biofuels used pesticides, fertilizers, and food seeds at their farm, the access to crucial inputs had also greatly improved for the local family farmers since the supply of these goods increased. The seasonal workers at Sun Biofuels’ jatropha farming project also learned to use farming techniques and technologies, such as fertilizers and other tools, that they later also could use on their family farm (Gouveia, 2011).

In contrast to Sun Biofuels’ project there are also several examples of companies failing to grow jatropha on large scale farms in Mozambique. After the government started to promote biofuels in 2006-2007 some large scale projects were approved without much prior research being done. The large farms were placed primarily in Maputo, Gaza, and Inhambahne provinces. The placement of the farms did take economic factors into consideration rather than biological, as they were placed in proximity to good infrastructure, rather than on good soils and in a good climate (Alves, 2011).

Many of the failed companies had expected jatropha to be more of a wonder crop than it turned out to be. As the yields for jatropha in many cases turned out to take longer than expected and less than expected, many of the companies got economic problems (Alves, 2011).

### 3.1.2. Small Scale Farming

During the field study three projects for small scale biofuel production in Mozambique was studied; ADP’s jatropha project which helped to promote jatropha plantations in Cabo Delgado province, CleanStar Mozambique’s outgrower scheme project in Sofala province which cultivated cassava for ethanol production and pongamia for biodiesel production, and Hende Wayela that collected and processed copra in the Inhambane province.

ADPP is a Danish NGO which arranges farming clubs in 12 provinces in Mozambique. They currently have 12 000 farmers enrolled in the program where they educate the farmers in different farming techniques. For example, the farmers learn to grow crops in a more productive way, without the need for external inputs such as pesticides or fertilizers. ADPP also teach the farmers of how to grow, prune, and harvest the trees. ADPP have, in cooperation with FACT foundation, developed a program where they grew jatropha in hedges around smallholder farms that primarily grew food crops, in their farming clubs in Cabo Delgado province (Schurmann, 2011).

In total 600 000 jatropha trees have been planted in ADPP’s program, an equivalent of around 600 ha. The seeds from the jatropha grown by ADPP are used for production of diesel engine oil, soap, and lamp oil. ADPP arranged for the training, the investments into transportation, processing, and marketing the jatropha seeds (Schurmann, 2011).

All investments by ADPP were made as donations to provide an income opportunity for the farmers, and no financial return was expected. On average a family farm participating in ADPP’s jatropha program had around 350 jatropha trees. At the time of the field study the yield for one tree was around 0.5 kg per year, but the expectation is around 0.8-1 kg per tree and year once its full potential has been reached. ADPP paid 5 MTN per kg of seeds to the farmers. This currently gives the farmers an average income from the jatropha of around 875 MTN per year, and a potential income of around 1750 MTN once the full yields can be produced (Schurmann, 2011).
CleanStar Mozambique used an agroforestry system with a combination of food and biofuel production for its outgrower scheme. The feedstock was being purchased and processed by CleanStar at local community centers. At the time of the field study CleanStar had not started to market their products. The ethanol was going to be produced and sold from the end of 2011, and the pongamia had a longer lead time of further 4-5 years. (Laborda, 2011)

Hende Wayela was a company producing coconut oil in Inhambane province. The Portuguese had planted around 60 million coconut trees in the Inhambane province before Mozambique gained independence. Until a few years ago this was a largely unused resource. Hende Wayela had no own plantations at the time of the field study, but collected, processed, and marketed copra from around 5000 families that had coconut trees on their premises. Coconut trees can be intercropped with other crops such as cassava, and this type of intercropping can give these families an extra income opportunity (Herman, 2011). The families harvested the coconuts either by climbing up the trees and cutting of the coconuts that were ready, or by collecting the fallen coconuts from the ground. (Kritzinger, 2011)

Only 40% of the produced coconuts in Inhambane province are currently collected and used. Hende Wayela aimed at collecting some of the unused 60% by building 13 collection points, in addition to the currently existing ones, within transportation range of their factory in Maxixe. At the collection points the copra was bought from local traders and stored until tractors or trucks from Hende Wayela transported them to their factory for processing. It was not applied today but it was seen as a possibility that companies that are setting up collection points provide smallholder farmers with micro credits in order to increase the productivity at the farms. (Herman, 2011)

3.2. The Regulatory Process

The regulatory process was cited by several of this study’s interviewees as one of the main obstacles for running a business in Mozambique. The regulatory process is not a value adding part of the biodiesel value chain. The regulatory process can be beneficiary for some of the biodiesel value chain stakeholders, such as the labor that can benefit from work safety legislation that improves their working conditions, but this study has not identified that the current regulatory system noticeably benefit anyone other than the bureaucrats. (Macuacua, 2011)

To perform any kind of business activity in Mozambique a business- and location specific license is required. For example, if a trader wants to buy maize from farmers to sell on the local market, the trader needs to specify in the contract for the license where these farmers are located. Traders also have to specify where they have their office for their trading business located. But most of the traders in Mozambique have no office, and they are most likely buying more than one type of crop, and they are constantly changing customer base. In order to be a formal trader, traders therefore have to rent an office, and apply for licenses for each different type of crop they are buying from farmers. According to Eduardo Macuacua, an economist at the traders association CTA, this system incurs unrealistic costs for acquiring licenses, and for regulatory demands that are not needed, such as offices. The rules are very inflexible and the incitements for acquiring a formal business license are very unclear (Macuacua, 2011). The informal sector for small businesses in Mozambique is therefore enormously big, but at the same time the illegality is largely overlooked by the government (De Arauji, 2011.a).

For larger companies the number of licenses needed to run a business can be overwhelming. For example, to run a factory, it might be needed to have several different permits for the factory, several
different permits for the trading, and several different permits for the environmental aspects, etc. This study has identified that the amount of licenses and permits required led some government bureaucrats to use their position to get bribes, in order for them to speed up the process or be more flexible. If no bribes were paid the process to get these permits and licenses that in many cases should take no more than a day, could take several weeks. It was also reported that some officials refused to approve any document with even a very minor typo in it, no matter if it was applicant’s wrongdoing or not.

The traders association, CTA, promoted a system where there were no formal needs for starting a business except that you need to put your name and a company name on a paper. This would greatly increase the opportunities for informal businesses to go formal, and it would also greatly reduce the bureaucratic burden for bigger companies (Macuacua, 2011). An institutional framework where public officials have too much authority has also been identified as one of the main drivers of corruption. Limiting and simplifying the business license system could therefore also help to prevent corruption (USAID, 1999, p.7).

3.3. Processing

The first process activity after farming in the biodiesel production chain is peeling of jatropha or dehusking of coconuts. After the peeling or dehusking process the jatropha seeds and the copra are dried. After the drying process, when the feedstock has lost its moisture redundancy, the seeds are pressed and the oil is extracted. There are different techniques to extract oil from the biodiesel feedstock. The extracting process can use different techniques with different levels of advanced technology and it can be done in small or large scale. The two main products from the extraction process is vegetable oil and the byproduct called presscake. After the extraction process the vegetable oil can be refined and processed into biodiesel. (Zílio, 2008) The calorific value of biodiesel is 0.041 GJ/liter, and the calorific value of vegetable oil is 0.0395 GJ/liter (Rahman, Mashud, Roknuzzaman & Al Galib, 2010)

3.3.1. Peeling and Dehusking

The process of peeling jatropha or dehusking the coconuts is often carried out at the farm. At small scale farms the peeling and dehusking process was carried out by hand with the help of very simple tools such as hammer and machetes. At large scale farms more advanced tools for peeling and dehusking are an option, although no such tools were identified by this study. (Herman, 2011)

3.3.2. Feedstock Drying

The biodiesel feedstock has to be dried before it can be processed into oil and diesel. There are different techniques used for the drying process. The drying process can be carried out fully without any machinery in direct sunlight or in the shadow. The drying process can also be carried out partly with machinery, or fully by a machine (Kritzinger, 2011). For example, the coconut feedstock Copra can be naturally dried, in the sun, or artificially, with the help of hot air, fire, kiln or other drying equipment (TIS, 2011).

The drying process has a significant effect on the quality of the end products in the biodiesel production value chain. Therefore it is a crucial process that needs to be paid attention (Goda, 2011). For example, naturally drying and hot air drying process gives higher quality of the copra than fire or kiln dried copra (TIS, 2011). At the time of the field study several ideas and opinions of the best way of drying the feedstock were pointed out, and different techniques and methods were identified. One risk with the drying process pointed out was the risk of having the feedstock rotten if moisturized, for example if rain comes when stored directly under the sky with no protecting roof (Schurmann, 2011). At the time for the field study no training in drying techniques was identified. This study has also identified that there is a
need for more knowledge about how to handle the feedstock for drying to be able to control and ensure quality. The lack of information about how the feedstock best is stored is a major problem. If jatropha seeds or copra are stored incorrectly their quality will decrease which will decrease the value of the feedstock (Goda, 2011).

### 3.3.3. Oil Pressing - The Extracting Process

The technique for extracting oil is a value adding process. The oil has to be separated from the feedstock before it is useful and valuable for the customer. This study has analyzed the pressing process in both large scale processing plants and small scale processing plants. The different techniques for oil extraction can be divided into two groups; the mechanical pressing method, and the method of using chemicals for solvent extraction. This study only focused on mechanical pressing as the technique for oil extraction, since the effects on quality from chemical techniques are not covered and that type of technology was not identified in Mozambique. (Schurmann, 2011)

The different technologies used for oil extraction have different efficiency rates and different ability to extract different percentage of oil from the feedstock. It has been identified by this study that the optimal or most suitable technique, concerning efficiency rate of press and level of advancement of the technology, is not always used at the extraction plants. (Gouveia, 2011)

This study has investigated three different types of extraction technique; one manual, one simple machinery, and one advanced machinery. The different techniques differ in efficiency rate, in investment cost, and in capacity. The simplest method has the lowest efficiency rate, lowest investment cost, and lowest capacity. The most advanced method has the highest efficiency rate, highest investment cost, and highest capacity. (Gouveia, 2011)

One example of a small scale oil pressing plant is ADPP who uses simple machinery for its small scale oil extraction process. The machines used by ADPP are simple and uses a small diesel engine (Schurmann, 2011). Sun Biofuels is one example of a company using large scale oil pressing machines with more advanced technology (Gouveia, 2011).

### 3.3.4. Oil Refining

This study has found one biodiesel refining plant in Mozambique. That plant was located in the area of Maputo and was set up in response to the government promotion of the growth of biodiesel crops. Although at the time of the field study the refining plant was not running since it lacked of feedstock supply (James, 2011).

The biodiesel refining plant analyzed by this study was owned by Petromoc. It was solely a refining plant with no extraction capabilities. The capacity of the plant was 80 000 liters of biodiesel per day if using its full capacity. At the time for the field study the minimum volume per day in order for the plant to be profitable was 30 000 liter. But since the price of biodiesel is depending on the world market price for crude oil, which is highly volatile, the critical point of 30 000 liter can therefore change over time (James, 2011).

### 3.4. Trading

Trading is the exchange of goods between the activities in the biodiesel production value chain. The trading process is carried out between the farmer and extractor, between the extractor and the refiner, and
between the refiner and the end consumer (De Arauj, 2011.a). As identified earlier one of the main issues is that the flow of information from the consumer to the farmer is not working very well, which leads to a less profitable value chain.

### 3.4.1. Feedstock Trading

Most of the products sold by small scale family farmers were sold to informal traders. These informal traders used different means of transportation, but in general their access to capital was limited, hence the means of transportation were often simple. Many traders carried the feedstock by walking, used trolleys, or bicycles, and some traders used animals, tractors or trucks. The capacity of what distance these traders could travel, and how much they can carry therefore varies widely (De Arauj, 2011.b).

On the district level, which is similar to a municipality and is the lowest administrative level of the Mozambican government, it is more common with formal traders than among family farmers. The traders on district level in general have more access to capital, such as trucks to transport feedstock for longer distances. One common practice is that the family farmers sell their feedstock to informal traders, who then sell their products to formal traders that operate on the district level. The formal traders then sell their products to regional or national markets. It is also common that there are several, both informal and formal, traders in between two activities in the biodiesel value chain. The typical trading practice is illustrated in the figure below (De Arauj, 2011.b).

![Figure 4: The trading system for family farmers in Mozambique](image)

One problem that occurred for the farmer because of the trading process was the information asymmetry between the traders and the farmers. The traders usually knew the correct market price of the product, while the farmers did not. Consequently it was common for farmers to get underpaid for their feedstock. As the information asymmetry has been identified as a major development problem, there were programs aimed at improving information sharing to the farmers. For example information about market prices was supplied to farmers by the government through radio broadcasts, bulletin boards, newspapers, and the Internet (De Arauj, 2011.a).

As described earlier in this paper the information sharing is largely informal in Mozambique, particularly in rural communities where neighbors often are the only source of information. This means that the only information available for farmers in some cases is information from the direct competitors on the local
market. However, if the products are sold to a national or international market this sense of competition will decrease and the local competitors will have a common interest to share the correct information (Degado, 1999).

For small scale biofuel production these informal and existing trading systems are largely dysfunctional. There are examples of farmers that, due to a government initiative of handing out jatropha seeds for free, have feedstock to sell, but no one to sell it to (Goda, 2011). The only cases this study has seen where the biodiesel trade with family farmers work, has been where the trade has been conducted by a company in a specific area in the cases of ADPP (Schurmann, 2011), CleanStar Mozambique (CSM, 2011), and Hende Wayela (Herman, 2011). All three of these companies however used some of the informal trading structures that already existed, but provided the access to regional, national, or international markets. As illustrated in the figure below this trade was done by using collection points to collaborate with the local traders and/or farmers.

According to the trading association, CTA, the trading with cashew nuts was one of the few well-functioning small scale value chains in Mozambique. The main reason why the trade with cashew nuts worked well was because the product was very uniform, i.e. the quality does not vary with any significance and it was very easy to handle the nuts without any particular training (Macuacua, 2011). This suggests that one of the main problems with dysfunctional value chains are the lack of information and correct training.

The large scale farming trading works very differently from the small scale trading. Sun Biofuels collected their own feedstock at their own farm, and also extracted the oil from the feedstock at the farm. The value chain steps, farming, trading, and processing are therefore conducted internally within the farm, as illustrated in figure 6 (Gouveia, 2011).
### 3.4.2. Vegetable Oil Trading

The vegetable oil extracted from jatropha and copra can be sold either directly for consumption, or further processed into biodiesel. The oil extraction companies this study investigated used different methods for trading with the vegetable oil.

Sun Biofuels had at the time of the interview just sold their first batch of jatropha oil, to Lufthansa. The 30,000 tons of jatropha oil were being exported to Europe, where it was to be refined into jet fuel (Gouveia, 2011).

ADPP extracted the oil from the jatropha seeds locally, and sold the oil to local consumers either as soap, a substitute for diesel-oil, or as lamp oil. In the case of soap the oil had to be converted into soap before it could be sold to the consumer (Schurmann, 2011).

Hende Wayela sold the extracted coconut oil to a South African oil broker, who sold it to different customers on the international market. The transportation and delivery was arranged for by Hende Wayela but the customers were arranged by the oil broker (Herman, 2011).

### 3.4.3. Biodiesel Trading

This study only found one biodiesel refining facility in Mozambique. The facility was operated by Petromoc, a state-owned oil company primarily involved in fuel retailing. The factory was at the time of the field study not being used as Petromoc could not get access to any vegetable oil to process. They were however in the process of investigating the possibility to buy vegetable oil from South Africa. Petromoc’s aim was to sell the biodiesel primarily as a blend-in in petroleum diesel to local customers at their petrol stations (James, 2011).

### 3.5. Transportation

A wide range of transportation methods are used in Mozambique. The many different options for transportation are mainly a result of the country’s poorly developed infrastructure, but also a result from the stakeholders’ lack of capital. As an example of the poorly developed infrastructure only 32 % of the population has less than 2 km to the nearest road, and many places are not even accessible by tractor (EEAS, 2011). As a result of the lack of capital the farmers have difficulties to do investments in more efficient transportation technology with higher capacity such as trucks (De Arauj, 2011).

The transportation system for the biodiesel value chain is closely connected to the infrastructure in Mozambique. One problem identified is that the infrastructure was poor in the areas of fertile land, and in the areas with less suitable land for growing biodiesel crops the infrastructure was more developed. One example of how this inefficiency was causing weak links in the system of biodiesel production in Mozambique was that Petromoc’s refining factory was located in Matola. The factory was built close to the capital where the infrastructure is good, i.e. the roads are in good condition and the city is located close to the coast and the Maputo port. At the same time the feedstock production was carried out at another location, far from Maputo, where the land was fertile and suitable for the crops. The problem in this case was that many of those areas where the feedstock production was carried out had no efficient infrastructure, and therefore no efficient transportation process can be carried out between the production location and the location of the factory. As a result of this some plantations have been put up in areas with good infrastructure to create an efficient transportation process. The result from those projects was poor yields from the harvests and the plantations turned out to be unprofitable. (Tsamba, 2011)
The poorly developed infrastructure also has an effect on the supply of spare parts for technology used for biodiesel production in Mozambique. The manufacturing of spare parts domestically in Mozambique is very low, and the demand for spare parts was low as well, so no retailers were storing spare parts to supply the market. In most cases spare parts for biodiesel production technology therefore had to be imported. This was a major inefficiency since there was a high risk that breakdowns cause expensive production stops. It was for example common that someone had to travel in person to South Africa to get the spare part to the factory. (Kritzinger, 2011)

3.5.1. Transportation of Feedstock

As described in the trading section of this report the transportation options for biodiesel feedstock in Mozambique are depending on the scale of the farming operation. From small farms in rural areas transportation by bike, with cattle, or fully manual by walking and carrying the feedstock are the most commonly used options. These low capacity transportation options are often used between the farming point and the closest road at which point a shift of transportation method was made and a transportation option with higher capacity such as tractor or truck was taking over (De Arauj, 2011).

As illustrated in figure 6 under the trading section, large scale industrial farms, such as Sun Biofuels’, have its extracting facility in connection to the plantation and the transportation process works internally within the farm (Gouveia, 2011).

In outgrower schemes many different transportation options are combined and used in cooperation to collect the feedstock from small farms and transport it to larger processing plants. In the collection point systems transportation methods with lower capacity are often used to transport the feedstock between the farm and the collection point. Furthermore the transportation method used between the collection point and the processing plant often has higher capacity. As an example, Hende Wayela used vehicles with high capacity to transport the collected feedstock from the collection points to the factory for oil extraction. In the areas with more developed infrastructure trucks were used, and in the areas with poorly developed infrastructure tractors were used. Each collection point had the capacity of 20 t each and the trucks had the capacity of 6 t each. The transportation methods used between the farmers and the collection point had much lower capacity hence the number of transportation operations into the collection point were higher than the number of transportation operations to the oil extraction factory (Herman, 2011). The copra can be transported both as break-bulk cargo, commonly packaged in woven bags of natural materials or plastic, or as bulk cargo (TIS, 2011).

3.5.2. Transportation of Vegetable Oil and Biodiesel

Since the chemical structure of biodiesel is similar to petroleum diesel the same transportation methods can be used for biodiesel as for petroleum diesel. However not all the transportation methods suitable for biodiesel can be used for petroleum diesel since petroleum diesel is classified as a hazardous liquid and biodiesel as a nonhazardous liquid. The same transportation methods as for biodiesel can therefore also be used for transportation of the vegetable oil since vegetable oil is also classified as nonhazardous. The transportation of vegetable oil and biodiesel can therefore be done in several different tank models customized for nonhazardous liquid fuel (Wilkie, 2011).

The shipment of the fuel can be done either by road or by sea. Since Mozambique is a long country, geographically located by the coast, there are potentially high capabilities to transport goods by sea. The country has 5 larger ports spread along the coast with the most southern port in Maputo and the most northern port in Pemba. From the Mozambican ports shipments can be done both to international ports
and internally between the domestic ports, but since some of the ports are in bad condition the transportation capabilities are not fulfilling the potential (Dibben, 2007). The cost of transportation by sea is lower than transportation by road. But transportation by sea means a much higher risk, since there is a higher uncertainty in the on time delivery when shipping by sea than transporting by road (Demaeyer, 2011).

At the time of the field study the domestic capability to transport oil and biodiesel through tankers, tanker trucks, and tanktainers in Mozambique was very low. Only one transportation company with an established business of liquid transportation fuel in bulk and with own vehicles was identified at the domestic market in Mozambique. That company was working for several of the big fuel retailing companies. For example Petromoc, who both provided its own profit making petrol stations and FUNAE’s nonprofit making petrol stations with fuel, used tanker trucks from that only transportation company (Tsamba, 2011). In addition, a small number of transportation and shipping companies, using external capabilities to set up transportation solutions were identified, but these companies had limited experience in liquid fuel transportation.

3.5.3. Storing

The storing time, and the method for storing the biodiesel feedstock, have a considerable effect on the quality of the feedstock, and hence also the quality of the vegetable oil and the biodiesel. The methods and recommended time for storing biodiesel feedstock differs between the different crops. For example, if the jatropha seeds are not stored right there is a risk that the acid content in the seeds increases, which will decrease the quality of the vegetable oil and biodiesel (Goda, 2011).

Since the chemical structure of biodiesel is similar to petroleum diesel the storing methods used for petroleum diesel can also be used for biodiesel. Hence tanks at the refinery and at the petrol stations are suitable storing options for the biodiesel. However, since biodiesel is classified as nonhazardous and petroleum diesel is classified as hazardous it is not always the case that storing options customized for biodiesel can be used also for petroleum diesel (Willkie, 2011).

3.6. Markets

This study has covered the domestic and international markets for biodiesel, vegetable oil, and biodiesel feedstock in Mozambique. Mozambique has a domestic need for biodiesel and is currently importing fuel for its own usage. Depending on the prices, the domestic demand could potentially be covered by fuel produced in Mozambique. Depending on the prices, and a possible surplus of production, there is also an international market for the biodiesel and the biodiesel feedstock (Van der Putten, 2010).

As seen in table 1, table 2, and table 3 the total price of petroleum diesel consists of several different factors. The process activities in table 1 for production of imported petroleum diesel are the same type activities as in the biodiesel production chain in Mozambique. The prices in table 2 are the taxes and fees associated with imported petroleum diesel, and table 3 presents the total price of petroleum diesel for the end user. For the biodiesel production chain to be financially sustainable and work as a developing tool for rural farmers the total cost of the biodiesel value chain has to be competitive with the cost of the imported petroleum diesel. If the total cost of the biodiesel value chain is lower than the price of the petroleum diesel it is competitive. But it is also possible that the taxes and fees can be lower for the biodiesel than for the petroleum diesel, and therefore it is possible for the biodiesel to be competitive even if the process activity prices are higher since the total price can be lower thanks to lower taxes and fees. (Zílio, 2008)
### Process activity prices:

<table>
<thead>
<tr>
<th>Description</th>
<th>USD/liter petroleum diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base price (CIF)</td>
<td>0.586</td>
</tr>
<tr>
<td>Wholesaler’s margin</td>
<td>0.086</td>
</tr>
<tr>
<td>Retailers’ margin</td>
<td>0.051</td>
</tr>
<tr>
<td>Transportation differential</td>
<td>0.008</td>
</tr>
<tr>
<td>Port fees</td>
<td>0.029</td>
</tr>
<tr>
<td>Losses and rounding</td>
<td>(0.016)</td>
</tr>
<tr>
<td>Sum</td>
<td>0.744</td>
</tr>
</tbody>
</table>

**Table 1: Breakdown of petroleum prices in Mozambique**

### Prices for taxes and fees:

<table>
<thead>
<tr>
<th>Description</th>
<th>USD/liter petroleum diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Import tariff</td>
<td>0.029</td>
</tr>
<tr>
<td>IVA (import, wholesale, retail)</td>
<td>0.134</td>
</tr>
<tr>
<td>Fuel Tax (TSC)</td>
<td>0.141</td>
</tr>
<tr>
<td>Sum</td>
<td>0.304</td>
</tr>
</tbody>
</table>

**Table 2: Breakdown of petroleum taxes in Mozambique**

### Sum of process activity prices and prices for taxes and fees:

<table>
<thead>
<tr>
<th>Description</th>
<th>USD/liter petroleum diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total price to end user</td>
<td>1.048</td>
</tr>
</tbody>
</table>

**Table 3: End user price of petroleum in Mozambique**

In figure 7 it can also be seen that the price of petroleum diesel differs a lot in Mozambique. It can for example be seen that the price of imported petroleum diesel is much higher in the inland of Mozambique, and lower close to the ports. Therefore it is easier for domestically produced fuel to be competitive in the inland of Mozambique than close to the ports.
3.6.1. Domestic Market for Vegetable Oil and Biodiesel

This study has investigated the domestic market for biodiesel and for vegetable oil for fuel usage. Both the vegetable oil and the biodiesel can be used as fuel in diesel generators and in some other diesel machines. The biodiesel can also be used as a blend in fuel in the petroleum diesel for cars and trucks. It is also possible to use the pure vegetable oil as fuel in cars and trucks if their fuel system is converted (Schurmann, 2011). The government has decided on a 10 % blending mandate of biodiesel into the petroleum diesel at the year of 2012 (De Arauj, 201). Today all the domestically used diesel is imported (Gouveia, 2011).

The price of biodiesel is correlated with the oil price, but since vegetable oil is an ingredient in several products besides biodiesel, other markets are at some points offering a higher price for the vegetable oil than the biodiesel market does. At those points the vegetable oil is sold to other markets. As an example,
at the time of the field study the Petromoc refining plant was not in use because it lacked of feedstock since the price of coconut oil had gone up because of an increasing demand from the health and cosmetic industry (James, 2011).

3.6.2. International Market for Vegetable Oil and Biodiesel

There is an international demand for biofuels such as biodiesel. Several countries have decided on a biodiesel blend in mandate for petroleum diesel. In 2003 the European Union decided on a target of 5.75% blending of biodiesel within the petroleum diesel (EU, 2006), and several of the member states have further increased their blending mandate (Biodiesel Magazine, 2011). As a consequence to that demand both feedstock and extracted oil from the Mozambican market has been sold on the international market. The reason for exporting the feedstock or oil is in some cases that the capabilities for extraction and refining domestically are limited. In other cases the reason for exporting the feedstock or oil instead of refined biodiesel is that the connection, the cooperation, and the communication between the different activities in the biodiesel value chain, such as between the collection of feedstock and the extraction facility, are too weak or nonexistent. One example of export of vegetable oil is the Sun Biofuel 30 ton oil shipment to Lufthansa in July 2011 (Gouveia, 2011).

3.6.3. Market for Byproducts

This study has investigated what byproducts from the biodiesel production chain are currently used for in Mozambique and the potential markets for the byproducts. Three main potential usage of the presscake from the biodiesel crops jatropha and copra has been identified. The presscake can be used for fertilizer, cattle food, and biomass (Gouveia, 2011). Since the jatropha seeds are poisonous, there was no example of usage of jatropha presscake as cattle food at the time of the field study. Although there is an interest and ongoing research projects on developing toxic free jatropha seeds (Goda, 2011). The jatropha presscake has an energy content of 20-25 MJ per kg (Putten, 2010), and the coconut meal has an energy content of about 16 MJ/kg (Raghavan, 2010).

The byproduct from the extracting process can hence be used for different applications, but it has been identified that the presscake in many cases is not taken care of. During the refining glycerol is formed as a byproduct because of the chemical reactions. The glycerol could for example be used to make soap, but no such application was identified in the field study (James, 2011).
4. Method

To investigate the biodiesel value chain in Mozambique, a scalable model was set up with the simulation program Stella. The input variables for the model, see Appendix A,B,C, were found in the literature study and during the field study executed in Mozambique. The variables found in the field study were collected through interviews with different stakeholders and by observations on visited plants.

The model is designed to simulate the flow of feedstock from both jatropha and coconuts since the use of both crops were identified as feedstock to biodiesel production in Mozambique. The processes of producing oil and biodiesel from jatropha and from coconuts are very similar, only some input variables differ, which will be considered in the model.

The aim of this model is to define the biodiesel production chain as a scalable simulation tool in which different scenarios easy can be set, and different input variables easily can be changed. The aim of the model is furthermore to calculate and plot the total cost, and the cost of each activity, of the biodiesel production chain for the different scenarios. The aim is also to calculate and plot the total use of energy, and the use of energy for each activity, in the biodiesel production chain for each scenario. The model is also constructed to calculate the total CO2 emission, and the CO2 emission from each activity, of the biodiesel production chain for the different scenarios. The purpose is to investigate which activities have the largest cost, requires the most energy, and which activities contribute with the largest CO2 emission.

4.1. Main Structure of the Model

The model is a structured description of the biodiesel production chain from one hectare of land described over a ten year period. The model consists of three main modules; the farming module, the extraction module, and the refining module. Through these three modules five different flows; the mass flow, the cost flow, the diesel flow, the electric flow, and the embedded energy flow are defined. Two end consumers are defined in the biodiesel production chain; the oil consumer and the biodiesel consumer. The potential use of the byproduct presscake is also included in the model. To summarize the data from the model the modules are connected to a summarize module in which all the data is analyzed, see figure 8. The data is sent to the summarize module through summarize flows which are summarizing all values in each module. Thanks to the summarize flows each model can be analyzed separately.
Figure 8: The main structure of the model

All five flows go through the three modules. In each module each flow has different activities that add different values to the total accumulated value for each flow. Exceptionally the electricity flow has no activity in the farming module, and the embedded energy flow has no activity in extraction module, see figure 14 and figure 15. An example of one activity is the “cost of preparing and maintaining land” activity in the farming module, see figure 16. The activities are defined by different sub-activities and different input variables. The input variables are fixed values, such as “cost of using an ox”, see figure 16 and appendix A,B,C, and the sub-activities are defined by, and get their values from, other input variables, and from other sub-activities, such as “preparing labor time”, see figure 16 and appendix A,B,C. In the model the equations for the activities, the equations for the sub-activities, and the input variables can be found under each respective icon in the Stella model. Many of the equations for the activities and sub-activities contains conditional statements such as “if”, “else” etc., since some equipment, tools, and techniques are incompatible. All the equations for the activities can be found in appendix D,E,F.

The summarize module is also constructed to calculate the CO2 emission from the biodiesel value chain. Each energy flow contributes to the total CO2 emission for each produced liter of oil and for each produced liter of biodiesel. Each type of energy flow has a specific emission ratio measured in kg CO2 per produced liter. Each respective emission ratio is multiplied with the total energy use for each flow in
each module, and summarized in the summarize module. With this method the CO2 emission can be analyzed both as a total, and also for each module and flow.

To make it easily to set and change different scenarios for simulations in the model, the model has an interface connected to its modules where input variables easily can be set and changed, see figure 9. In this interface results from the different scenarios can also be generated and further analyzed by letting the data values be plotted in graphs, see figure 10. When running the model, the data values plotted in the graphs are also saved in tables. To generate cleaner charts for the report, that are easier to interpret than the graph shown in figure 10, the data values in the tables from the different runs are transferred to an excel document where more visual charts are generated. Those charts are presented in the result and conclusion part of the report.

![Figure 9: The interface where different input variables can be changed to simulate different scenarios](image)
4.2. The Flows in the Model

In this chapter the model's five different flows and the construction of the equation system to calculate the accumulated values for the different flows will be presented.

4.2.1. The Mass Flow

The mass flow is the main flow in the production chain and consists of the biodiesel feedstock measured in kg. The mass flow of the feedstock starts in the farming module as jatropha and coconut crops, and is further in the value chain converted through the model's activities into oil and biodiesel. Through the mass flow different byproducts, such as moisture, presscake, and glycerol, are diverted from the main mass flow into new flows, where presscake is the only byproduct simulated for potentially use. The activities with mass diversion are marked with an arrow icon in the figure 11. The two end markets for the production chain are marked with a circle with an x.
Figure 11: The models mass flow with the three modules, and its 15 activities

For further details about the construction of the flow and connections between its activities, sub-activities and the input variables see appendix D,E,F. The calculations behind the different activities MFP, MFH, MFS, MFT, MED, MEP, MEO, MES, MET, MEM, MER, MRT, MRR, MRS, and MRM can be seen in appendix D,E,F.

4.2.2. The Cost Flow

As shown in figure 12 the cost flow consists of 14 activities that all add different costs in USD to the product.

Figure 12: The models cost flow with the three modules, and its 14 activities
The total cost $C$ of the biodiesel production chain is calculated by adding the cost of each module. For calculation of the total cost of the biodiesel value chain the total cost of farming, $CF$, the total cost of extraction, $CE$, and the total cost of refining, $CR$, are hence added as seen in equation 1. See appendix D,E,F for more details of the construction of $CF$, $CE$, and $CR$.

$$C = CF + CE + CR \quad \text{Equation 1}$$

The cost of each module is calculated by adding the cost of each activity in the module, and the cost of each activity is based on the sub-activities and the input values connected to the activity.

Total cost of farming $CF$ is calculated as below in equation 2 by adding the costs of the activities Cost of preparing and maintaining land $CFP$, Cost of harvesting feedstock $CFH$, Cost of processing and storing feedstock $CFS$, and Cost of processing and storing feedstock $CFT$. See appendix D,E,F for more details of the construction of $CFP$, $CFH$, $CFS$, and $CFT$. The same principle is used for calculation of $CE$ in equation 3, and for calculation of $CR$ in equation 4.

$$CF = CFP + CFH + CFS + CFT \quad \text{Equation 2}$$

$$CE = CED + CEP + CEO + CES + CET + CEM \quad \text{Equation 3}$$

$$CR = CRS + CRR + CRD + CRI \quad \text{Equation 4}$$

For further details about the construction of the flow and the connections between its activities, and sub-activities see appendix D,E,F. And for further details about the activities’ and sub-activities’ input variables see appendix A,B,C. For further details about the underlying equations for the activities $CFP$, $CFH$, $CFS$, $CFT$, $CED$, $CEP$, $CEO$, $CES$, $CET$, $CEM$, $CRS$, $CRR$, $CRD$, $CRT$ see appendix D,E,F. The same concept for calculations as described in this chapter is used for the diesel flow calculations, the electric flow calculations, and the embedded energy flow calculations, since the structure of the modules, the activities, the sub activities, and the input variables, is the same.

### 4.2.3. The Diesel Flow

As seen in figure 13 the diesel flow consists of five activities that accumulate the use of diesel in liters through the whole flow chain. This diesel is the diesel used in the different process activities in the biodiesel production chain, such as the diesel use in tractors for plowing and transportation. As in the cost flow, the total diesel usage is calculated by adding the diesel used in each activity in the value chain.
The total diesel input for the biodiesel value chain $D$ is calculated as below in equation 5.

$$D = DF + DE + DR$$  \hspace{1cm} \text{Equation 5}

The total diesel use in farming $DF$, in extraction $DE$, and in refining $DR$ is calculated as below in equation 6, equation 7, and equation 8 respective.

$$DF = DFP + DFH + DFT$$  \hspace{1cm} \text{Equation 6}
$$DE = DET$$  \hspace{1cm} \text{Equation 7}
$$DR = DRT$$  \hspace{1cm} \text{Equation 8}

For further details about the connections between the activities, sub-activities and input variables in the flow see appendix D,E,F. More details about the input variables for the activities and sub-activities in the diesel flow can be seen in appendix A,B,C, and for further details about the underlying equations for the activities DFP, DFH, DFT, DET, and DRT see appendix D,E,F.

4.2.4. The Electric Flow
As shown in figure 14 the electric flow consists of three activities that accumulate the use of electricity in kWh through the whole flow. In the extraction module the electricity is generated from diesel generators and in the refining module the electricity is taken from the national grid. In the summarize module the electricity is converted to the primary energy it takes to produce the electricity. All grid electricity in Mozambique are produced by hydropower, hence the primary energy needed to produce 1 kWh of grid electricity is lower than what is needed to produce 1 kWh of electricity from a diesel generator. By converting all energy into primary energy the electric energy can be added up together with the diesel energy and the embedded energy.

![Figure 14: The models electric flow with the two modules, and its three activities](image)

The total electric input for the biodiesel value chain $E$ is calculated as below in equation 9.

$$ E = EE + RR $$  \hspace{1cm} \text{Equation 9}

The total electric input from extraction $EE$ and the total electric input from refining $ER$ is calculated as below in equation 10 and equation 11.

$$ EE = EES + EEP $$  \hspace{1cm} \text{Equation 10}

$$ ER = ERR $$  \hspace{1cm} \text{Equation 11}

For further details about the connections between the activities, sub-activities and input variables see appendix D,E,F. More details about the input variables for the activities and sub-activities in the electric flow can be seen in appendix A,B,C. For further details about the underlying equations for the activities $EES$, $EEP$, and $ERR$ see appendix D,E,F.

**4.2.5. The Embedded Energy Flow**
As shown in figure 15 the embedded energy flow consists of two activities that accumulate the energy from use of different chemicals, such as fertilizer, pesticides and chemicals for the refining process. To calculate the total use of embedded energy for the whole biodiesel value chain the value of the two activities in the electric flow can be added.

\[ B = BF + BR \]  
\text{Equation 12}

The total embedded energy input from farming BF and the total embedded energy input from refining BR can be seen below in equation 13 and equation 14.

\[ BF = BFP \]  
\text{Equation 13}

\[ BR = BRR \]  
\text{Equation 14}

For further details about the construction of the embedded energy flow, sub-activities and input variables see appendix D,E,F. More details about the input variables for the activities and sub-activities can be seen appendix A,B,C. For further details about the underlying equations for the activities MFP and MRR see appendix D,E,F.

For further details about the connections between the activities, sub-activities and input variables see appendix D,E,F. More details about the input variables for the activities and sub-activities in the electric flow can be seen in appendix A,B,C. For further details about the underlying equations for the activities EES, EEP, and ERR see appendix D,E,F.
4.3. The Structure of a Module

Figure 16 shows a part of the farming module concerning the growth and maintenance of the biodiesel crops. This chapter will explain this part thoroughly in details. As the rest of the model is built up with the same principles as this part all parts will not be described in details. This is to avoid too much repetition in the method chapter. The formulas, calculations, and data for the all activities in the model can be found in appendix A-F. The model has a scalable construction, and hence it is easy to change the difference input variable values to try new specific scenario or update the values if new data is available.

Figure 16: The start of the farming module with mass flow, cost flow, diesel flow, and embedded energy flow, different activities, sub-activities, and input variables.

In figure 16 the mass flow can be found at the top of the figure. This mass flow in the figure is also the start of the flow and is dependent of the farming activities. The mass flow is regulated by the “Planting and maintaining feedstock” activity, illustrated as a valve in the figure, which in turn is dependent on the productivity of the one hectare of land that is modeled. In figure 16, and throughout the model, this dependence is illustrated by the arrows that goes from the “Productivity” to the “Planting and maintaining feedstock”.

The productivity of the land is based on the input variable base yield and the input variable increase in productivity, brought out by farming activities, such as fertilizing and pruning. The input variables for fertilizing and pruning can be turned on or off in the interface in order to evaluate what their impact of the whole value chain is. Some of the sub-activities and input variables that can be turned on or off also affect other parts of the model, such as how much labor is needed, what the cost will be, and what the energy inputs are. Examples of these on or off variables can be seen below the productivity activity in figure 16, named “Pesticides”, “Fertilizers”, “Type of mechanization”, “Irrigation” and “Pruning”. They
can be set to the value 1 or 0, where 0 represents that the activity is not performed (off), and 1 represents that the activity is performed (on). For a visual view of the interface see figure 9.

To the right in figure 16 there are two different calculations for labor time, one for growing jatropha; “Jatropha labor time”, and one for growing coconuts; “Coconut labor time”. The labor time needed to grow one hectare of the plant is dependent on different factors such as the level of mechanization and what chemical inputs are used. So for example if a tractor is used instead of a hand plough, the labor time for ploughing is reduced. These factors are also different for the different plants, as the planting and maintaining practices are vastly different between jatropha and coconut trees.

The cost flow activity “Cost of preparing and maintaining land” can be seen in the lower middle of figure 16. The cost flow is dependent on all cost drivers in the shown part in the model. This means that if something changes, for example if more labor is needed, or if the salary goes up, the total calculated costs will increase. The total cost is also dependent on what activities are performed. For example, if pesticides are used the labor cost will decrease because of less weeding, and the costs for using pesticides will increase. By this the model gives an opportunity to test different scenarios and evaluate what the best options for designing the biodiesel value chain are.

The diesel flow activity “Diesel input for preparing and maintaining land” works in a similar way as the cost flow, where all the activities that consume diesel generate a flow of diesel accordingly. The embedded energy flow activity “Embedded energy input for preparing and maintaining land” works in the same way where all the activities generating an input of embedded energy affects the flow.

The cost flow, diesel flow, and embedded energy flow all generate flows that are accumulated when running the model to the total costs, total diesel input and total embedded energy input. The values from the simulation runs are saved to make it possible analyze the total use over time. When the values from the flows are accumulated the different flows in the model can be compiled to see what sections are most cost and energy driving. To make it easier to compile and analyze data the flows are also connected to a summarizing flow that summarizes the whole farming module. The summarizing cost and energy flows are then connected to the summarizing module described earlier which is summarizing the data from the whole model.

4.4. Definition of Different Scenarios

To study the biodiesel value chain the different costs, the use of energy, and the CO2 emissions from the biodiesel value chain are calculated. For calculation of these values and for investigation of the impact from different input variables different scenarios are set up for test and analysis through simulation runs in the model. The different scenarios are set up module by module to make it possible to analyze both the total biodiesel value chain and each module separate.

4.4.1. Definition of Farming Scenarios

The scenarios for the farming module are divided into two small scale scenarios and into two large scale scenarios, and will in the analysis be done separate for jatropha and coconut. The farming scenarios and the input values for each scenario are described in table 4. Pruning is applied in all scenarios, but is only used for jatropha. The reason for including pruning in all scenarios is because it greatly affects the yield and can easily be carried out with little training and simple tools. Irrigation is only used in the large scale scenarios since the technique was not found suitable for small farms in Mozambique, but commonly used in the large scale farms.
The simple small scale scenario was experienced by this study as the most commonly represented farming practice in Mozambique today. The typical small scale farmers did not have access to inputs such as fertilizers or pesticides, and most of the feedstock trading was carried out by simple transportation means such as walking and trolleying. In the small scale scenarios the extraction facility is assumed to be within a 120 km distance from the farmers. This distance is based on the average distance for ADPP’s small scale farmers to their extraction facility, and the transportation means and distances used in the small scale scenarios are based on research done by De Arauj, B.

The advanced small scale scenario is based on a potential hypothetical scenario where the farmers have access to more inputs and tools than in the simple small scale scenario. In the advanced small scale scenario farmers use fertilizers and pesticides and tools for harvesting. It is also assumed that collection points are used in this scenario, similar to the type Hande Wayela used. These collection points make the transportation more efficient, since less walking and more tractors and trucks are used. However, the farmers in the small scale advanced scenario still have no access to farming machinery with high upfront investment cost, such as tractors for cultivation.

The large scale farming scenarios are largely based on the conditions on Sun Biofuels’ farm. In the large scale farming scenarios fertilizers, tools, and tractors are used. It is also assumed that the extraction facility is located at the farming facility. The difference between the two large scale scenarios is the salary. The reason for simulating this difference is to test what is happening if salaries in Mozambique goes up, in order to investigate if jatropha and coconut cultivation will stay sustainable in the long term with a rising salaries.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Fertilizers</th>
<th>Pesticides</th>
<th>Irrigation</th>
<th>Harvesting tools</th>
<th>Pruning</th>
<th>Salary (USD/month)</th>
<th>Type of machinery for cultivation</th>
<th>Transportation to extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small scale (Simple)</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>73</td>
<td>None</td>
<td>None</td>
<td>15 km walking, 20 km trolleying, 85 km trucking</td>
</tr>
<tr>
<td>Small scale (Advanced)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>73</td>
<td>None</td>
<td>None</td>
<td>3 km walking, 27 km tractor, 90 km trucking</td>
</tr>
<tr>
<td>Large scale (Current salaries)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>73</td>
<td>Tractor</td>
<td>8 km tractor</td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>200</td>
<td>Tractor</td>
<td>8 km tractor</td>
<td></td>
</tr>
</tbody>
</table>
4.4.2. Definition of Extraction Scenarios

Table 5 shows the scenarios for the extraction module. Three different scenarios are set up for analysis of costs, energy use, and CO2 emissions of the extraction process in the biodiesel value chain, and will in the analysis be done separate for jatropha and coconut.

In the simple local scenario a manual extraction machine is used. The extraction rate for the manual extraction machine is based on the rate at ADPP’s extraction facility. The oil produced in this scenario can be sold directly to the local market for use in generators or in converted diesel engines. By selling the oil directly to the local market the cost for refining and transportation to the refining facility is zero.

The advanced local scenario is based on the same assumptions as the simple local scenario, except that more advanced extraction machinery is used. As in the simple local scenario, the oil from the advanced local scenario is sold at the local market. The extraction rate for the more advanced extraction machinery in the advanced local scenario is based on that of Sun Biofuels.

The advanced national scenario have the same extraction machinery as the advanced local scenario but instead of selling the oil locally the oil is sold on the national market, to refineries that can convert the oil into biodiesel.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Typ of extraction</th>
<th>Extraction rate (jatropha/coconut)</th>
<th>Market for sales</th>
<th>Transportation to market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple local</td>
<td>Manual</td>
<td>20/50%</td>
<td>Local</td>
<td>0km (sold at the extraction site)</td>
</tr>
<tr>
<td>Advanced local</td>
<td>Advanced machinery</td>
<td>35/65%</td>
<td>Local</td>
<td>0km (sold at the extraction site)</td>
</tr>
<tr>
<td>Advanced national</td>
<td>Advanced machinery</td>
<td>35/65%</td>
<td>National refinery</td>
<td>600km trucking</td>
</tr>
</tbody>
</table>

Table 5: Extraction scenarios

4.4.3. Definition of Refining Scenarios

Table 6 shows two different refining scenarios. The only difference between these two is the location where the diesel is sold. The regional scenario is based on the assumption that the diesel is sold at the Southern African market, which includes the Mozambican market and other southern African cities like Johannesburg and Durban, which are within 500 km from Maputo. The international scenario is based on the assumption that the diesel is exported to the EU market by ships.

As the coconut and jatropha oil are both refined with the same methods, two different refining scenarios for the two different types of oil are not presented as for the different type of feedstock in the farming and extraction scenarios.
### 4.5. Sensitivity Analysis

To test the model for its sensitivity, a sensitivity analysis was carried out. The model was tested regarding the variables’ uncertainty and level of technical significance. The uncertainty of the variable value can depend on two different things. There is either a lack of previous research behind the value, or the value is based on an average of values from different potential practices in the biodiesel value chain. The technical significance of a variable indicates the level of impact a change in the variable value has on the results.

The variables in the model were tested to see what impact a change in their value had on the results of costs and energy input in the biodiesel value chain. The data for the sensitivity analysis was taken from the model and analyzed with the help of a spreadsheet. The variables tested in the sensitivity analysis were selected because of their high probability of having large impact on the results from the simulation runs.

For each variable selected for the sensitivity analysis an evaluation of the uncertainty of the value for each variable was made, and a test range was set. For example, if there is an uncertainty for the “Base yield” value of around 340-580kg/ha, and a base yield value of 460kg/ha is selected for the model, the uncertainty range is +/- 26%, which will be the test range for the analysis. The test range for each variable was used in the sensitivity analysis to test the impact on the results from changes in respective value. The result of the sensitivity analysis will be shown as an “Effect on total costs” and a “Sensitivity factor”.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Market for sales</th>
<th>Transportation to market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional</td>
<td>Southern Africa</td>
<td>500 km trucking</td>
</tr>
<tr>
<td>International</td>
<td>EU</td>
<td>10 000 km boat</td>
</tr>
</tbody>
</table>

Table 6: Refining scenarios
5. Result

In this chapter the results from the technical analysis of the biodiesel value chain are presented. In the first section the values from the runs in the modules for each scenario is viewed and discussed. The second section of the Result chapter presents the results from the sensitivity analysis.

The results from the different scenarios from the model are analyzed in order to investigate what impact different variables have on the total biodiesel value chain. The goal is to compare different scenario options to analyze what the most optimal scenarios are in order to make the biodiesel value chain sustainable. All scenarios are based on observations from the field study in Mozambique and scenarios that are reasonable to implement.

In order to limit the number of scenarios the tests will be carried out separately on the three different modules in the model, the farming module, the extraction module, and the refining module. The results will then be combined to see what the most optimal scenario is in order to maximize the sustainability of the value chain. The four different scenarios that previously was specified in chapter 4.4 have been simulated for both jatropha and coconut production. The cost results, the energy results, and the CO2 results from the farming module, the extraction module, and the refining module will be presented in the following chapters.

5.1. Farming Module Scenarios

In this chapter the cost results, the energy results, and the CO2 results from the runs in the model will be presented for both jatropha and coconut farming as a part of the total biodiesel production chain. The different scenarios are defined in the method chapter, so for more information about what methods and technology are included in the different scenarios see chapter 4.4.

5.1.1. Cost Result of Jatropha Farming Scenarios

Table 7 shows the cost result from the simulation run in the model of the jatropha farming scenarios. The table shows; the cost percentage of each activity of the total cost for the farming module, the total cost for the farming module per kg of produced feedstock, and the total production of jatropha feedstock over the first 10 years.

<table>
<thead>
<tr>
<th>Jatropha scenarios [costs]</th>
<th>Cost of preparing and maintaining land</th>
<th>Cost of harvesting feedstock</th>
<th>Cost of processing and storing feedstock</th>
<th>Cost of trading feedstock to feedstock market</th>
<th>Total cost of farming module [USD/kg feedstock]</th>
<th>Total production over 10 years [kg/ha]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small scale (Simple)</td>
<td>45%</td>
<td>25%</td>
<td>13%</td>
<td>16%</td>
<td>0.258</td>
<td>16574</td>
</tr>
<tr>
<td>Small scale (Advanced)</td>
<td>59%</td>
<td>1%</td>
<td>27%</td>
<td>12%</td>
<td>0.129</td>
<td>33913</td>
</tr>
<tr>
<td>Large scale</td>
<td>63%</td>
<td>1%</td>
<td>34%</td>
<td>2%</td>
<td>0.104</td>
<td>44062</td>
</tr>
</tbody>
</table>
This simulation run shows that the use of inputs such as pesticides and fertilizers greatly reduces the cost per produced kg of feedstock, with no dependence of what type of machinery is used. The reason is that the pesticides and fertilizer inputs increase the yield substantially. The results also show that the use of tools for harvesting greatly reduces the costs for harvesting, and using collection points for collecting the feedstock by tractor closer to the small-scale farmers reduces the costs for trading. Small scale farmers using advanced farming methods can cut the farming production cost by half by using chemical inputs and get access to collection points. The costs for the large scale farm with higher salaries almost double when increasing the salaries. This indicates that the jatropha farming is highly labor intensive, primarily the peeling procedure, and techniques to increase the efficiency of the process is required in order to make the process sustainable since it is likely for the salaries to increase by time.

Large scale farming is the most efficient scenario out of a cost perspective, since it has the largest total production per hectare with the lowest cost per kg. The advanced small scale farming scenario using inputs and tools however do not have much higher cost. As small scale farming might be better out of a poverty reduction perspective, it will probably be better for the development of rural Mozambique to promote small scale farms instead of large scale farmer. In order to reduce the small scale farmers’ costs to a manageable level the small scale farmer will need help with access to inputs, and with transportation through collection points. This could for example be done in a similar manner to what Hende Wayela did, by building collection points in remote areas and collected the copra with tractors. Such collection points can also possible be used to provide inputs to the farmers.

### 5.1.2. Energy Result of Jatropha Farming Scenarios

Table 8 shows the energy results from the simulation run in the model of the jatropha farming scenarios. The table shows the percentage of energy use for each activity of the total energy used for the whole farming module, and the total energy used for the farming module per kg of produced feedstock. All energy is converted into GJ of primary energy.

<table>
<thead>
<tr>
<th>Jatropha scenarios [energy]</th>
<th>Energy for preparing and maintaining land</th>
<th>Energy for harvesting feedstock</th>
<th>Energy for processing and storing feedstock</th>
<th>Energy for trading feedstock to feedstock market</th>
<th>Total energy of farming module [GJ/kg feedstock]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small scale (Simple)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
<td>0.0000357</td>
</tr>
<tr>
<td>Small scale (advanced)</td>
<td>88%</td>
<td>5%</td>
<td>0%</td>
<td>7%</td>
<td>0.00205</td>
</tr>
</tbody>
</table>
The simple small scale scenario is by far the most energy efficient scenario, due to its simple characteristics with no chemical inputs. The use of inputs such as fertilizers increases the energy inputs substantially in both the advanced small scale scenario and large scale scenarios. But the energy inputs per kg of produced feedstock is actually lower in the large scale scenarios than in the small scale scenario, the reason is that irrigation is used, which increases the yield. Another reason is that the transportation distances are shorter in the large scale scenarios since the extraction facility is assumed to be located at the farm. If the small scale farmers organized in clusters closer to the extraction facility the energy use for the farming module would decrease.

### 5.1.3. CO2 Result of Jatropha Farming Scenarios

Table 9 shows the result for the simulation in the model of the defined scenarios of jatropha production. The table shows the percentage of how much CO2 each activity emits of the total CO2 emitted for the farming module, and the total CO2 emitted for the farming module per kg of produced feedstock.

<table>
<thead>
<tr>
<th>Jatropha scenarios [CO2]</th>
<th>CO2 for preparing and maintaining land</th>
<th>CO2 for harvesting feedstock</th>
<th>CO2 for processing and storing feedstock</th>
<th>CO2 for trading feedstock to feedstock market</th>
<th>Total CO2 of farming module [kg/kg feedstock]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small scale (Simple)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
<td>0.00199</td>
</tr>
<tr>
<td>Small scale (advanced)</td>
<td>70%</td>
<td>12%</td>
<td>0%</td>
<td>18%</td>
<td>0.0442</td>
</tr>
<tr>
<td>Large scale (current salaries)</td>
<td>77%</td>
<td>17%</td>
<td>0%</td>
<td>5%</td>
<td>0.314</td>
</tr>
<tr>
<td>Large scale (Higher salaries)</td>
<td>77%</td>
<td>17%</td>
<td>0%</td>
<td>5%</td>
<td>0.314</td>
</tr>
</tbody>
</table>

Table 9: CO2 emissions for jatropha farming

There is a correlation between the CO2 emissions and the energy inputs for the farming module scenarios. The energy drivers that consume diesel instead of embedded energy or electricity however have a higher CO2 emission rate. In these scenarios this is evident for the harvesting tools and transportation.
The use of tractors for some of the planting and growing activities also increases the emissions for the large scale scenarios.

As in the energy inputs in table 8 the CO₂ emissions could be reduced for the small scale farmers if the farmers could be organized in clusters closer to the extraction facility. If the fertilizer and pesticides are manufactured in a more energy efficient way or if the energy source for producing the inputs are more CO₂ neutral then the emissions can be reduced greatly.

### 5.1.4. Cost Result of Coconut Farming Scenarios

Table 10 shows the result from the simulation run in the model of the coconut production scenarios. The table shows the cost percentage of each activity of the total cost for the farming module, the total cost for the farming module per kg of produced feedstock, and the total production over the first 10 years.

<table>
<thead>
<tr>
<th>Coconut scenarios [costs]</th>
<th>Cost of preparing and maintaining land</th>
<th>Cost of harvesting feedstock</th>
<th>Cost of processing and storing feedstock</th>
<th>Cost of trading feedstock to feedstock market</th>
<th>Total cost of farming module [USD/kg feedstock]</th>
<th>Total production over 10 years [kg/ha]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small scale (Simple)</td>
<td>5%</td>
<td>57%</td>
<td>19%</td>
<td>19%</td>
<td>0.221</td>
<td>7310</td>
</tr>
<tr>
<td>Small scale (advanced)</td>
<td>67%</td>
<td>5%</td>
<td>20%</td>
<td>8%</td>
<td>0.210</td>
<td>13305</td>
</tr>
<tr>
<td>Large scale (current salaries)</td>
<td>71%</td>
<td>5%</td>
<td>24%</td>
<td>1%</td>
<td>0.181</td>
<td>17297</td>
</tr>
<tr>
<td>Large scale (Higher salaries)</td>
<td>55%</td>
<td>7%</td>
<td>37%</td>
<td>1%</td>
<td>0.306</td>
<td>17297</td>
</tr>
</tbody>
</table>

**Table 10: Cost of coconut farming**

The total costs per kg produced feedstock for the two small scale scenarios do not differ a lot. Using inputs as in the advanced small scale scenario does however lower the cost per kg somewhat, but increase the yield by almost 100%. The use of collection points halves the transportation and trading costs for the small scale scenarios.

The large scale scenarios are more economically efficient than the small scale scenarios. The main reason for the lower costs is the lower trading costs and higher productivity. The trading costs can be lowered since the extraction facility is assumed to be closer if a large scale coconut farm is used. The large scale farm is also using irrigation which increases the yield.

As the level of mechanization is very low in the large scale scenarios cost of producing one kg of coconuts increase substantially if the salaries are increased. It is however possible that more machinery could be used for planting, maintaining, and harvesting the coconuts as the industry develop.
5.1.5. Energy Result of Coconut Farming Scenarios

Table 11 shows the energy result from the simulation run in the model of the jatropha farming scenarios. The table shows the percentage of how much energy each activity requires of the total energy used for the farming module, and the total energy used for the farming module per kg of produced feedstock. All energy is converted into GJ of primary energy.

<table>
<thead>
<tr>
<th>Coconut scenarios [energy]</th>
<th>Energy for preparing and maintaining land</th>
<th>Energy for harvesting feedstock</th>
<th>Energy for processing and storing feedstock</th>
<th>Energy for trading feedstock to feedstock market</th>
<th>Total energy of farming module [GJ/kg feedstock]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small scale (Simple)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
<td>0.0000357</td>
</tr>
<tr>
<td>Small scale (advanced)</td>
<td>96%</td>
<td>0%</td>
<td>0%</td>
<td>4%</td>
<td>0.00332</td>
</tr>
<tr>
<td>Large scale (current salaries)</td>
<td>99%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>0.00247</td>
</tr>
<tr>
<td>Large scale (Higher salaries)</td>
<td>99%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>0.00247</td>
</tr>
</tbody>
</table>

Table 11: Energy input for coconut farming

Since no chemical inputs or machinery is used in the simple small scale scenario the only energy needed to produce one kg of coconut feedstock is that from transportation of the feedstock in the trading activity. For the advanced small scale scenario the use of chemical inputs increases the energy use substantially. The energy used for transportation in the advanced small scale scenario also increases the energy use since the collection points use more tractors and trucks and less walking than the simple small scale scenario. The tools used for harvesting coconuts do not use any energy inputs at all.

The energy input per kg of feedstock produced by large scale farming is lower than for feedstock produced by small scale advanced farming. The reason is that the same type of machinery is used in the both scenarios, but the distance to the extraction facility is shorter in large scale farming and the coconut yield is bigger due to irrigation. In order to make coconut production sustainable with higher salaries the rate of mechanization will have to increase, something which will also consume more energy.

In the current scenarios all fertilizers are artificial fertilizers. If for example coconut husks were used for fertilizers the energy input needed to produce fertilizers would greatly decrease.

5.1.6. CO2 Result of Coconut Farming Scenarios

Table 12 shows the result for the simulation in the model of the defined scenarios of jatropha production. The table shows the percentage of how much CO2 each activity emits of the total CO2 emitted for the farming module, and the total CO2 emitted for the farming module per kg of produced feedstock.
Coconut scenarios [CO\textsubscript{2}]

<table>
<thead>
<tr>
<th>Coconut scenarios [CO\textsubscript{2}]</th>
<th>CO\textsubscript{2} for preparing and maintaining land</th>
<th>CO\textsubscript{2} for harvesting feedstock</th>
<th>CO\textsubscript{2} for processing and storing feedstock</th>
<th>CO\textsubscript{2} for processing and storing feedstock</th>
<th>Total CO\textsubscript{2} of farming module [kg/kg feedstock]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small scale (Simple)</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
<td></td>
<td>0.00199</td>
</tr>
<tr>
<td>Small scale (advanced)</td>
<td>87%</td>
<td>0%</td>
<td>13%</td>
<td></td>
<td>0.0621</td>
</tr>
<tr>
<td>Large scale (current salaries)</td>
<td>96%</td>
<td>0%</td>
<td>4%</td>
<td></td>
<td>0.0434</td>
</tr>
<tr>
<td>Large scale (Higher salaries)</td>
<td>96%</td>
<td>0%</td>
<td>4%</td>
<td></td>
<td>0.0434</td>
</tr>
</tbody>
</table>

Table 12: CO\textsubscript{2} emissions for coconut farming

The main CO\textsubscript{2} emitter in the small scale advanced scenario, and in both the large scale scenarios, is the embedded energy contained in the chemical inputs used for planting and growing. However, if the fertilizers and pesticides were manufactured in a more environmentally friendly way or with a different energy mix the CO\textsubscript{2} emissions would be reduced greatly.

The transportation is also a main emitter and because of shorter distances the large scale scenarios have lower total CO\textsubscript{2} emissions than the advanced small scale scenario. The CO\textsubscript{2} emissions from the simple small scale farming comes only from the transportation and is very low compared to the other three scenarios.

5.2. Extraction Module Scenarios

In this chapter the cost results, the energy results, and the CO\textsubscript{2} results from the simulation runs in the model will be presented for both jatropha and coconut oil extraction as a part of the total biodiesel production chain.

5.2.1. Cost Result of Jatropha Extraction Scenarios

Table 13 shows the result from the simulation run in the model for the jatropha extraction scenarios. The table shows the cost percentage for each activity of the total cost for the extraction module, and the total cost for the extraction module per kg of produced oil.
The cost of the oil extracting process with manual machinery is a lot higher than that of more advanced machinery, even though the capital cost is included in the above calculations. The advanced machinery costs more than 100 times more up front than the manual machinery, but because the extraction rate is higher the price per extracted kg of oil is still substantially lower for the advanced machinery. The manual machinery also requires more labor than the advanced machinery. The capacity is higher for the advanced machinery and the model assumes that the machinery is using its full capacity. Not running on full capacity could alter the results significantly.

As the extraction module is directly connected to the farming module the extraction rate is crucial for the total biodiesel value chain. If the extraction rate is high the value added to the feedstock from the farming module is highly utilized, and if the extraction rate is low a lot of the value added in the farming module is lost and the cost of producing one kg of oil increases since more work needs to be added in the previous step in the value chain, the farming module.

The cost of transporting the oil to the national refineries will add around 0.033 USD to the costs. The relatively low cost is suggesting that the transportation to the national market will not be a major cost obstacle for marketing the product.

### 5.2.2. Energy Result of Jatropha Extraction Scenarios

Table 14 shows the result from the simulation run in the model of the jatropha extraction scenarios of jatropha production. The table shows the percentage of energy required for each activity of the total energy required in the extraction module, and the total energy used for the extraction module per kg of produced oil. All energy is converted into GJ of primary energy.

<table>
<thead>
<tr>
<th>Jatropha scenarios [energy]</th>
<th>Energy for drying and storing feedstock</th>
<th>Energy for oil pressing</th>
<th>Energy for storing oil</th>
<th>Energy for trading oil to oil market</th>
<th>Energy for storing presscake</th>
<th>Energy for trading presscake to market</th>
<th>Total energy of extraction module [GJ/liter of oil]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple local</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Advanced local</td>
<td>0%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0.00151</td>
</tr>
</tbody>
</table>
The manual machinery in the simple local scenario uses only manual inputs with energy from human work operation. The embedded energy for manufacturing the machinery or the energy that human work operations consume is not included in the model. The electricity used for the pressing process is the only energy driver in the advanced local scenario. The transportation of oil to the national markets adds around 25% energy to the extraction module in the advanced national scenario compared to the advanced local scenario.

5.2.3. CO2 Result of Jatropha Extraction Scenarios

Table 15 shows the result from the simulation run in the model of the jatropha extraction scenarios. The table shows the percentage of CO2 emissions from each activity of the total CO2 emitted from the whole extraction module, and the total CO2 emitted for the extraction module per kg of produced feedstock.

<table>
<thead>
<tr>
<th>Jatropha scenarios [CO2]</th>
<th>CO2 for drying and storing feedstock</th>
<th>CO2 for oil pressing</th>
<th>CO2 for storing oil</th>
<th>CO2 for trading oil to oil market</th>
<th>CO2 for storing presscake</th>
<th>CO2 for trading presscake to market</th>
<th>Total CO2 of extraction module [kg/liter oil]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple local</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Advanced local</td>
<td>0%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0.0841</td>
</tr>
<tr>
<td>Advanced national</td>
<td>0%</td>
<td>80%</td>
<td>0%</td>
<td>20%</td>
<td>0%</td>
<td>0%</td>
<td>0.105</td>
</tr>
</tbody>
</table>

5.2.4. Cost Result of Coconut Extraction Scenarios

Table 16 shows the result from the simulation run in the model of the coconut extraction scenarios. The table shows the cost percentage of each activity of the total cost for the extraction module, and the total cost for the extraction module per liter of produced oil.
For coconut extraction the cost for the simple local scenario is substantially higher than for the two advanced scenarios. The difference between the extraction rate in the simple local scenario and in the advanced scenarios is however smaller for coconut extraction than for jatropha extraction. This smaller difference in the extraction rate explains the smaller difference in costs between the advanced extraction scenarios and the simple local extraction scenario.

The costs for extracting one liter of coconut oil is less than for one liter of jatropha oil, the reason for this is the higher oil content in copra compared to jatropha seeds. Another difference between the coconut extraction process and the jatropha extraction process is that machinery for drying the copra is used but not for the jatropha, this adds an additional cost to the coconut extraction module.

The simple local scenario does despite its unfavorable economics open up for other opportunities. The simple local scenario does not require a substantial upfront investment, and can hence be placed at more remote places, to produce oil locally, to be used in for example diesel generators. This could reduce the fuel prices for people in rural communities and increase access to fuel in the remote villages. As the manual extraction for copra is more efficient than the manual extraction of jatropha seeds, copra could potentially be better suited for this kind of local oil production.

### 5.2.5. Energy Result of Coconut Extraction Scenarios

Table 17 shows the result from the simulation run in the model of the coconut extraction scenarios. The table shows the percentage of energy use for each activity of the total energy required for the whole extraction module, and the total energy used for the extraction module per kg of produced oil. All energy is converted into GJ of primary energy.
For the simple local scenario there is no energy input other than the human work needed to extract the oil and the embedded energy in the manufacturing process for the machine. For the advanced scenarios using advanced extraction machines the majority of the energy used comes from the extraction process. Some energy is also required for drying the copra in the advanced scenarios since drying machines are used. As the extraction rate for coconuts is higher than that for jatropha the extraction process is more energy efficient per kg of produced oil.

### 5.2.6. CO2 Result of Coconut Extraction Scenarios

Table 18 shows the result from the simulation in the model of the coconut extraction scenarios. The table shows the percentage of CO2 emission from each activity of the total CO2 emitted in the extraction module, and the total CO2 emitted for the extraction module per kg of produced oil.

<table>
<thead>
<tr>
<th>Coconut scenarios [CO2]</th>
<th>CO2 for drying and storing presscake</th>
<th>CO2 for oil pressing</th>
<th>CO2 for storing oil</th>
<th>CO2 for trading oil to oil market</th>
<th>CO2 for storing presscake</th>
<th>CO2 for trading presscake to market</th>
<th>Total CO2 of extraction module [kg/kg feedstock]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple local</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Advanced local</td>
<td>31%</td>
<td>69%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0.0675</td>
</tr>
<tr>
<td>Advanced national</td>
<td>24%</td>
<td>52%</td>
<td>0%</td>
<td>24%</td>
<td>0%</td>
<td>0%</td>
<td>0.00889</td>
</tr>
</tbody>
</table>

Table 18: CO2 emissions for coconut extraction

As for the jatropha extraction scenario the percentage rates for the CO2 emissions are identical to the percentage rates of the energy used in the same scenarios, due to the same primary energy source. As in the jatropha extraction scenarios the electricity is assumed to be taken from a generator and the CO2 emissions could be greatly reduced by connecting the extraction facility to the national grid.

### 5.3. Jatropha and Coconut Refining Module Scenarios

In this chapter the cost results, the energy results, and the CO2 results from the runs in the model will be presented for both jatropha and coconut oil refining as a part of the total biodiesel production chain. The two different scenarios that previously were specified have been simulated for the oil flow, which is the same regardless of what plant was used to make the oil.
5.3.1. Cost Result of Jatropha and Coconut Refining Scenarios

Table 19 shows the result from the simulation run in the model of the biodiesel refining scenarios. The table shows the cost percentage of each activity of the total cost for the refining module, and the total cost for the refining module per liter of produced biodiesel.

<table>
<thead>
<tr>
<th>Scenarios [Costs]</th>
<th>Costs of storing oil</th>
<th>Costs of oil refining</th>
<th>Costs of storing diesel</th>
<th>Costs of trading diesel to market</th>
<th>Total cost of refining module [USD/liter diesel]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local</td>
<td>5%</td>
<td>77%</td>
<td>5%</td>
<td>13%</td>
<td>0.205</td>
</tr>
<tr>
<td>International</td>
<td>4%</td>
<td>60%</td>
<td>4%</td>
<td>32%</td>
<td>0.261</td>
</tr>
</tbody>
</table>

Table 19: Cost of refining

The costs for storing the diesel and the oil in tanks are considerably higher than the costs of storing feedstock in a warehouse. The main cost however is the cost of the oil refining process. The cost of exporting the biodiesel to Europe in tanker ships is around 0.056 USD/liter higher than shipping the biodiesel to Durban or Johannesburg.

5.3.2. Energy Result of Jatropha and Coconut Refining Scenarios

Table 20 shows the result from the simulation run in the model of the biodiesel refining scenarios. The table shows the percentage of energy used in each activity of the total energy required for the refining module, and the total energy used for the refining module per kg of produced biodiesel. All energy is converted into GJ of primary energy.

<table>
<thead>
<tr>
<th>Scenarios [Energy]</th>
<th>Energy for storing oil</th>
<th>Energy for oil refining</th>
<th>Energy for storing diesel</th>
<th>Energy for trading diesel to market</th>
<th>Total energy of refining module [GJ/liter diesel]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local</td>
<td>0%</td>
<td>96%</td>
<td>0%</td>
<td>4%</td>
<td>0.00793</td>
</tr>
<tr>
<td>International</td>
<td>0%</td>
<td>83%</td>
<td>0%</td>
<td>17%</td>
<td>0.00923</td>
</tr>
</tbody>
</table>

Table 20: Energy input for refining

The embedded energy in the chemicals needed for the refining process has the biggest share of the energy used in the refining module. The energy needed to ship the diesel to Europe is about 0.00130 GJ/liter.

5.3.3. CO2 Result of Jatropha and Coconut Refining Scenarios

Table 21 shows the result from the simulation run in the model of the biodiesel refining scenarios. The table shows the percentage of CO2 emitted from each activity of the total CO2 emitted from the refining module, and the total CO2 emitted for the refining module per kg of produced oil.

<table>
<thead>
<tr>
<th>Scenarios [CO2]</th>
<th>CO2 for storing oil</th>
<th>CO2 for oil refining</th>
<th>CO2 for storing diesel</th>
<th>CO2 for trading diesel to market</th>
<th>Total CO2 of refining module [kg/liter diesel]</th>
</tr>
</thead>
</table>

55 of 94
Local | 0% | 99% | 0% | 1% | 1.06  
International | 0% | 92% | 0% | 8% | 1.13  

Table 21: CO2 emissions for refining

Relative to the percentage rates of energy input in table 20 the CO2 emissions for the trading process are lower and the CO2 emissions from refining are higher as a percentage of the total energy use and CO2 emissions in the model. The reason for this is that the energy content for the embedded energy in the refining process is based on world average for CO2 emissions for electricity production, which is higher than that of the CO2 emissions from the diesel used in transportation.

### 5.4. Results of the sensitivity analysis of the model

The result of the sensitivity analysis is shown in table 22 as the “Effect on total costs” and the “Sensitivity factor”, using the “Test range” for calculation.

The percentage value of the “Tested range” shows the uncertainty of the value for the tested variable. The “Effect on total costs” is the percentage the total cost for the biodiesel value chain will change if the maximum value in the “Test range” is used. The “Sensitivity factor” is defined by the “Tested range” percentage value divided by the “Effect on total cost” percentage value. The “Sensitivity factor” describes how much a change in one variable will change the total costs. This value is used to illustrate what impact a small change in certain variables has on the total cost or energy use.

For the variables with high technical significance the impact on the results from the simulation runs were big. For the variables with high technical significance even small changes of its value have big impacts on the results. Other variables can have big impacts on the results even without high technical significance. If a value has high uncertainty and/or a wide test range the value can have a big impact on the results from the simulation runs even if the variable itself technically has a low significance in the model.

The result of the sensitivity analysis for the jatropha biodiesel value chain is presented in the next two chapters. In appendix A,B,C a complete table of the values used in the performance of the tests can be found.

#### 5.4.1. Jatropha costs sensitivity analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Tested range [+/- %]</th>
<th>Effect on total cost [%]</th>
<th>Sensitivity factor [%/%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency of manual extraction machinery [%]</td>
<td>25</td>
<td>30</td>
<td>1.21</td>
</tr>
<tr>
<td>Efficiency of advanced extraction machinery [%]</td>
<td>14</td>
<td>13</td>
<td>0.93</td>
</tr>
<tr>
<td>Harvest (Without tools for harvesting) [kg/h]</td>
<td>64</td>
<td>33</td>
<td>0.51</td>
</tr>
<tr>
<td>Labour salary [USD/month]</td>
<td>50</td>
<td>22</td>
<td>0.45</td>
</tr>
<tr>
<td>Pruning produktivity increase [%]</td>
<td>38</td>
<td>15</td>
<td>0.40</td>
</tr>
</tbody>
</table>
The variables that affect the yield, such as fertilizer, pesticides, and the base yield have a high uncertainty and have big impact the total results from the model. These values have a high uncertainty because many different data, both in the literature and from the field study, have been identified. One reason for this disparity in data is the lack of proper botanical research on jatropha cultivation. Another reason is that jatropha is grown in vastly different conditions, which affects the yield from the plant. How large the yield is affects the harvest, which in turn has a great impact on the overall results.

In the model there is a possibility to simulate the use of a harvesting tool. This tool does not exist in the jatropha harvesting process today, but is currently being developed. The values for this tool are estimated from values of similar tools in the olive industry, an industry with very similar harvesting procedure to jatropha. But in this case the estimation is not a big issue since the analysis shows that even a 50% change in efficiency rate of this tool does not have a significant impact on the overall cost.

When harvesting manually there is also a large uncertainty in the values of how long time it takes to harvest the jatropha fruits. Many different data have been cited in different sources, both in the field study in Mozambique and in the literature. In the model an average of these data is being used. The sensitivity analysis shows that these values affect the total cost of the value chain greatly.

The value for the efficiency of the oil extracting machine is a value with a high technical significance in the model since it has a big impact of the whole value chain is. The efficiency of the extraction process has great impact on the economies of the whole value chain. This study also experienced big differences in these extraction rate values in Mozambique, and also found a great variation in the data from the literature. This makes the efficiency rate highly crucial for the biodiesel value chain. But it is also possible to see in the sensitivity analysis that the investment cost for advanced machinery does not affect the overall results significantly.

### 5.4.2. Jatropha energy input sensitivity analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Tested range [+/- %]</th>
<th>Effect on total energy [%]</th>
<th>Sensitivity factor [%/%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base yield [kg/ha]</td>
<td>26</td>
<td>10</td>
<td>0.39</td>
</tr>
<tr>
<td>Fertilizer productivity increase [%]</td>
<td>24</td>
<td>4</td>
<td>0.17</td>
</tr>
<tr>
<td>Kg peeling per hour [kg/h]</td>
<td>20</td>
<td>2</td>
<td>0.10</td>
</tr>
<tr>
<td>Investment cost up front advanced machinery [USD]</td>
<td>25</td>
<td>2</td>
<td>0.08</td>
</tr>
<tr>
<td>Refining cost per kg oil [USD/kg]</td>
<td>67</td>
<td>5</td>
<td>0.08</td>
</tr>
<tr>
<td>Irrigation productivity increase [%]</td>
<td>67</td>
<td>0.04</td>
<td>0.07</td>
</tr>
<tr>
<td>Pesticides productivity increase [%]</td>
<td>33</td>
<td>0.01</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 22: Jatropha costs sensitivity analysis
<table>
<thead>
<tr>
<th>Description</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embedded energy input per kg of oil refining [GJ/kg]</td>
<td>15</td>
<td>7.5</td>
<td>0.50</td>
</tr>
<tr>
<td>Kg use of fertilizer for jatropha [kg]</td>
<td>20</td>
<td>9.3</td>
<td>0.47</td>
</tr>
<tr>
<td>Tractor diesel for ploughing in liters [l/ha]</td>
<td>38</td>
<td>14</td>
<td>0.37</td>
</tr>
<tr>
<td>Electricity use in kWh per kg for simple machinery [kWh/kg]</td>
<td>18</td>
<td>1.8</td>
<td>0.10</td>
</tr>
<tr>
<td>Electric input per kg of oil refining [kWh/kg]</td>
<td>17</td>
<td>0.76</td>
<td>0.05</td>
</tr>
<tr>
<td>Kg use of pesticides for jatropha [kg]</td>
<td>20</td>
<td>0.76</td>
<td>0.04</td>
</tr>
<tr>
<td>Liters of diesel per hour of harvesting with tools [l/h]</td>
<td>50</td>
<td>1.5</td>
<td>0.03</td>
</tr>
<tr>
<td>Diesel input for trading feedstock to feedstock markets [l/kg jatropha]</td>
<td>25</td>
<td>0.76</td>
<td>0.03</td>
</tr>
<tr>
<td>Electricity use in kWh per kg for advanced machinery [kWh/kg]</td>
<td>29</td>
<td>0.76</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**Table 23: Jatropha energy input sensitivity analysis**

The result from the jatropha sensitivity analysis shows that the value for the Tractor diesel variable has a high sensitivity factor, hence a change in tractor efficiency could have a big influence on the energy use for the jatropha biodiesel value chain. The Tractor diesel variable has a high sensitivity factor partly because of the big differences in fuel consumption between different tractors, but also because the energy for tractor use is a relatively big part of the total energy use.

The Fertilizer embedded energy variable also has a high sensitivity factor, hence the value of the variable for embedded energy in fertilizers affects the model a great lot. The amount of fertilizer needed for one hectare of land depends on the type of land used, and on other factors that affect the fertility of the soil. In this model a value for average conditions is used. The embedded energy in fertilizers also represents a big part of the total energy inputs for the jatropha biodiesel value chain, and hence the variable for the embedded energy in fertilizers has a big impact of the overall results.

The embedded energy for the refining process also has a high sensitivity factor, hence the value of its variable greatly affects the total energy results. The uncertainty range is derived from the large number of different methods that can be used for refining.

Despite the Tractor diesel variable, and the variables for the embedded energy in fertilizers and for the refining process none of the other variables tested and shown in table 23 has any significant impact of the total energy result.
6. Result Analysis

The purpose of this study was to investigate whether biodiesel crops can be grown to reduce poverty, and if the biodiesel production chain can be designed in a socially, environmentally, and financially sustainable way in Mozambique. The purpose of this study was also to investigate what structures in Mozambique need to be changed in order to make the biodiesel value chain sustainable. In this chapter a concluding analysis from the results for the biodiesel value chain are presented.

According to previous research on poverty reduction, increasing the productivity for smallholder farmers, through for example outgrower schemes, is more socially sustainable and a better way to reduce poverty than efficient large scale farms. If it is possible to also make the smallholder farms economically and environmentally sustainable, it is possible to design a sustainable biodiesel value chain using smallholder farms for biodiesel production.

Different scenarios for producing biodiesel have been tested in the model developed for this study. As seen in table 7 and table 10 the total cost of the advanced small scale farming scenario was identified by this study to have a very similar total cost to the large scale farming scenario with current salaries. The advanced small scale farming scenario is therefore the best option for the farming module to design a sustainable biodiesel value chain.

As seen in table 13 and table 16 the advanced extraction machinery is the most financially sustainable option for the extraction module. For the best design of the biodiesel value chain this advanced extraction scenario is combined with the advanced small scale farming scenario. The vegetable oil can after the extraction module be sold to the local market, the market in rural areas or markets in cities close to the extraction site for use in for example diesel generators. Or, the vegetable oil can be sold to the national market to be refined into biodiesel. Since the combination of the advanced small scale farming scenario and the advanced extraction scenario has been identified as the most sustainable option the combination of these two is the design presented in this chapter. The biodiesel from the refining process is set to be sold to either the southern African market or to the EU market. The total cost, energy use, and CO2 emissions from the best design of the first part of the biodiesel value chain, including farming module and extraction module, can be seen in table 24, table 25, and table 26, for discussion of how to design a complete biodiesel value chain with respect to social, environmental, and financial sustainability.

6.1.1. Total Cost of the Biodiesel Value Chain

Table 24 shows the total cost for one liter of oil sold to the local market, the total cost for one liter of biodiesel sold to the southern African market, and the total cost for one liter of biodiesel sold to the EU market for the jatropha and coconut biodiesel value chain. All costs are based on the advanced small scale farming scenario, and the advanced extraction scenario.

<table>
<thead>
<tr>
<th></th>
<th>Biodiesel to southern African market [USD/liter]</th>
<th>Biodiesel to EU market [USD/liter]</th>
<th>Oil to local market [USD/liter]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jatropha</td>
<td>0.67</td>
<td>0.72</td>
<td>0.43</td>
</tr>
<tr>
<td>Coconut</td>
<td>0.86</td>
<td>0.91</td>
<td>0.60</td>
</tr>
</tbody>
</table>
The most notable learning from the cost analysis of the biodiesel value chain is that the cost of producing oil for the local market is significantly lower than the cost of producing biodiesel. In table 24 it can also be seen that the cost of producing jatropha biodiesel is lower than the cost of producing coconut biodiesel, and that the cost of selling the biodiesel at the EU market is higher than the cost of selling the biodiesel at the southern African market.

### 6.1.2. Total Energy Use in the Biodiesel Value Chain

Table 25 shows the total energy input needed for one liter of oil sold to the local market, the total energy input needed for one liter of biodiesel sold to the southern African market and the total energy input needed for one liter of biodiesel sold to the EU market. All energy values are based on the advanced small scale farming scenario, and the advanced extraction scenario.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jatropha</td>
<td>0.0116</td>
<td>0.0125</td>
<td>0.00544</td>
</tr>
<tr>
<td>Coconut</td>
<td>0.0152</td>
<td>0.0160</td>
<td>0.00868</td>
</tr>
</tbody>
</table>

Table 25: Total energy use in the biodiesel value chain

The energy needed for the biodiesel sold to the southern African market is similar to the energy needed to export the biodiesel to the EU market, although slightly higher because of the ship transportation. There is however a big difference between the energy needed for the oil to be sold to the local market and the energy needed for the biodiesel. This is mainly a cause of the added energy the refining process requires. As seen in table 25 the refining process almost doubles the total energy needed.

### 6.1.3. Total CO2 Emission from the Biodiesel Value Chain

Table 26 shows the total CO2 emissions for one liter of oil sold to the local market, the total CO2 emissions for one liter of biodiesel sold to the southern African market and the total CO2 emissions for one liter of biodiesel sold to the EU market.

<table>
<thead>
<tr>
<th></th>
<th>Biodiesel to Southern African market [kg CO2/liter]</th>
<th>Biodiesel to EU market [kg CO2/liter]</th>
<th>Oil to local market [kg CO2/liter]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jatropha</td>
<td>1.49</td>
<td>1.53</td>
<td>0.741</td>
</tr>
<tr>
<td>Coconut</td>
<td>1.99</td>
<td>2.04</td>
<td>1.190</td>
</tr>
</tbody>
</table>

Table 26: Total CO2 emissions from the biodiesel value chain

As seen if comparing table 25 and table 26 the resulting CO2 emissions from the production of vegetable oil and biodiesel are strongly correlated to the total energy needed for the same production processes. Hence it can be seen in table 26 that selling oil at the local market is the most environmentally sustainable option, and for biodiesel the most environmentally sustainable option is to sell the diesel at the southern African market.
6.1.4. Energy Ratio for the Biodiesel Value Chain

Figure 27 shows the energy ratios for the three different market options for the biodiesel value chain. As the utilization of the byproducts from the biodiesel production chain further improves the energy ratio, the energy ratios in figure 27 are presented both excluding and including the energy content of the byproducts.

<table>
<thead>
<tr>
<th></th>
<th>Biodiesel to Southern African market Energy ratio</th>
<th>Biodiesel to EU market Energy ratio</th>
<th>Oil to local market Energy ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jatropha, byproducts excluding</td>
<td>3.1</td>
<td>2.89</td>
<td>6.51</td>
</tr>
<tr>
<td>Jatropha, byproducts including</td>
<td>6.43</td>
<td>5.99</td>
<td>13.14</td>
</tr>
<tr>
<td>Coconut, byproducts excluding</td>
<td>2.38</td>
<td>2.25</td>
<td>4.16</td>
</tr>
<tr>
<td>Coconut, byproducts including</td>
<td>2.91</td>
<td>2.76</td>
<td>5.02</td>
</tr>
</tbody>
</table>

Table 27: Energy ratio for the biodiesel value chain

From the calorific values of biodiesel, vegetable oil, and the biodiesel value chain byproduct presscake, the energy ratios are calculated. The energy ratios are greater than one, for both the vegetable oil sold at the local market, and for the biodiesel sold at the southern African market or exported to the EU market. With an energy ratio greater than one the energy output of the vegetable oil or biodiesel is greater than the energy input in the biodiesel production chain, hence the biodiesel value chain can be environmentally sustainable.

In figure 17 and 18 the cost share for the three modules in the biodiesel production chain for biodiesel from jatropha and coconuts exported to the EU market can be seen. For the biodiesel sold to the southern African market the share of the different modules are almost identical to the shares in figure 17 and 18. For the oil to be sold to the local market the ratio between the farming module and the extraction module is also very similar to the shares in figure 17 and 18. The most important observation from figure 17 and 18 is that the farming costs constitute a majority share of the total cost. Another significant aspect to note is that the cost of farming is much higher for the coconut production compared to the jatropha production.
In figure 19 and 20 the energy input share for the three modules in the biodiesel production chain for biodiesel from jatropha and coconuts exported to the EU market can be seen. It is clear that the farming and refining processes are the most significant contributors to the total energy use in both jatropha and coconut biodiesel production.

In figure 21 and 22 the share for the CO2 emission from the three modules in the biodiesel production chain for biodiesel from jatropha and coconuts exported to the EU market can be seen.

As seen if comparing figure 21 and 22 with figure 19 and 20 the three different shares of the total energy use for the different modules are strongly correlated to the shares of CO2 emissions from the different modules. Around half of the total CO2 emissions in jatropha biodiesel production come from the
refining process, and around half of the total emissions come from the farming process. For coconut biodiesel production the share of CO2 emissions is slightly larger for the farming process.

In figure 23 the energy ratios of vegetable oil and biodiesel from the biodiesel value chain, both excluding and including utilization of byproducts, are shown.

![Energy Ratio Chart]

**Figure 23: Energy ratio for the biodiesel value chain**

Likely to the sustainability regarding the cost aspect and the CO2 emission aspect, the most feasible option for designing the biodiesel value chain is to sell the vegetable oil to the local market. The high energy ratio makes the oil to market option the most environmentally sustainable option for both jatropha and coconut, both excluding and including byproducts. The big difference in energy ratio, between the oil to local market option and the biodiesel options, is mainly a cause of the energy needed for the refining process. The difference in energy ratio between the two biodiesel scenarios, selling it to the EU market or to southern African market, is very small.

### 6.2. Discussion

As seen in table 24 the cost for exporting the refined diesel to the EU market is higher than for selling the fuel at the southern African market. If the biodiesel price on the southern African market is competitive compared to petroleum based diesel, and the premium for biodiesel on the EU market is lower than the export cost, selling biodiesel at the regional market is a better option both economically and environmentally. If it is possible to get a premium at the EU market, higher than the costs for exporting the biodiesel, selling the biodiesel to the EU market is a more financially profitable option, but on the other hand, selling the biodiesel at the regional market is a more environmentally friendly option.

As seen in table 24 this study shows that use of jatropha for biodiesel production is more economically sustainable than use of coconuts for biodiesel production. Coconut production does however give a greater opportunity for intercropping with food crops. In cases where land is sparse coconuts can therefore be a better option than jatropha for biodiesel production. The type of soil and the climate also has to be considered when deciding on crops. Since coconuts have been cultivated for longer the knowledge about how to best grow the coconut plants rely on more reliable research, hence the risks taken by the farmers are lower for coconut cultivation.
Both the cost and the environmental impact from oil sold at the local market are much lower than the cost and the environmental impact from refined diesel. To maximize the environmental sustainability the vegetable oil should therefore be sold to as large extent as possible on the local market. The use of diesel generators that can be run on oil is very common in rural Mozambique. The vegetable oil from jatropha and coconuts can potentially be sold in these rural areas to a lower price than the imported petroleum based diesel, which can have a positive effect on the rural communities in two ways. First the people living in the rural areas will get access to fuel to a lower price, and second the financial assets will be kept in the community instead of when buying fuel from importers in Maputo. Selling oil at the local market can therefore benefit the rural development significantly. Eventual surplus oil, which cannot be sold to the local market, can be sold to the national market for refining and possibly exporting.

The comparable cost of imported diesel including import duties and port fees but before national taxes and wholesaler/retailer margins in 2008 was 0.64 USD/liter. This means that the cost of biodiesel from jatropha produced by smallholder farmers of 0.67 USD/liter is slightly higher than the imported petroleum based diesel. If the government of Mozambique wants to promote national biodiesel production the fuel taxes for locally produced diesel can be reduced. The price of imported diesel including import duties, port fees and the fuel tax but excluding national sales taxes and wholesaler and retailer margins in 2008 was 0.79 USD/liter. A full fuel tax exemption can hence make the jatropha diesel price competitive. In order to promote biodiesel production the government of Mozambique can hence introduce tax exemptions for biodiesel produced in Mozambique.

Petroleum diesel has a higher price in remote areas than in areas close to the port of entry, such as the areas around Maputo, Beira, and Nacala. As a cause of that the price of oil produced locally by jatropha of 0.43 USD/liter, or by coconuts of 0.60 USD/liter, is much lower than the price of the imported petroleum diesel in the remote areas. In many cases the oil can be used in the same machines as the petroleum diesel, hence the use of the locally produced vegetable oil is a cheaper option for the users.

Since the total cost of the vegetable oil and biodiesel can be competitive to the price of the imported petroleum diesel the biodiesel value chain can be used as a development tool. The biodiesel value chain can reduce poverty for farmers in rural areas in Mozambique since the production of biodiesel crops can give an extra income or the oil used locally as a cheaper substitute to imported petroleum diesel. To design a sustainable biodiesel value chain tradeoffs between rural development, environmental sustainability, and commercial business have to be done. But this study has identified that with the right systems and structures it is possible to fulfill all the three sustainability requirements, see figure 24.
To make it possible to design the biodiesel value chain in a socially, environmentally, and financially sustainable way some structures have to be changed.

The structures, which require changes to design a sustainable biodiesel production chain, identified in this study are both concerning the biodiesel production processes and the government’s influences. The two main structures that have to be changed in the production process is the use of and investments in more efficient extraction machines, and the setup and use of collection points which can also provide inputs to the farmers.

The extraction machinery has a significant role in the biodiesel value chain. The model shows that the efficiency of the machine has a large impact on the total cost of the oil or diesel. It has also been identified that the farming module has the largest cost in the biodiesel value chain, hence only a small increase in efficiency in the extracting module have a large impact on the total cost. The model also shows that the cost of the machine has low impact on the total cost of the oil and diesel, hence investments in more efficient extraction machines would be recommended.

But to make the change of the structures in the biodiesel value chain possible this study has found that a change in the systems of the spread of knowledge and information has to be done. Collection points is one possibility to enhance the spread of information and knowledge since the collection points can give the farmers access to tools, fertilizer, etc. It is also possible that the companies that are setting up collection points act as micro creditors, by providing inputs to farmers on credit, and deducting the cost on the price of the final product. The cash flow to the smallholder farmer from a company, promising to buy the product at a certain price, can also work as collateral for a micro credit, which in turn can be used by the farmers to buy inputs and improve both farmers’ productivity and company profits. At the collection points the farmers can also be given information about price setting to reduce the information asymmetry, and to ensure workers are paid the right price and not utilized.

Other structures that have to be changed in order to make the design of the biodiesel value chain sustainable are the information sharing systems. At the farming level education and training of the
farmers to enhance their farming skills and knowledge of how to use different farming techniques need to be improved. The agronomic research and the spread of knowledge to stakeholders also have to be improved in order to ensure the availability of reliable information.

In order to improve the environmental impact from the biodiesel value chain the energy content in the byproduct can be utilized. If the jatropha presscake is used as biomass or as fertilizer the energy ratio for the vegetable oil or biodiesel can be greatly improved since it both use more of the energy content in the biodiesel crops and lower the energy input from embedded energy in chemicals. Using the presscake can therefore reduce the CO2 emissions from the biodiesel value chain.

To improve the business climate for all the stakeholders in the biodiesel value chain the government of Mozambique can reduce the regulatory burden. More efficient bureaucracy can give the stakeholders more cost efficient systems to run their business and do business with other companies formally.

The biodiesel value chain can be a way for the government of Mozambique to reduce poverty and the country’s heavy reliance on foreign aid. If designed correctly the value chain can be a way to promote local entrepreneurs and create positive incentives for the local population that aid often cannot do.

### 6.3. Conclusion

If the biodiesel value chain is designed properly it is possible to use the biodiesel value chain to reduce poverty in a socially, environmentally, and financially sustainable way in Mozambique. The best way to design the biodiesel value chain in order to achieve rural development with environmental, social, and financial sustainability is to use smallholder farmers with advanced farming technology to grow the biodiesel crops, use advanced extraction machines for oil pressing, and sell the oil at the local market.

#### 6.3.1. Recommendations

To make it possible to design the biodiesel value chain in a socially, environmentally, and financially sustainable way some structures need changes.

- The government of Mozambique needs to reduce the regulatory burden to make it easier for smallholder farmers and traders to gain access to the formal economy, and to make it easier for larger companies to trade with smallholder farmers and with informal traders at collection points.
- In order to make the smallholder farmers competitive collection points need to be set up by stakeholders in the biodiesel value chain to reduce trading costs, ease access to the market, and make inputs and tools available.
- Companies setting up collection points need to provide smallholder farmers with micro credits in order to increase the productivity at the farms.
- Education and training of farmers to learn how to use advanced farming technology such as fertilizers, pesticides and harvesting tools.
- Systems for sharing information with farmers need to be implemented in order to promote sustainable agricultural practices and a fair price setting.
- To maximize the financial return of the grown feedstock, investments in efficient extraction machinery with high extraction rates are needed.
- In order to maximize the environmental, economical, and social benefits of the biodiesel value chain as much of the oil as possible need to be sold to the local market, and possibly surplus oil need to be sold to refineries in Maputo.

- The presscake need to be used as fertilizers or biomass to improve the energy ratio and minimize the environmental impacts from the biodiesel value chain.

- To promote the local production of fuel and reduce the country's dependence on foreign energy the government of Mozambique need to introduce a tax exemption for fuel produced in Mozambique.

- More agronomic research, especially about jatropha, is needed in order to maximize the output of the crop and minimize the risks with the uncertainties that are currently associated with it.

- Information sharing needs to be improved and formalized in order to have the agronomic information from the research institutions to reach companies, farmers, government agencies, and NGOs.
7. Further research

To strengthen the validity of the different scenarios from runs of the model more agronomic research on the jatropha and the coconut plants are required. Currently there is a lack of research of how the plants best can be cultivated. The cultivation methods that are used by farmers today are often inefficient, and not only because of lack in capital, but also in lack of knowledge.

It has also been found that there is a synergy between biodiesel crop production and food security. It is possible that the extra income from the biodiesel crops, the access to tools and machinery, increased knowledge in farming technique and the possibility to intercrop increase the food production at the rural smallholder farms. Although, to draw a conclusion, this question has to be further investigated, since this study did not have the possibility to take all aspects of food security in account.

The model developed in this study is today including several activities, sub-activities and input variables for the biodiesel value chain. The model is built with the prospect of future developments and changes in mind. Since the model is the first version there is a great possibility of developing the model further by enhancing the number of activities, sub-activities and input variables, such as the use of the byproduct soap from the refining process and the use of machinery for peeling and dehusking. Increasing the numbers of activities, sub-activities and input variables in the model makes it possible to analyze more aspects in the biodiesel value chain.
8. References


Brüntrup, M (2011). DEG & DIE. Outgrowers – a key to the development of rural areas in Sub-Saharan Africa and to poverty reduction.


Delgado, C. L. (1999). *SOURCES OF GROWTH IN SMALLHOLDER AGRICULTURE.*


Gunathilake, H. A. J (2005). *Fertilizer Usage for Coconut and Intercrops in Sri Lanka*. Presentation on Importance of site-specific fertilizer use on small holders) IPI + CCB project coconut-intercropping systems (For Sri Lanka Foundation Institute on 05 December 2005


Key, N & Runsten, D (1999).


Singh, G (2006). Agricultural Machinery Industry in India (Manufacturing, marketing and mechanization promotion). Status of Farm Mechanization in India; IARI


Wilkie, M (2011). Tanks for biodiesel and vegetable oil. [E-mail] Onsbring Gustafson, C. 2011-09-09


## Appendix A

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Feedstock</th>
<th>Value</th>
<th>Unit</th>
<th>Calculation</th>
<th>Comment</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Yield</td>
<td>Jatropha</td>
<td>460</td>
<td>kg/ha</td>
<td>Per year</td>
<td></td>
<td>(Van der Putten, Franken, Nielsen, de Jongh, Rijsenbeek, Beerens, et. al, 2010)</td>
</tr>
<tr>
<td>Base Yield</td>
<td>Coconut</td>
<td>3850</td>
<td>kg/ha</td>
<td>Per year</td>
<td></td>
<td>(FAO RAP, 2011)</td>
</tr>
<tr>
<td>Jatropha yield development</td>
<td>Jatropha</td>
<td>0.2, 0.4, 0.8, 1.0, 1.0, 0.1, 1.0, 1.0</td>
<td></td>
<td>Proportion of base yield each year in a ten years period</td>
<td></td>
<td>(Van der Putten et. al, 2010)</td>
</tr>
<tr>
<td>Coconut yield development</td>
<td>Coconut</td>
<td>0, 0, 0, 0, 1, 1, 1, 1, 1</td>
<td></td>
<td>Proportion of base yield each year in a ten years period</td>
<td></td>
<td>(Raghavan, 2010)</td>
</tr>
<tr>
<td>Fertilizer productivity increase</td>
<td>Jatropha</td>
<td>105</td>
<td>%</td>
<td>(90 % + 120 %) / 2</td>
<td></td>
<td>(Britaine and Lutaladio, 2010)</td>
</tr>
<tr>
<td>Fertilizer productivity increase</td>
<td>Coconut</td>
<td>40</td>
<td>%</td>
<td></td>
<td></td>
<td>(Ochs and Ollagnier, 1977)</td>
</tr>
<tr>
<td>Pesticide productivity increase</td>
<td>Jatropha</td>
<td>15</td>
<td>%</td>
<td></td>
<td></td>
<td>(Nielsen, 2008)</td>
</tr>
<tr>
<td>Pesticide productivity increase</td>
<td>Coconut</td>
<td>30</td>
<td>%</td>
<td>(1,349+1,531+0,956) / 3 - 1</td>
<td></td>
<td>(McKinlay, 2009)</td>
</tr>
<tr>
<td>Irrigation productivity increase</td>
<td>Jatropha</td>
<td>30</td>
<td>%</td>
<td></td>
<td></td>
<td>(Van der Putten et. al, 2010)</td>
</tr>
<tr>
<td>Irrigation productivity increase</td>
<td>Coconut</td>
<td>30</td>
<td>%</td>
<td></td>
<td></td>
<td>(Mohanty and Suresh, 2008)</td>
</tr>
<tr>
<td>Pruning productivity increase</td>
<td>Jatropha</td>
<td>650</td>
<td>%</td>
<td></td>
<td></td>
<td>(Chalapathy and Vishal, 2009)</td>
</tr>
<tr>
<td>Pruning productivity increase</td>
<td>Coconuts</td>
<td>%</td>
<td>Not used for coconut</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------</td>
<td>---</td>
<td>---------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kg use of fertilizer for jatropha</td>
<td>Jatropha</td>
<td>64 95 191 286 286 286 286 286</td>
<td>kg/ha</td>
<td>Mass used each year in a ten years period</td>
<td>(Patolia, Ghosh, Chikara, Chaudhary, Parmar and Bhuya, 2007)</td>
<td></td>
</tr>
<tr>
<td>Kg use of fertilizer for coconuts</td>
<td>Coconuts</td>
<td>29 89 179 263 263 263 263 263</td>
<td>kg/ha</td>
<td>Mass used each year in a ten years period</td>
<td>(Raghavan, 2010)</td>
<td></td>
</tr>
</tbody>
</table>

<p>| Cost of Fertilizer | J/C | 0,6 USD/kg | (290 + 890) / 2 ) / 1000 | Per year | (American Crystal Sugar Company, 2011) |
| Kg use of pesticides for jatropha | Jatropha | 1,23 kg/ha | | Per year | (Williamson a, Ball and Pretty, 2008) |
| Kg use of pesticides for coconuts | Coconuts | 0,46 kg/ha | | Per year | (United Plantations Berhad, 2008) |
| Cost of pesticides | J/C | 21 USD/kg | | Per year | (Williamson a et. al, 2008) |
| Cost of irrigation | J/C | 520 USD/ha | | Up front cost | (Van der Putten et. al, 2010) |
| Cost of using an ox | J/C | 24 USD/ha | 32 NAD * 0,123 USD/NAD = 6,4 USD/day, 12 h/acre -&gt; 0,033ha/h -&gt; 0,27ha/day, 6,4 USD/day / 0,27 ha/day = 24 USD/ha | Used first year | (Teweldemedhin and Conroy, 2010) |
| Cost of using a tractor | J/C | 8 USD/h | | Used first year for plowing and each year for spraying pesticides | (Sylvester and Baanda, 2008) |
| Cost of jatropha seeds | Jatropha | 1,2 USD/ha | 1,2 kg/ha * 5 MZN/kg * 0,2 USD/MZN | Used first year | (Raghavan, 2010) |</p>
<table>
<thead>
<tr>
<th>Cost of coconut seedlings</th>
<th>Coconu t</th>
<th>63</th>
<th>USD/ha</th>
<th>6574 Rs/ha -&gt; 63 USD/ha</th>
<th>Used first year</th>
<th>(Gunathilake, 2005)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tools for harvesting</td>
<td>Jatroph a</td>
<td>7</td>
<td>USD/ha</td>
<td>400 USD/st / 60 ha/st</td>
<td>One each tenth year</td>
<td>(Aliexpress, 2011)</td>
</tr>
<tr>
<td>Cost of tools for coconut harvesting</td>
<td>Coconu t</td>
<td>0,4</td>
<td>USD/ha</td>
<td>30 USD/st / 70 ha/st</td>
<td>One each year</td>
<td>(Raghavan, 2010)</td>
</tr>
<tr>
<td>Km cost of walking trader</td>
<td>J/C</td>
<td>0,0019</td>
<td>USD/kg /km</td>
<td>77 USD/ha / 10000 kg/ha / 5 km</td>
<td>(Hine and Ellis, 2001)</td>
<td></td>
</tr>
<tr>
<td>Km cost of trolling trader</td>
<td>J/C</td>
<td>0,0057</td>
<td>USD/kg /km</td>
<td>23 USD/ha / 10000 kg/ha / 5 km</td>
<td>(Hine et. al, 2001)</td>
<td></td>
</tr>
<tr>
<td>Km cost of biking trader</td>
<td>J/C</td>
<td>0,0076</td>
<td>USD/kg /km</td>
<td>31 USD/ha / 10000 kg/ha / 5 km</td>
<td>(Hine et. al, 2001)</td>
<td></td>
</tr>
<tr>
<td>Km cost of animal trader</td>
<td>J/C</td>
<td>0,0015</td>
<td>USD/kg /km</td>
<td>(0,00025 + 0,000125) / 2 Average on short and long transportation, long transportation more commonly used</td>
<td>(Ellis and Hine, 1998)</td>
<td></td>
</tr>
<tr>
<td>Km cost of tractor trader</td>
<td>J/C</td>
<td>0,0005</td>
<td>USD/kg /km</td>
<td>2000 USD / 30000 kg / 1217 km</td>
<td>(Edson, 2011)</td>
<td></td>
</tr>
<tr>
<td>Investment cost per kg of storing warehouse</td>
<td>J/C</td>
<td>0,13</td>
<td>USD/kg</td>
<td>Initial cost first kg</td>
<td>(Herman, 2011)</td>
<td></td>
</tr>
<tr>
<td>Labour salary</td>
<td>J/C</td>
<td>0,45625</td>
<td>USD/h</td>
<td>((2005 MZN/month) * 0.04 = 73 USD/month) / 160 h/month Minimum wage in Mozambique</td>
<td>(Wageindicator, 2012)</td>
<td></td>
</tr>
<tr>
<td>Time for clearing jatropha fields</td>
<td>Jatroph a</td>
<td>25</td>
<td>h/ha</td>
<td>10 h/acre / 0,4046 ha/acre</td>
<td>Done first year</td>
<td>(Vodounon , 2011)</td>
</tr>
<tr>
<td>Task</td>
<td>Crop</td>
<td>Time (h/ha)</td>
<td>Time (h/acre)</td>
<td>Notes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>-------------</td>
<td>---------------</td>
<td>-------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for clearing coconut fields</td>
<td>Coconut</td>
<td>25</td>
<td>10 h/acre / 0.4046 ha/acre</td>
<td>Done first year (Vodounon, 2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for planting and digging for coconut trees</td>
<td>Coconut</td>
<td>15</td>
<td>10 h/acre / 0.4046 ha/acre</td>
<td>Done first year (Raghavan, 2010)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for jatropha manual plowing</td>
<td>Jatropha</td>
<td>66</td>
<td></td>
<td>Done first year (Lawrence Dijkman and Jansen, 1996)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for jatropha oxen plowing</td>
<td>Jatropha</td>
<td>28</td>
<td></td>
<td>Done first year (Lawrence et. al, 1996)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for jatropha tractor plowing</td>
<td>Jatropha</td>
<td>2.5</td>
<td></td>
<td>Done first year (Sylvester et. al, 2008)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for jatropha manual planting</td>
<td>Jatropha</td>
<td>76</td>
<td></td>
<td>Done first year (Lawrence et. al, 1996)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for jatropha oxen planting</td>
<td>Jatropha</td>
<td>140</td>
<td></td>
<td>Done first year (Lawrence et. al, 1996)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for jatropha tractor planting</td>
<td>Jatropha</td>
<td>2.5</td>
<td></td>
<td>Done first year (Sylvester et. al, 2008)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for fertilizing jatropha fields</td>
<td>Jatropha</td>
<td>12</td>
<td></td>
<td>Done once each year (Vodounon, 2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for applying coconut fertilizer manually</td>
<td>Coconut</td>
<td>28</td>
<td>13 min/tree * 130 trees/ha / 60 min/h</td>
<td>Done twice each year (Department of Agriculture, 2000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for jatropha pesticide spraying</td>
<td>Jatropha</td>
<td>12</td>
<td></td>
<td>Done once each year (Vodounon, 2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for manual coconut pest control</td>
<td>Coconuts</td>
<td>59</td>
<td>h/ha</td>
<td>Done once each year</td>
<td>(Girisha and Nandihalli, 2009)</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>----------</td>
<td>----</td>
<td>------</td>
<td>---------------------</td>
<td>-------------------------------</td>
<td></td>
</tr>
<tr>
<td>Time to prune jatropha</td>
<td>Jatropha</td>
<td>350</td>
<td>h/ha</td>
<td>30 min/tree * 1100 trees/ha</td>
<td>Done twice each year</td>
<td>(Van der Putten et. al, 2010)</td>
</tr>
<tr>
<td>Time for jatropha manual weeding</td>
<td>Jatropha</td>
<td>250</td>
<td>h/ha</td>
<td>100 h/acre / 0,4046 ha/acre</td>
<td>Done twice each year</td>
<td>(Vodounon, 2011)</td>
</tr>
<tr>
<td>Kg harvest per hour of manual labour</td>
<td>Jatropha</td>
<td>11,1</td>
<td>kg/h</td>
<td></td>
<td></td>
<td>(Van der Putten et. al, 2010)</td>
</tr>
<tr>
<td>Kg harvest per hour of manual labour</td>
<td>Coconuts</td>
<td>25</td>
<td>trees/day, 6 harvests per year</td>
<td>16h/day</td>
<td>Variabel; are depending on other input variables by ((16/8)*((Max_predicted_yearly_feedstock_yield_over_10_years[Coconuts]/130)/6)/2)</td>
<td>(Mathes and Manikka, 2004)</td>
</tr>
<tr>
<td>Kg harvest per hour of manual labour</td>
<td>Jatropha</td>
<td>635</td>
<td>kg/h</td>
<td></td>
<td></td>
<td>(Autumn in the Olive Grove, 2011)</td>
</tr>
<tr>
<td>Kg harvest per hour of manual labour</td>
<td>Coconuts</td>
<td>250</td>
<td>trees/day, 6 harvests per year, 24h/day</td>
<td></td>
<td>Variabel; are depending on other input variables by ((250/8)*((Max_predicted_yearly_feedstock_yield_over_10_years[Coconuts]/130)/6)/3)</td>
<td>(Foodmark et Exchange, 2011)</td>
</tr>
<tr>
<td>Kg peeling per hour</td>
<td>Jatropha</td>
<td>25</td>
<td>kg/h</td>
<td>Mass of whole fruit</td>
<td>(Van der Putten et. al, 2010)</td>
<td></td>
</tr>
<tr>
<td>Kg peeling per hour</td>
<td>Coconuts</td>
<td>36</td>
<td>kg/h</td>
<td>(7500 nuts * 1,15 kg/nut) / (15 pers * 8 h/pers) / 2</td>
<td>Mass of whole fruit</td>
<td>(Singh, 2006)</td>
</tr>
<tr>
<td>Tractor diesel for ploughing in liters</td>
<td>Jatropha</td>
<td>13</td>
<td>l/ha</td>
<td>[Moitzi, Weingartner and Boxberger, 2006]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>---------</td>
<td>----</td>
<td>------</td>
<td>-----------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel use per km kg of tractor J/C</td>
<td>0,00008</td>
<td>l/kgkm</td>
<td></td>
<td>(Institute of Agricultural Economics and Information, 2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel use per km kg of tractor J/C</td>
<td>0,0000875</td>
<td>l/kgkm</td>
<td></td>
<td>(Mårtensson, 2003)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liters of diesel per hour of harvesting with tools J/C</td>
<td>0,8</td>
<td>l/h</td>
<td></td>
<td>(Abbey garden sales, 2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liters of diesel per hour of harvesting with tools J/C</td>
<td>0,23</td>
<td>GJ/kg</td>
<td></td>
<td>(AREI, 1994)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy content in GJ per kg of fertilizer Jatropha</td>
<td>0,025</td>
<td>GJ/kg</td>
<td>36% N, 11% P, 53% K</td>
<td>(West and Marlan, 2001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy content in GJ per kg of fertilizer Coconut</td>
<td>0,019</td>
<td>GJ/kg</td>
<td>24% N, 17% P, 59% K</td>
<td>(West et. al, 2001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of husk shells and water Jatropha</td>
<td>37%</td>
<td>Weight loss</td>
<td></td>
<td>(Van der Putten et. al, 2010)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of husk shells and water Coconut</td>
<td>69%</td>
<td>Weight loss</td>
<td></td>
<td>(Raghavan, 2010)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Appendix B

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Feedstock</th>
<th>Value</th>
<th>Unit</th>
<th>Calculation</th>
<th>Comment</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of drier</td>
<td>Coconut</td>
<td>1500</td>
<td>kg/h</td>
<td></td>
<td></td>
<td>(Alibaba, 2011)</td>
</tr>
<tr>
<td>Percent of weight loss from drying</td>
<td>Jatropha</td>
<td>1</td>
<td>%</td>
<td></td>
<td></td>
<td>(Van der Putten et. al, 2010)</td>
</tr>
<tr>
<td>Percent of weight loss from drying</td>
<td>Coconut</td>
<td>46</td>
<td>%</td>
<td></td>
<td></td>
<td>(Raghavan, 2010)</td>
</tr>
<tr>
<td>Efficiency of manual machinery</td>
<td>Jatropha</td>
<td>20</td>
<td>%</td>
<td>Oil from feedstock when pressing</td>
<td></td>
<td>(Hening, 2011)</td>
</tr>
<tr>
<td>Efficiency of manual machinery</td>
<td>Coconut</td>
<td>50</td>
<td>%</td>
<td>Oil from feedstock when pressing</td>
<td></td>
<td>(Raghavan, 2010)</td>
</tr>
<tr>
<td>Efficiency of simple machinery</td>
<td>Jatropha</td>
<td>20</td>
<td>%</td>
<td>Oil from feedstock when pressing</td>
<td></td>
<td>(Schurmann, 2011)</td>
</tr>
<tr>
<td>Efficiency of simple machinery</td>
<td>Coconut</td>
<td>60</td>
<td>%</td>
<td>Oil from feedstock when pressing</td>
<td></td>
<td>(Raghavan, 2010)</td>
</tr>
<tr>
<td>Efficiency of advanced machinery</td>
<td>Jatropha</td>
<td>35</td>
<td>%</td>
<td>Oil from feedstock when pressing</td>
<td></td>
<td>(Gouveia, 2011)</td>
</tr>
<tr>
<td>Efficiency of advanced machinery</td>
<td>Coconut</td>
<td>65</td>
<td>%</td>
<td>Oil from feedstock when pressing</td>
<td></td>
<td>(Kritzinger, 2011)</td>
</tr>
<tr>
<td>Initial warehouse cost per kg</td>
<td>Jatropha</td>
<td>0.13</td>
<td>USD/kg</td>
<td></td>
<td>Initial cost for first kg</td>
<td>(Herman, 2011)</td>
</tr>
<tr>
<td>Investment cost up front for drier</td>
<td>Coconut</td>
<td>6000</td>
<td>USD</td>
<td></td>
<td>Up front cost</td>
<td>(Alibaba, 2011)</td>
</tr>
<tr>
<td>Investment cost up front manual machinery</td>
<td>J/C</td>
<td>150</td>
<td>USD</td>
<td></td>
<td>Investment cost up front each fifth year</td>
<td>(Hening, 2011)</td>
</tr>
<tr>
<td>Investment cost up front simple machinery</td>
<td>J/C</td>
<td>5125</td>
<td>USD</td>
<td>Investment cost up front each fifth year</td>
<td>(Oil Seed Press, 2011)</td>
<td></td>
</tr>
<tr>
<td>Investment cost up front advanced machinery</td>
<td>J/C</td>
<td>20000</td>
<td>USD</td>
<td>Investment cost up front each tenth year</td>
<td>(Cirkle Energy, 2011)</td>
<td></td>
</tr>
<tr>
<td>Investment cost of presscake warehouse per kg</td>
<td>J/C</td>
<td>0,13</td>
<td>USD/kg</td>
<td>Initial cost first kg</td>
<td>(Herman, 2011)</td>
<td></td>
</tr>
<tr>
<td>Investment cost per kg of storage tank for oil</td>
<td>J/C</td>
<td>0,53</td>
<td>USD/kg</td>
<td>Initial cost first kg, average price from three distributors</td>
<td>(Navigator, Polem and Hurtado, 2011)</td>
<td></td>
</tr>
<tr>
<td>Kg pressed per hour with manual machinery</td>
<td>J/C</td>
<td>5</td>
<td>kg/h</td>
<td></td>
<td>(Hening, 2011)</td>
<td></td>
</tr>
<tr>
<td>Kg pressed per hour with simple machinery</td>
<td>J/C</td>
<td>8</td>
<td>kg/h</td>
<td></td>
<td>(Oil Seed Press, 2011)</td>
<td></td>
</tr>
<tr>
<td>Kg pressed per hour with advanced machinery</td>
<td>J/C</td>
<td>100</td>
<td>kg/h</td>
<td></td>
<td>(Cirkle Energy, 2011)</td>
<td></td>
</tr>
<tr>
<td>KWh per kg for use of drier</td>
<td>Coconut</td>
<td>0,005</td>
<td>kWh/kg</td>
<td></td>
<td>(Alibaba, 2011)</td>
<td></td>
</tr>
<tr>
<td>Electricity use in kWh per kg for simple machinery</td>
<td>J/C</td>
<td>0,081</td>
<td>kWh/kg</td>
<td></td>
<td>(Oil Seed Press, 2011)</td>
<td></td>
</tr>
<tr>
<td>Electricity use in kWh per kg for advanced machinery</td>
<td>J/C</td>
<td>0,021</td>
<td>kWh/kg</td>
<td></td>
<td>(Cirkle Energy, 2011)</td>
<td></td>
</tr>
<tr>
<td>Hours of drying per year</td>
<td>Coconut</td>
<td>1840</td>
<td>h/year</td>
<td>230 days/year * 8 h/year</td>
<td>Estimation</td>
<td></td>
</tr>
<tr>
<td>Technical write of time for drier in year</td>
<td>Coconut</td>
<td>10</td>
<td>years</td>
<td>Technical write of time (Cirkle Energy, 2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>--------</td>
<td>----</td>
<td>-------</td>
<td>-------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours of pressing per year</td>
<td>J/C</td>
<td>1840</td>
<td>h/year</td>
<td>230 days/year * 8 h/year</td>
<td>Estimation</td>
<td></td>
</tr>
<tr>
<td>Technical write off time for pressing machines in years (manual)</td>
<td>J/C</td>
<td>5</td>
<td>years</td>
<td>Technical write of time (Hening, 2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical write off time for pressing machines in years (simple)</td>
<td>J/C</td>
<td>5</td>
<td>years</td>
<td>Technical write of time (Oil Seed Press, 2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical write off time for advanced pressing machine in years</td>
<td>J/C</td>
<td>10</td>
<td>years</td>
<td>Technical write of time (Cirkle Energy, 2011)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max percentage of yearly yield in storage tank</td>
<td>Jatropha</td>
<td>20</td>
<td>%</td>
<td>Up to the user of the model to decide this rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max percentage of yearly yield in storage tank</td>
<td>Coconut</td>
<td>10</td>
<td>%</td>
<td>Up to the user of the model to decide this rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max percentage of yearly presscake in warehouse</td>
<td>J/C</td>
<td>10</td>
<td>%</td>
<td>Up to the user of the model to decide this rate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Appendix C

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Feedstock</th>
<th>Value</th>
<th>Unit</th>
<th>Calculation</th>
<th>Comment</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refining cost per kg oil</td>
<td>J/C</td>
<td>0.15</td>
<td>USD/kg</td>
<td></td>
<td></td>
<td>(James, C 2011)</td>
</tr>
<tr>
<td>Investment cost per liter of diesel storage tank</td>
<td>J/C</td>
<td>0.59</td>
<td>USD/kg</td>
<td></td>
<td>Initial cost first kg</td>
<td>(Navigator et. al, 2011)</td>
</tr>
<tr>
<td>Electric input per kg of oil refining</td>
<td>J/C</td>
<td>0.03</td>
<td>kWh/kg</td>
<td></td>
<td></td>
<td>(Pleanjai and Gheewala, 2009)</td>
</tr>
<tr>
<td>Embedded energy input per kg of oil refining</td>
<td>J/C</td>
<td>0.005296</td>
<td>GJ/kg</td>
<td></td>
<td></td>
<td>(Pleanjai et. al, 2009)</td>
</tr>
<tr>
<td>Percentage of oil to diesel</td>
<td>J/C</td>
<td>95</td>
<td>%</td>
<td></td>
<td></td>
<td>(Van Gerpen and Knothe, 2005)</td>
</tr>
<tr>
<td>Cost of sea freight to EU per kg</td>
<td>J/C</td>
<td>0.0835</td>
<td>USD/kg</td>
<td>83,5/1000</td>
<td></td>
<td>(Zilio, Liddell, Muaendane and Nogueira, 2008)</td>
</tr>
<tr>
<td>Diesel use per kg of biodiesel transported to EU</td>
<td>J/C</td>
<td>0.00000179</td>
<td>l/kgkm</td>
<td></td>
<td></td>
<td>(Responsible Care, ECTA and cefic, 2011)</td>
</tr>
<tr>
<td>Distance to EU for sea transport</td>
<td>J/C</td>
<td>13700</td>
<td>km</td>
<td></td>
<td>Estimation with the help of maps.google.se</td>
<td></td>
</tr>
</tbody>
</table>
## Appendix D

<table>
<thead>
<tr>
<th>Flow</th>
<th>Activity</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass flow of farming (MF)</td>
<td>Planting and maintaining feedstock (MFP)</td>
<td>$\text{Coconut_yield_development<em>Base_yield[Coconuts]</em>/(1+Fertilizer_productivity_increase[Coconuts])<em>(1+Pruning_productivity_increase[Coconuts])</em>(1+Irrigation_productivity_increase[Coconuts])*(1+Pesticides_productivity_increase[Coconuts])}$</td>
</tr>
<tr>
<td></td>
<td>Harvesting feedstock (MFH)</td>
<td>Output of variables</td>
</tr>
<tr>
<td></td>
<td>Processing and storing feedstock (Diversion of byproducts) (MFS)</td>
<td>$\text{Harvesting_feedstock[Plants]*Percentage_of_husk_shells_and_water[Plants]}$</td>
</tr>
<tr>
<td></td>
<td>Feedstock to feedstock market (MFT)</td>
<td>$(1-$Percentage of husk shells and water[Plants]) *Harvesting_feedstock[Plants]$</td>
</tr>
<tr>
<td>Total cost of farming (CF)</td>
<td>Cost of preparing and maintaining land (CFP)</td>
<td>$(\text{IF (Fertilizers=1) THEN Cost_of_Fertilizer[jatropha]<em>kg_of_fertilizer_for_jatropha} \text{ ELSE 0}) + (\text{IF (Pesticides=1) THEN Cost_of_pesticides</em>kg_use_of_pesticides_for_jatropha} \text{ ELSE 0}) + (\text{IF (Typ_of_Mehanisation=3) THEN Cost_of_using_a_tractor ELSE IF (Typ_of_Mehanisation=2) THEN Cost_of_using_an_oxe ELSE 0}) + (\text{IF (Irrigation=1) THEN Cost_of_irrigation ELSE 0}) + \text{Cost_of_jatropha_seeds} + \text{Labour_salary/160}*$Preparing_labour_time[jatropha]$</td>
</tr>
<tr>
<td></td>
<td>Cost of harvesting feedstock (CFH)</td>
<td>$(\text{IF (Use_of_tools_for_harvesting=1) THEN Cost_of_tools_for_coconut_harvesting ELSE 0}) + \text{Harvesting_labour_time[Coconuts]*(Labour_salary/160)}$</td>
</tr>
<tr>
<td></td>
<td>Cost of processing and storing feedstock (CFS)</td>
<td>$\text{Cost_of_Storing_facility[Coconuts] + (Labour_salary/160)*Processing_labour_time[Coconuts]}$</td>
</tr>
<tr>
<td><strong>Cost of trading feedstock to feedstock market (CFT)</strong></td>
<td>Feedstock_to_feedstock_market[Coconuts]<em>(km_cost_of_animal__trader</em>km_use_of_animal__trader+km_cost_of_biking__trader<em>km_use_of_biking__trader+km_cost_of_tractor__trader</em>km_use_of_tractor__trader+km_cost_of_trollying__trader<em>km_use_of_trollying__trader+km_cost_of_trucking__trader</em>km_use_of_trucking__trader+km_cost_of_walking__trader*km_use_of_walking__trader)</td>
<td></td>
</tr>
<tr>
<td><strong>Total diesel input for farming (DF)</strong></td>
<td>Diesel input for preparing and maintaining land (DFP)</td>
<td></td>
</tr>
<tr>
<td>Diesel input for preparing and maintaining land (DFP)</td>
<td>IF (Typ_of_Mehanisation=3) THEN Tractor_diesel_in_liters ELSE 0</td>
<td></td>
</tr>
<tr>
<td>Diesel input for harvesting feedstock (DFH)</td>
<td>Diesel input for harvesting feedstock (DFH)</td>
<td></td>
</tr>
<tr>
<td>Diesel input for harvesting feedstock (DFH)</td>
<td>IF (Use_of_tools_for_harvesting=1) THEN (Harvesting_labour_time[Plants]*Liters_of_diesel_per_hour_of_harvesting_with_tools[Plants]) ELSE 0</td>
<td></td>
</tr>
<tr>
<td>Diesel input for trading feedstock to feedstock market (DFT)</td>
<td>Diesel input for trading feedstock to feedstock market (DFT)</td>
<td></td>
</tr>
<tr>
<td>Diesel input for trading feedstock to feedstock market (DFT)</td>
<td>Feedstock_to_feedstock_market[Coconuts]<em>(Diesel_use_per_km_kg_of_tractor</em>km_use_of_tractor__trader+Diesel_use_per_km_kg_of_truck*km_use_of_trucking__trader)</td>
<td></td>
</tr>
<tr>
<td><strong>Total embedded energy input for farming (BF)</strong></td>
<td>Embedded energy input for preparing and maintaining land (BFP)</td>
<td></td>
</tr>
<tr>
<td>Embedded energy input for preparing and maintaining land (BFP)</td>
<td>(IF (Fertilizers=1) THEN (Kg_use_of_fertilizers_for_coconuts<em>Energy_content_in_GJ_per_kg_of_fertilizer[Coconuts]) ELSE 0) + (IF (Pesticides=1) THEN (kg_use_of_pesticides_for_coconuts</em>Energy_content_in_GJ_per_kg_of_pesticide) ELSE 0)</td>
<td></td>
</tr>
</tbody>
</table>
## Appendix E

<table>
<thead>
<tr>
<th>Flow</th>
<th>Activity</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass flow of extraction (ME)</strong></td>
<td>Drying and storing feedstock <em>(Diversion of byproducts)</em> (MED)</td>
<td>Drying_and_storing_feedstock[Plants]*Percent_of_weight_loss_from_drying[Plants]</td>
</tr>
<tr>
<td></td>
<td>Feedstock to oil pressing (MEP)</td>
<td>Drying_and_storing_feedstock[Plants]* (1 - Percent_of_weight_loss_from_drying[Plants])</td>
</tr>
<tr>
<td></td>
<td>Oil pressing <em>(Diversion of byproducts)</em> (MEO)</td>
<td>Feedstock_to_oil_pressing[Coconuts]* (1 - Efficency_of_press[Coconuts])</td>
</tr>
<tr>
<td></td>
<td>Oil to storage (MES)</td>
<td>Feedstock_to_oil_pressing[Coconuts]* (Efficency_of_press[Coconuts])</td>
</tr>
<tr>
<td></td>
<td>Oil to trading (MET)</td>
<td>Output of variables</td>
</tr>
<tr>
<td></td>
<td>Trading point <em>(To end market)</em> (MEM)</td>
<td>Oil_to_trading[Coconuts]* (1 - Percentage of oil sold to refiners)</td>
</tr>
<tr>
<td></td>
<td>Oil to refineries (MER)</td>
<td>Oil_to_trading[Coconuts]* Percentage of oil sold to refiners</td>
</tr>
<tr>
<td><strong>Total cost of extraction (CE)</strong></td>
<td>Cost of drying and storing feedstock (CED)</td>
<td>Cost_of_warehouse[Coconuts] + IF (Use_of_drier = 1) THEN (Cost_of_using_drier__per_kg*Farming.Feedstock_to_feedstock_market[Coconuts]) ELSE 0</td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Cost of trading presscake to market (CET)</td>
<td>(Oil_to_oil_users[Plants]+Oil_to_refiners[Plants])<em>(Farming.km_cost_of_tractor_trader</em>km_use_of_tractor_trader+Farming.km_cost_of_trolleying_trader<em>km_use_of_trolleying_trader+Farming.km_cost_of_trucking_trader</em>km_use_of_trucking_trader)</td>
<td></td>
</tr>
<tr>
<td>Cost of trading oil to oil market (CEM)</td>
<td>(Selling_to_oil_users[Plants]+Selling_to_refiners[Plants])<em>(Farming.diesel_use_per_km_kg_of_tractor</em>km_use_of_tractor_trader+Farming.diesel_use_per_km_kg_of_trucking_trader*km_use_of_trucking_trader)</td>
<td></td>
</tr>
<tr>
<td>Total diesel input for extraction (DE)</td>
<td>Trading diesel energy input (DET)</td>
<td></td>
</tr>
<tr>
<td>Total electric input for extraction (EE)</td>
<td>Electric input for drying and storing feedstock (EES)</td>
<td></td>
</tr>
<tr>
<td>Electric input for oil pressing (EEP)</td>
<td>IF (Type_of_machinery=3) THEN (Feedstock_to_oil_pressing[Plants]*Electricity_use_in_kWh_per_kg_for_advanced_machinery) ELSE IF (Type_of_machinery=2) THEN (Feedstock_to_oil_pressing[Plants]*Electricity_use_in_kWh_per_kg_for_simple_machinery) ELSE 0</td>
<td></td>
</tr>
</tbody>
</table>
## Appendix F

<table>
<thead>
<tr>
<th>Flow</th>
<th>Activity</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass flow of refining (MR)</strong></td>
<td><strong>Oil to refining (MRT)</strong></td>
<td>Output of variables</td>
</tr>
<tr>
<td></td>
<td><strong>Oil refining (Diversion of byproducts) (MRR)</strong></td>
<td>Oil_to_refining[Plants]*(1-Percentage_of_oil_to_diesel[Plants])</td>
</tr>
<tr>
<td></td>
<td><strong>Diesel to storage (MRS)</strong></td>
<td>Oil_to_refining[Coconuts]*Percentage_of_oil_to_diesel[Coconuts]</td>
</tr>
<tr>
<td></td>
<td><strong>Trading diesel to markets (To end market) (MRM)</strong></td>
<td>Output of variables</td>
</tr>
<tr>
<td><strong>Total cost of refining (CR)</strong></td>
<td><strong>Cost of storing oil (CRS)</strong></td>
<td>Extraction.Maximum_yearly_oil_to_refiners_over_10_years[Plants]*Max_percentage_of_yearly_yield_in_storage[Plants]*Investment_cost_per_kg_of_storage_tank_for_oil</td>
</tr>
<tr>
<td></td>
<td><strong>Cost of oil refining (CRR)</strong></td>
<td>Oil_to_refining[Plants]*Refining_cost_per_kg_oil</td>
</tr>
<tr>
<td></td>
<td><strong>Cost of diesel storage (CRD)</strong></td>
<td>Extraction.Maximum_yearly_oil_to_refiners_over_10_years[Plants]*Max_percentage_of_yearly_yield_in_diesel_storage[Plants]*Investment_cost_per_liter_of_diesel_storage_tank</td>
</tr>
<tr>
<td></td>
<td><strong>Cost of trading diesel to market (CRT)</strong></td>
<td>Trading_diesel_to_market[Plants]<em>km_use_of_trucking_trader</em>Extraction.Cost_of_trucking_trader</td>
</tr>
<tr>
<td><strong>Total diesel input for refining (DR)</strong></td>
<td><strong>Diesel input for trading diesel to market (DRT)</strong></td>
<td>Trading_diesel_to_market[Plants]<em>Extraction.Diesel_use_per_km_kg_of_truck</em>km_use_of_trucking_trader</td>
</tr>
<tr>
<td>Total electric input for refining (ER)</td>
<td>Electric input for refining (ERR)</td>
<td>( \text{Oil}_{\text{to_refining[Plants]}} \times \text{Electric_input_per_kg_of_oil_refining} )</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>----------------------------------</td>
<td>------------------------------------------------------------------</td>
</tr>
<tr>
<td>Total embedded energy input for refining (BR)</td>
<td>Embedded energy input for refining (BRR)</td>
<td>( \text{Oil}_{\text{to_refining[Plants]}} \times \text{Embedded_energy_input_per_kg_of_oil_refining} )</td>
</tr>
</tbody>
</table>
Appendix G